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SUMMARY

The present work was confined to a very restricted range of trees dominated primarily by pine (**Pinus kesiya** Royle). Investigations on the biodiversity of invertebrate fauna, particularly arthropods, which were associated within a range of ecological conditions were studied in detail. The forest sites undertaken were near-to-natural ecosystems since they were an outcome of plantations managed over several years. At the outset this forest was divided into two major divisions for easier analysis of the consumer populations. The young plantations were analysed for sap-sucking consumers and the older ones for chewing and mining insect consumers, the latter by the light trap method. For decomposer studies both soil and litter fauna were analysed in the oldest plantations to help in elucidating the return of nutrients to the soil. An attempt has been made to interrelate these different components to get a total understanding of the ecosystem considered.

Both the aspects dealing with fauna at the consumer level had many attributes of similar nature probably proving that the effect of environmental factors on the species of populations considered was in a regular systematic manner. The prediction of populations for succeeding years stood as one very important feature enabling control of species if and when they would reach pest status. Most populations had distinctive biomodal patterns of fluctuation over an annual cycle. Temperature and rainfall were two factors which seemed to play a major role in regulation of both sap-sucking, and chewing and mining consumers, proving either one of these factors as operationally significant. In those cases where statistical significance of any one factor on a population failed to express itself it was seen that a highly significant relationship existed when a multiple correlation was computed for all factors with the groups of populations considered. There was a decrease in the population abundance of the species considered during the second year of investigation proving thereby that rates of increase never reached beyond the net biotic potential known to be effected by factors like emigration, predators and parasites. The next aspect dealt with the role of microarthropods in plant litter decomposition and their importance in soil. In both cases Collembola and Acarina formed the dominant groups. One common factor effecting their population levels was water content as rainfall for soil and moisture for litter. pH was another factor which positively influenced the soil organisms and understandibly much more in the pine litter. There was a clear indication of an interplay between Collembola and Acarina with the season, for summer had a dominance of Collembola, while the winter months revealed a greater activity of Acarina. One of the effects of faunal population on detrital processing was comminution which exposed greater surface area for microbial action. The average turnover rates for the trophic levels studied, changed during the season as temperature and moisture changed and populations underwent shifts in abundance. The results of this study had an unique advantage of these emerging general concepts of ecosystem, in that unmeasured ecosystem parameters could be predicted. On the one hand community dynamics were interpreted whenever possible as population phenomena, and on the other hand population biology was studied only within the community concept. What had emerged from this study of community analysis was to identify the kinds of research for the next phase and that greater opportunities existed for building models and to solve the underlying machanisms of integration between the community and the population.

CONSUMER & DECOMPOSER ARTHROPODS IN PINE PLANTATIONS OF MEGHALAYA, N. E. INDIA – A BIODIVERSITY AND ECOLOGICAL ANALYSIS

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INTRODUCTION

Forests vary greatly in structure, their productivity and turnover rates in general, though offering a stable microhabitat. The physical conditions of the microclimate and consequently the microhabitats are generally important in determining the composition of fauna (Stout, 1974).

Trees and forests have always been subjected to dual attitude, on the one hand a feeling of beauty, awe, reverence or mystery and on the other a sense of utility, a desire to cut them down, make houses and bridges and clear the land for farming, as seen throughout mans history (Botkin and Miller, 1974). The need to study forest systems, stems from the need to understand, not only as a value for mans soul - his recreation and aesthetic appreciation, but to understand those organisms that exist in communities involving many biological interactions. It is in this context, that the forest ecosystem is relevant not only to professional ecologists but also in view of mans present day environmental problems that it has been studied in greater detail than ever before. This led Odum (1971) to define ecosystem from both anthropocentric and professional angles. Either definition involves the structure and function of a system under consideration. The word Ecosystem coined by Tansley (1935) had passed through a phase of related terminologies like Biocenosis (Mobius, 1877), Microcosm (Forbes, 1887) and Biogeocenosis (Sukacheva, 1944). However, no one has expressed the ecosystem concept to man better than Leopold (1933) who wrote, that christianity tries to integrate the individual to society, democracy to social organisation in the individual, with no ethic of man's relation to his environment. It is for these reasons that ecological processes have been traditionally studied from convenient vantage points. Three of these could be identified, (1) the geographical distribution of species and their relationships between species diversity and area, (2) species interactions in terms of population dynamics and (3) energy flow in ecological communities from primary producers to consumers through higher trophic levels (Rapport and Turner, 1975).

With these in mind the present investigation was undertaken from a merological point of view where parts of the system could be studied and finally to build up a whole. The ambition was soon realised to be far fetched when, as the work progressed, it dawned, that we had to start from scratch. Though ideal to study all the three components defined above, a total understanding of all aspects

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and from all points of view was virtually unattainable. The present study was therefore, confined to the understanding which was required to use it for some specific purpose and the nature of this purpose was the outcome of the present work.

As mentioned earlier, about the diversity in forest ecosystems, the present work was confined to a very restricted range of trees dominated primarily by pine (*Pinus kesiya* Royle). Investigations on the kinds of invertebrate fauna, particularly arthropods, which were associated within a range of ecological conditions were studied in detail. The forest sites undertaken were near-to- natural ecosystems, since they were an outcome of plantations managed over several years. Two major factors affecting this system were the consumers and decomposers. The questions we asked ourselves, to enable the realisation of the objectives of the present study were, (1) What were the dominant arthropod groups?, (2) What were their population dynamic relationships?, (3) What were the detrimental and beneficial effects of these, on the forest stands, and (4) How much was their functional interplay ?

At the outset we divided the forest into two major divisions for easier analyses of the consumer populations. The young plantations were analysed for sap-sucking consumers and the older ones for chewing and mining insect consumers, the latter by the light-trap method. For the decomposer studies both soil and litter fauna were analysed to help in elucidating the return of nutrients to the soil. An attempt has been made to interrelate these different components to get a total understanding of the ecosystem considered. A lack in the understanding of species differences of the fauna became very obvious and therefore the establishment of the relationship on firm grounds required the specialized, detailed knowledge, which was unlikely to be found in one person. The present study revealed the need for a range of specialists combined with a knowledge of whole system behaviour leading to requirement of a multi-disciplinary research team. However, the components analysed have been discussed with confidence, wherever possible, to reflect the scene in its totality.

The specific goals of these studies were to advance the understanding of ecosystems through measurements of rates of change in system components, expand the data to base on the whole system, increase the reliability of production estimates and improve the scientific basis for determining the resource management practices.

STUDY AREA

Location

The study area named as Riatkhwan Pine Plantation is about 15 kms. from the montane city of Shillong (Latitude 25° 34°N and Longitude 90° 56'E) on the western side of Gauhati-Shillong Road (Fig. 1a, b). The Riatkhwan pine plantation lies in a altitudinal range of 900 to 1250 m MSL. Khasi pine (*Pinus kesiya* Royle ex- Gordon) planted by the Meghalaya Government occupies the major area. The rest are bare hills with weeds and extensions of undergrowths (Table-I). Nearly all the area is situated above the Barapani Reservoir and the hills run parallel to Umroi River.

Origin

Physiogeographically, the area represents a remnant of an ancient plateau of precambrian Indian

TABLE I

List of plants present in the Raitkhwan Pine Plantation Area

	TREES		
*	*Pinus besiya*		*Schima wallichii*
	HERBS		
*	*Eupatorium adenophorum*		*Pouzolzia zeylanica*
	Urena lobata		*Oxalis corniculata*
	Oxalis corymbosa		*Frageria indica*
	Rubos cupticus		*Heydichium coronarium*
	Commelina bengalensis		*Erigeron linifolius*
	Oldenladia burmanniana	*	*Anemone rivularis*
	Scutelaria bicolor		*Anaphalis contorta*
	Hypochaeris radicata		*Trifolium repans*
	Artemisia vulgaris		
	Poa annula		
	SHRUBS		
	Lantana camara		*Desmodium triflorium*
			Osbecia crinata
	GRASSES		
*	*Setaria glauca*	*	*Capillipedium assimile*
*	*Imperata cylindrica*	*	*Paspalum dilatatum*
*	*Digitaria abscendens*		*Saccharum officinalis*
	Erianthus spp.		

* Indicates dominant species

Table I A list of plants found in the study area throughout the year.

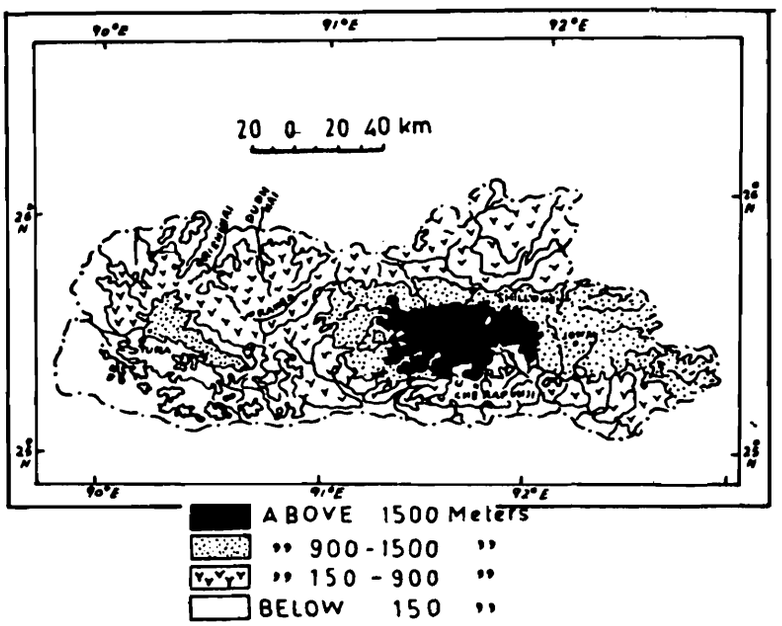


Figure 1a showing the physiographical map of Meghalaya and the location of Shillong.

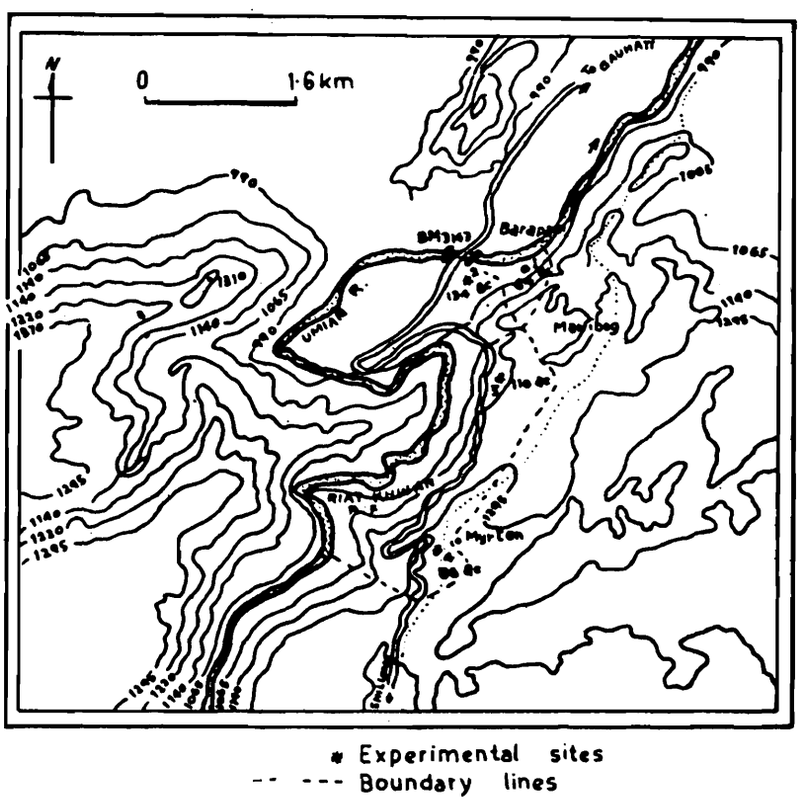


Figure 1b showing the physiographical map of the study area

peninsular shield block uplifted to its present height. The kernel of the plateau is the exposed Archean gneisses and schists covered in this area by pre-cambrian quartzites and phyllites intruded later by younger granites and basic/ultrabasic suites. This ancient peripheral surface of the plateau is still preserved with marks of different cycles of denudation. It is hidden beneath the Mesozoic traps along the central Southern fringe and Cretaceous/Tertiary and post-tertiary sediments. The present physiographic configuration of the plateau was attained through different geological events since Mesozoic to present day as indicated by the polycyclic erosional surface at various levels.

The Shillong plateau is a horst which has been block uplifted since Jurassic times to its present height of 610-1544 m above M.S.L. and its tectonic history begins with the effusion of plateau basalts (Sylhet traps) through fractures and faults in the basement and uplift and subsidence of adjacent basement blocks. These were followed by upper Cretaceous/Tertiary sedimentation into the relatively down thrown portions along faults. The tectonic force has been vertically dominated and controlled by differential movements, along these basement fractures.

Climate

The region experiences a sub-tropical monsoon climate, the summer temperatures reaching 28°C and the mean winter temperature falling down to 6°C, marked by appearance of ground frost at night and early morning for most of the winter. The average annual rainfall is around 258 cm, the maximum annual average of 1143 cm being recorded around nearby places at Cherrapunji and Mawsynram, the worlds rainiest spots.

REVIEW OF LITERATURE

Sap Sucking Consumer Arthropods

Forest ecosystems, in particular support myriads of phytophagous insects (Mattson and Addy, 1975), aphid constituting one such group. These are highly defenceless yet destructive, showing a high degree of polymorphism (Raychaudhuri, 1975). However, Owen and Weigert (1970) suggested that aphids can be good agents for nitrogen fixation. The aphids can multiply so rapidly that they can reach also pest proportion (Dixon, 1973), the study of their population dynamics being therefore highly essential for better management in farm, forestry and agriculture.

Careful population measurements together with experiments and observations to analyse both inter and intra-specific causes of numerical changes are few (Hughes, 1963; Way, 1967; Way and Banks, 1968; Wyatt, 1965). There is always an increasing rate of alate formation (with consequent emigration) as population density increases as well as a decrease in the fertility of apterae and alate (Hughes, 1963; Way and Banks, 1968). Bryant (1972) studied the distribution of first nymphs of *Adelges piceae* (Homoptera Phylloxeridae) on branches of Balsam fir.

The detrimental effect of different aphids to various forest trees have been reported by many workers viz., the effect of European adelgids on shoot growth in nurseries (Merker and Eichhorn, 1955), stunted trees in forest (Steffan, 1970), killing of older trees (Eichhorn, 1969b), volume loss of merchantable balsam fir caused by woolly aphids in Newfoundland (Page, 1975), the typical gnarled

or gouted branching of open growing trees caused by Asia adelgids (Bryant, 1974b), the shoot browning and killing of pine (DeBoo *et al*, 1964), stunting of needles and shortening of branch internodes (DeBoo *et al*, 1964) and damage caused to sitka spruce by *Elatobium abietinum* (Dumbleton, 1932; Parry, 1974).

Parry (1969, 1973) reported extensive defoliation during large aphid population in Countesswells and related abiotic factors such as temperature and frost to the aphid (*E. abietinum*) population rise or decline. Powell (1974) reported high aphid numbers and consequent needle loss, in spring and early summer and have associated with unusually mild climatic conditions in the preceeding winter. Parry (1969) reported all needle shedding being attributable to the summer populations which built up rapidly from the end of March onwards resulting in a loss of approximately 93% of needles.

Dixon (1971b) reported that in a single year, lime saplings increased very little in weight when an aphid population was allowed to develop on them. It was further observed that the roots were very much smaller in aphid infested saplings. Further he reported that heavy aphid infestation of trees must have a profound effect on the woodland ecosystem. Ford and Dimond (1973) reported that a knowledge of population fluctuation of aphids in relation to its reproductive environmental factors was very much essential for control measures. Dimond (1974) observed that sampling galls in mid May, one could predict the infestation levels of neosistances of *Pinus pinifoliae* on pine that occurred a month later. According to Bryant (1971, 1976a) a detailed knowledge of the seasonal history of the aphid was required for timing control measure and scheduling detection and appraisal surveys. To forecast outbreaks and to evaluate the effects of natural and applied control factors aphids must be sampled at frequent intervals to determine population level (Bryant, 1976b).

Behura (1977) reported that very little work has been done on the ecology of Indian aphids compared to that in other countries of the World. Raychaudhuri (1975) stated that in the interest of Indian economy much remains yet to be done with these tiny insects injurious to plants. In India, excellent work on aphid taxonomy has been done (Ghosh 1980, 19802, 1984, 1988, 1990), but very little is known about the population dynamics of Indian agricultural aphids and great neglect is seen in the population studies of Indian forest aphids.

The present work deals with the population fluctuation of the three different pine aphids *C. attrotibialis*, *E. thunbergii* and *N. circumflexus* in relation to various physical environmental factors on different pine nurseries.

Chewing and Mining Consumer Arthropods

Besides the sap-sucking entomofauna, chewing and mining entomofauna constitute a major group of forest consumer fauna. These insects were estimated both quantitatively and qualitatively by the use of a light-trap (Reddy and Alfred, 1977) during nights, as insects are capable of flight and more active primarily at nights (Barrett *et al*, 1974). Wheeler (1937) used such a method for *Empoasca* sp., Ghani and Afzal (1946) used light-traps for determining population of *Empoasca devestans* on cotton. The value of insect traps equipped with BL lamps in determining the time of appearance and the seasonal abundance of insects was reported by Pfrimmer *et al* (1955), Stanley and Dominick (1958), Apple (1962) and Gentry *et al* (1971b). Hanna (1969) stressed the importance of light traps

in the study of the period of activity and seasonal fluctuation of insects. Hassanein (1956), Hosni and Khattab (1960) and Nasr (1961) used different light traps to catch moths of cotton leaf worm, in trials to study the population fluctuation of pests during the cotton season in Egypt. Deay *et al* (1964) reported the use of light traps to determine the presence and absence of insects, specially moths, and the use of Blacklight insect traps to determine the seasonal occurrence and abundance of corn earworm and other insects.

Falcon *et al* (1967a, b) stated that a combination of black light (CBL) traps and field sampling, was a more effective means for detecting the onset of infestations and assessing the population levels of the boll worm. Wolf *et al* (1969) and Ford *et al* (1972) investigated the effect of BL trap baited with sex phermone of cabbage looper, on population of several lepidopteran pests of lettuce. Cantelo *et al* (1972a, 1974) used black lights in studying the population trends of many species of Lepidoptera, Orthoptera, Hemiptera and Coleoptera on an isolated tropical island. Bakke (1974) analysed the abundance and diversity in the fauna of nocturnal moths at two sites in South Norway, by light- trap. Jabber and Ahmed (1974) used light-traps for determination of population of *Z. quyumi* (Ahmed) a pest of wheat and maize in Pakistan. Frith (1975) studied the insect abundance on West Island, Aldabra Atoll, Indian Ocean. Hagen (1976) reported 14 years study of the populations of the Western bean cutworm using light traps located both in the field corn (Parks trap) and dry bean (Gering Valley trap) growing areas. Roome (1974) established a grid of light trap to study the seasonal fluctuation in the populations of certain economically important moth species. Belts *et al* 1971 and Odiyo, 1973 reported forecasting of armyworm by light trap. Many workers have used light-traps for taxonomic and seasonal variation studies of *Culicoides* (James, 1943; Khalaf, 1952; Williams, 1955; Beck, 1958; Jamnback and Matthews, 1963; Khalaf, 1967; Linley *et al* 1970; Kline and Axtell, 1976).

Insect population studies by various light-traps seem to be more in agroecosystems than in forests. Very few reports exist on the studies of seasonal population abundance of forest insects by light traps. Chaniotis *et al* (1971b) presented light trap data on the population dynamics of species occurring in lowland, highland and secondary forest biotopes. Rutledge *et al* (1975) analysed the sand fly (Diptera Psycholidae) light trap collections in the Panama Canal zone. Chaniotis and Correa (1974) presented light trap data on the population dynamics of phlebotomine sandflies in a mature forest and adjacent open space. Williams (1948) used the Rothamsted tungsten Lamp trap to survey moth population in Rothamsted Insect Survey in Britain. Williams (1951) and William *et al* (1955) developed an experimental layout to compare the catch of Macro-lepidoptera from Rothamsted and Robinson traps in a wood in Southern England and found differences in relative numbers of the major taxa. Yates and Ebel (1970, 1972) studied the occurrence and the effect of rainfall, temperature on the activity of long leaf, pine, slash and pine cone insects by light traps. Yates (1973) reported the use of light traps in studying the adult activity periods, relative abundance and geographical distribution of insects that infest pine seed and cones. Yates and Ebel (1975a, b) reported 4 different species of pine cone damaging lepidopteran pests attracted to light trap and studied their frequency distribution.

While identifying collected insects one of the unanswered questions always, is what percentage of the insects attracted does this catch represent (Hartstack *et al* 1966; Taylor and French, 1974). Numerous attempts have been made to use light traps catch for estimating total field populations of certain insects (King and Hind, 1960; Falcon *et al*, 1967a, b). The release and capture of insects

tagged with points, dyes or radioactive markers have been used in population estimating techniques (Henneberry *et al*, 1967; Alma, 1973). The percentage of the released insects that are captured is assumed to be indicative of the percentage of the total field population that a particular light trap will catch.

It has been reported that many factors may influence the light trap catches. These include time of the day (Graham *et al*, 1964), temperature (Sutherland, 1966), rainfall (King, 1966) evaporation and dispersion of the pheomone (Gentry and Davis, 1973). Bogush (1936) was one of the earliest to point out the use of light traps for the study of field populations and the effect of weather on them. Gentry and Davis (1973) showed the importance of the influence of weather conditions on insect activity in survey and controlling insect populations when they are stimulated by the BL or the BL + Pheromone traps. There are probably a number of measurable climatic and other environmental factors of which the daily variations correspond on the size of the light trap catches (Van Ark, 1975 and Williams, 1939, 1940, 1951, 1961). The insect activity under the presence of changing environmental influences like surface wind velocity and temperature, caused light trap catches to fluctuate widely, sometime on an hourly or nightly basis. Changes in the environmental factors that affect trap catches are usually short ranged (hours) at the most 1 or 2 days, and catch profiles can be smoothed by mathematical techniques to provide a reliable estimate of the insect population (Hartstack *et al*, 1973). In the earlier works, owing to the difficulties in analysing the inter-relationships of meteorological factors with abundance of insects, it was difficult to differentiate the exact role played by each factor in regulating the number and activity of animals (Uvarov, 1931). Williams (1935) was perhaps the first worker to apply the statistical formulae of partial regression analysis to isolate the effect of each environmental factor on the population and activity of insects. Cantelo *et al* (1974) stated that the decrease in collection by black light (BL) traps could have caused by weather conditions. The effect of environmental factors on insect flight behaviour has been studied for a wide variety of insects including serious economic pests such as the black cut worm, and the European corn borer, (Cook, 1961; Stirrett, 1938; Loewer *et al*, 1974). Broersma *et al* (1976) reported that in a field situation the influence of these factors cannot be easily isolated because of complex interactions among various environmental variables. Heinton (1974) reported that under optimum conditions of light intensity for moth attraction that exist before and after dark, the temperature and wind or air movement may reduce the number of moths captured. Pristavka (1969) reported on the effect of temperature and wind velocity which assumed to be the leading factors affecting the quantity of catches of the codling moth. Vail *et al* (1968) collected corn earworm moths from traps equipped with 15-W BL lamps in Home gardens and Riverside, California to determine possible correlations between seasonal abundance, mating of females, sex ratios and seasonal temperature.

In India, attempts to study the effect of phototrophism and other different weather conditions on relative seasonal abundance of insects dates back to 1934 (Ramakrishnayyar and Ananthnarayanan, 1934). Banerjee and Basu (1951) are probably the first in India to study the effect of weather on activity and abundance of certain Lepidoptera with the help of a Williams light trap at Chinsura (West Bengal). Usman (1954 a, b, 1956) made the use of light traps to study the fauna of a particular locality (Bangalore). Kundu *et al*, (1967); Kundu and Gupta, (1971) used light trap to work out the seasonal abundance of Hemiptera at Pilani, Rajasthan. Shull (1967) used the trap to study the

hemipteran fauna of Surat (Gujarat). Narula (1969) studied the seasonal abundance of certain heteropterans. Goel (1976) studied the ecology of hemipteran catch by the light trap at Muzaffarnagar. Naik and Kundu (1977) studied the activity of six species of Orthoptera of semiarid regions of Rajasthan in relation to weather conditions. Mathur and Singh (1959) brought out a list of insect pests on forest plants in India.

As indicated, although the subject is extensive and some knowledge of light trap performance has been accumulated, in India right now information regarding the study of insects with light-traps is far from satisfactory. The objectives of the present study were to analyse the species composition of the different consumer insect fauna attracted to light trap, to examine the catches of insects for identification of insects detrimental to the pine, to determine the seasonal population abundance and their rate of population increase, to collect information on the flight periods of some important species and to study the changes in abundance of various species during two annual cycles and to determine whether these insects could be controlled by the use of suitable light traps. Attempts have been made to correlate the activity and abundance of these insect pests with monthly meteorological data.

Decomposer Arthropods in Soil

As one of the important components of any terrestrial ecosystem soil, has been reviewed by Witkamp (1971). Soil, the principal substrate in which vegetation takes root, includes the dead organic material found both in and upon the mineral substrate (Drift, 1951), and the decomposing organic matter which lie immediately above it (Kevan, 1965). Soil fauna exists both in and below the litter layer often moving from one to the other. It is a broad term applicable to all the groups of animals which spend their whole life or one or more of their developmental stages, in soil or litter (Drift, 1951). Arthropods are one of the groups of soil fauna which inhabit the soil and the overlying layer of organic debris. According to Kuhnelt (1963), there was hardly an arthropodan group which was not found in the soil. The arthropods usually referred to collectively as the soil microarthropod fauna (Drift, 1951), included Acarina, Collembola, Protrura, Pauropoda, Diplura and Symphyla. The first two groups are the abundant in most soils (Kevan, 1965).

The observation on soil fauna dates back to the last quarter of the 18th century (Kevan, 1965) and perhaps it may be said to have begun when White (1789) expressed his opinion concerning earthworms and mole crickets. Among the early landmarks of soil zoology were the observations of Darwin (1840, 1881) on earthworms and of Scandinavian authors, culminating in the works of Muller (1879, 1884), who considered the role of various invertebrates in humus formation. Several studies on earthworms and a few on other groups, were published during the last part of the 19th and early 20th century. The general studies of soil fauna may perhaps be said to have begun with Diems (1903) pioneering investigations on certain Swiss alpine soils. During the first half of the present century, possibly the most far reaching general studies on soil fauna were those of Bornebusch (1930) and Forsslund (1945), although it might appear invidious not to refer to numerous other publications such as Ramann (1911), Cameron (1930), Tullgren (1917), Pillai (1922), Pfetten (1925), Escherich (1923); Grimmett (1926), Soudek (1928), Tragardh (1929). Snell (1933) had attempted to describe the general characteristics of soil microarthropod populations. The arthropod populations under

different soil conditions have also been studied by many other workers including Frenzel (1936); Strenzke (1949a, b); Thompson (1924); Edwards (1929); Ford (1937); Wies-Fogh (1948); Kubiena (1955); Sheals (1957); Kuhnelt (1950, 1955, 1957, 1961, 1963); Kevans (1955, 1960, 1961, 1962); Dhillon and Gibson (1962) and Madge (1965) in different countries.

Kuhnelt (1950) summarized in a single volume, *Badonbiologie*, the greater part of what was known about soil animals till that time. Franz (1950) published his *Bodenzoologie* where he emphasized the practical implications of the study of the soil fauna. Delamare-Debouteville (1951) studied the influence of animals in tropical soils. Hartman (1952) based his classification of forest soils on the activities of animals and Drift (1951) published a large research work in the tradition of Bornebusch. Bellinger (1954) studied soil fauna with special reference to Collembola of four habitats of different pine stands. Drift (1963) reviewed the early workers results on tropical soil faunal densities. Greenslade and Greenslade (1968) investigated the density and vertical distribution of the fauna of soil and litter in lowland rain forests and coconut plantations. Curry (1969) studied the qualitative and quantitative composition of the fauna of an old grassland and reviewed the earlier work on all grassland fauna. Curry (1971) attempted the seasonal and vertical distribution of the arthropod fauna. Wood (1967, 1970, 1971) studied the distribution and abundance of Acarina and Collembola and other microarthropods in arid and semiarid soils and found the greatest densities of Acarina and Collembola in the upper 4 cm. Price (1973) investigated the abundance and vertical distribution of microarthropods in the surface layers of a pine forest soil. McColl (1974) analysed the arthropod fauna of the floors of six forest types. Soil inhabiting microarthropods usually were most abundant near the surface in a zone ca 10 cm deep characterised by adequate living space, favourable moisture conditions and aeration rates and rich accumulation of organic debris (Wies- Fogh, 1948; Murphy, 1953; Harlov, 1960; Wallwork, 1970). Price and Benham (1977) stated that most arthropod groups declined rapidly in abundance with increasing depth. Wallwork (1967) felt that soil acari were primarily hemiedaphic, although their distribution may also extend into the other two zones, as with active and tolerant species. Murphy (1955) reported that the fauna of heath or forest moor was largely concentrated in the surface organic layers.

Price (1975) stated that high surface concentrations of the soil fauna was largely confined to a discrete organic layer of litter and humus which overlay the mineral sub-soil (Bornebusch, 1930; Bellinger, 1954; Murphy, 1953, 1955; Wallwork, 1959; Poole, 1961; Evans *et al*, 1961; Fujikawa, 1970). The species composition and abundance of soil fauna are influenced by the geographical location, climate, physical and chemical properties of the soil, type of vegetative cover, nature and depth of litter and humus and a variety of other environmental factors. Thus, the soil fauna may vary considerably from one locality to another (Price, 1973). Further, he mentioned, that seasonal changes in soil moisture and temperature, food supplies, biotic pressures from other components of the fauna and microflora and inherent factors in the life cycle of each species result in cyclic fluctuations and spatial movements within the soil community. Summers and Lussenhop (1976) reported that the response of soil arthropods to single habitat factors such as soil organic matter or particle size has been infrequently demonstrated. Most soil arthropod faunal studies were samples of species present in different habitats. In such studies, species differences among soil arthropods, from habitat to habitat were due to interaction of microclimate, vegetation and soil properties. Davis (1963)

correlated changes in soil arthropod fauna with changes in vegetation and soil properties occurring during grassland reclamation.

Among the earlier collembolan workers, the work of Bellinger (1954) and Christiansen (1964) were most important, where the former studied the microarthropod populations with reference to Collembola, from six different pine forest stands and the latter reviewed the early work on bionomics of Collembola. Stebaeva (1967) demonstrated the effect of climate on Collembola distribution, with reciprocal exchange of soil blocks between plant communities. Joosse (1969) investigated the population structure of six species of surface dwelling Collembola in a pine forest. Niijima (1971, 1975) studied the seasonal changes in Collembola populations in a warm temperate forest of Japan. Kaczmarek (1973) reported on Collembola in the biotopes of the Kampinos national park.

It is clear that the regular seasonal occurrence of Collembola was rare and these were readily marked by environmental conditions (Gisin, 1955). The result was that the pattern of population fluctuation varied not only from species to species but from year to year (Milne, 1962) and geographically (Christiansen, 1964). Seasonal changes of Collembola population have been studied by many investigators (Poole, 1961; Milne, 1962; Ogino *et al*, 1957; Marcuzzi, 1966; Choudhuri and Roy, 1967; Healey, 1967). Studies where seasonal population peaks occurred, they generally appeared in spring, in central Europe and parts of the United States, while in summer and winter in England and other regions of North America (Baweja, 1939; Sheal, 1957; Dunger, 1958). Winter populations appeared to be essentially similar in nature to summer populations, but most studies showed the occurrence or dominance of some species during the spring and summer months.

Nosek, (1959); Marcuzzi, (1959, 1962, 1966, 1967, 1968, 1973) studied the seasonal abundance, biogeography of Collembola of South-Eastern Alps. Greenslade and Greenslade (1973) reported the activity of epigeic Collembola in a semiarid locality in Southern Australia and in 1974, studied their ecology and zoogeography. Takeda (1973) studied the seasonal changes in numbers and distribution patterns of eight species of Collembola. Blackith (1974) studied the ecology of Collembola in Irish blanket bogs. Kaczmarek (1975) analysed Collembola communities in different pine forest environments. Tamura (1976) studied the population dynamics in a sub-alpine coniferous forest. There was a close relationship between population density and soil moisture. (Hammer, 1944; Strenzke, 1949 a,b). The degree of hygrophilia of these species being the best criterion for the ecological classification (Agrell, 1941; Gisin, 1943; 1952).

Mites constituted one of the most successful ubiquitous soil microarthropod groups (Kevan, 1965). Most mites are either free living in soil and or litter inhabiting species (Evans *et al*, 1961). In litter and humus some of the most abundant species of mites belonged to the Cryptostigmata (Kevan, 1965). Most of the qualitative and quantitative information on the ecology of soil Acarina population relate to the European fauna, particularly of Scandinavia, much of it concerning temperate forest and grassland communities (Wallwork, 1967).

A basic understanding of the population biology of orbatid mites was needed to assess their role in the soil, since their population parameters would directly influence their interactions with both the abiotic and biotic components of the system (Mitchell, 1977). Usher (1971, 1975) studied the seasonal and vertical distribution of a population of mesostigmatid mites in a scots pine forest. Pandey and Berthet (1975)

studied the vertical distribution of orbatid mites in a black pine woodland soil. Soil mites were important contributors to fundamental fertility, humification process and that agronomic or plant protection practices affected them adversely (Butcher *et al*, 1971). Attempts to correlate soil fauna with soil fertility dates back to Soudek (1928). Bornebusch (1930), Edwards and Heath (1963), Burges (1967), and Fujikawa (1970) have stressed on the role of soil microarthropods in litter decomposition and release of nutrients therefrom, which in turn had an impact on soil formation and fertility. The significance of Collembola and Mites in breakdown of organic matter and soil formation had also been pointed out by Dunger (1956, 1958), Stockli (1957), Schuster (1958), Poole (1961) and Fujikawa (1970). The role played by Oribatid mites in the comminution of decaying leaf tissues was of a high order. Moreover, the immature stages of Oribatid mites were of greater importance in so far as decomposition of organic matter was concerned, and hence had a major role in promoting soil fertility. However, according to Hale (1967) Insect Mull soil as named by Muller (1879, 1884) was almost entirely formed by Collembola faeces. Microarthropods may be of considerable importance in controlling soil microflora and pests inhabiting soil by feeding upon them. Several workers have suggested that soil microarthropods may serve as excellent indicators of soil quality (Balogh, 1963; Ghilarov, 1965; Karg, 1968).

In contrast, information regarding the arthropod fauna of tropical soil are scanty (Raw, 1967). Most of the papers dealt with description of new taxa and other taxonomic aspects. The investigation of soil microarthropods in India, their fluctuations and effect of various factors on them, was first undertaken by Trehan (1945) in Lyallpur, now in West Pakistan, followed by Choudhury and Roy (1967, 1970) in uncultivated soils; Bhaduri and Raychaudhuri (1968) and Prabhoo (1976) in uncultivated and cultivated soils, and by Mukherjee and Singh, (1967 and 1970), Singh and Mukherjee (1971, 1973), Singh and Pillai (1975a) and Gupta and Mukherjee (1976a, b and 1978) mostly in cultivated soils. Hence, it was clearly indicative that very few soil faunal studies exist for the tropics in general. Moreover, Indian studies were mostly if not all restricted to cultivated or uncultivated soils only. This study was therefore primarily undertaken to establish the soil faunal structure in forest soils. As the area under study comprised of pine forests our study was restricted only to the pine forest floors (Reddy and Alfred, 1977).

Decomposer Arthropods in Litter.

All phytomass in terrestrial ecosystems, dead and shed, forms what is referred to as the plant litter. Plant litter is defined in ecological terms as layers of dead plant material present on the soil surface and not attached to a living plant (Satchell, 1974). Rodin and Bazilevich (1967) defined litter as all dead organic matter from above and below ground plant parts either due to death as a result of slow ageing or natural thinning.

Decomposition of plant litter is one of the most important processes in an ecosystem (Rosswall *et al*, 1975) as its rate was directly related to the availability of nutrients for recycling (Gist and Crossley, 1975). Satchell (1974) stated that decomposition signified the mechanical disintegration of dead plant structure from the stage it was attached to the living plant to the humus stage when the gross cell structure became no longer recognizable. Alternatively, it meant the breakdown of complex organic molecules to carbon-dioxide, water and mineral components, in other words expressed as the proportion of the initial weight of the substrate lost per unit time. Three main decomposition

processes outlined by Heal and French (1974) were the release of carbon in gaseous form by microflora and fauna (respiration), leaching of soluble material and comminution by fauna and physical factors.

Edwards (1974), Edwards *et al*, (1970) and McBrayer *et al*, (1977) stated that decomposition was accomplished by the activity of both the floor microflora and fauna in a synergestic manner. Wood (1974) used Decomposition to designate weight losses due to removal and/or consumption of tissue by leaf-feeding invertebrates, losses due to leaching, losses due to biochemical degradation by microorganisms and losses due to biochemical degradation during passage through the guts of invertebrates. However, Satchell (1974) considered weight losses due to removal and/or consumption by invertebrates in terms of disappearance rather than biochemical degradation, as majority of soil and litter invertebrates had insufficient digestive systems, net assimilation being less than 20%, and their excreta consisted of finely comminuted food material, rich in energy and nutrients, which were a rich substrate for ultimate decomposition by microorganisms. Drift and Witkamp (1960) reported that during decomposition processes, biological attack was most important, as a large variety of microflora and fauna were involved in it. To understand the mechanism of this process, it was therefore necessary to evaluate the role of the most important groups of organisms, their succession and their natural influences. Kevan (1955, 1962) recognized the importance of soil animals in transforming plant remains into humus.

Dudich *et al* (1952) and Nef (1957) calculated that all the annual litter fall in woodlands were eaten by the soil fauna. Kurcheva (1960) reported that litter decomposition was five times faster with the presence of soil animals than without them, which was supported by Edwards and Heath (1963) who recorded no visual litter breakdown when the animals were completely excluded from the litter. Madge (1966) stated that in natural conditions small soil animals rapidly fragment tissue to fine powder. Styles (1967) examined changes in invertebrate populations of decomposing litter over a period of 4 years. Metz and Ferrier (1969) reported that Acarina which constituted a large part of the small animals living in forest floor, played a major role in nutrient cycling. Removal of fresh plant litter by decomposition offered evidence of animal activity in these processes, (Curry, 1969a). Wood (1970) reported the effect of soil fauna on decomposition of two species of Eucalyptus leaf litter in Australia. Weigert (1974) studied the litter microarthropods and related them to litter decomposition in three South Carolina Oil Fields.

McColl (1974) compared arthropod populations on the floors of three types of beach forest and McColl (1975) showed the effect of microclimate on the activity of invertebrate fauna. Anderson (1975) studied the succession, diversity and trophic relationships of some soil animals of decomposing leaf litter while Weigert and McGinnis (1975) studied the annual production and disappearance of detritus. Drift (1975) reported the significance of millipedes in litter decomposition and an approach of its parts in energy flow. Parkinson and Lousier (1974) studied litter decomposition in a cool deciduous woodland with dominant tree species exposed to extreme climatic conditions. Gist and Crossley (1975) studied the number, biomass and mineral element contents of the litter arthropod community in a Hardwood forest. Grimmett (1976) compared invertebrates in litter between a mixed rain forest with those of a beach forest.

Mitchell (1978), was of the opinion that insects were very essential in pulverizing plant parts and felt and flora or surface phenomenon alone would be a very slow process. Reddy and Alfred (1978a, b) reported the microarthropods associated with pine litter and related them to the rate of decomposition seasonally.

MATERIALS AND METHODS

Sap Sucking Consumer Arthropods

Population estimations were done following the method of Gray and Schuh (1941). Weekly samples were collected during the period March, 1976 to March, 1978 from the different pine plantations of less than one year old seedlings. The time of sampling was confined to the morning hours between 0800 and 1100 hrs. One year old seedling were chosen for *Cinara attrotibialis* and *Eulachnus thunbergii* and three months old for *Neomyzus circumflexus* (Buckton). Twenty of each were selected growing at different experimental sites. Seedling shoot length ranging from 15 to 20 cm were selected at random for *C. attrotibialis* and *E. thunbergii* and 6 to 9 cm for *N. circumflexus*. Sufficient care was taken to prevent loss of any aphid either by cutting and plucking the seedlings. Each seedling was then immediately sealed in a polythene bag and brought to the laboratory and the aphids were counted individually. In the present study no separate attempt has been made to analyse the population of alate forms as they were very negligible.

The maximum and minimum air temperature was recorded by an ordinary centigrade mercury thermometer. The air humidity was recorded by a hygrometer. The rainfall was recorded by a simple rain guage.

Study site

The area selected for sampling these pine aphids were the pine seedling plantations seeded in 1976 and 1977. The area covers three different hilly slopes continuous with each other. All these hilly slopes are situated at an average altitude of 1150 m. The size of each nursery bed is about twenty hectares (approximately fifty acres).

The pine seeds were seeded in each row at the beginning of the rainy season during May of each year. The seedlings were very close touching the needles of one another. The soil is red loam in nature. All rows are without any litter deposition, but patches of grass are present. Seedlings of other shrubs or trees were completely lacking.

Chewing and Mining Consumer Arthropods

Description of the trap

The light trap was specially designed for forest insect ecological studies where electricity did not exist. The light trap consisted of one petromax light and nine white enamel trays each of size 32x27 cm, making the entire trapping surface of 96x81 cm. The light source was of 400/500 candle power. The light trap was corroborated by a major source of attraction to nocturnal insects i.e. the reflection

of the enamel trays. Moreover, it was a combination of two traps : (1) light and (2) water trap. The insects attracted to the light fell in the water placed in the enamel trays surrounding light source. Detergent added to water, made the insects sink and prevented them from drifting to the edges for escape while narcotising them at the same time. Teepol was used as the detergent.

Procedure

The trapping was done on the new moon night of every month, not only avoiding the effect of moonlight on the catch, but also to collect greater numbers and variety (Provost, 1959; Brown and Taylor, 1971; Hartstack *et al*, 1973; Kline and Axtell, 1976). Care was taken to avoid the blackening of the glass enclosing the light source. One of the enamel trays was put upside down on the forest floor over which the petromax light was placed. Around the base tray of the petromax light, the other eight well-cleaned white enamel trays were placed. Care was taken to put all the trays on the same plane. 5 cc of Teepol was added to each tray which were half filled water, thoroughly mixed.

The total duration of the experiment was for a period of 12 hours (1800 to 0600 hrs.). At the end of every hour the samples were collected by pouring the water from the trays along with the insects caught through a plankton net of 50 μ pore size in a bucket and the water was reused. A uniform light was maintained by pumping the petromax light every hour. The light source was protected from the rain during the rainy season by mounting an umbrella over the trap. At the time of heavy rains two or more umbrellas were used. All the insects were preserved in 70% alcohol, except Lepidoptera in paper triangles. In the laboratory the catches were sorted upto families and some of the important orders were sent to Zoological Survey of India for identification. Few of the smaller insects could not be identified and were grouped under miscellaneous.

Study site

The size of the plantation was 20 ha (approximately 50 acres) and composed of pine trees 22 years old (planted in 1955) and 10 m high, at the time of investigation. The soil in the area was covered with a litter layer 1-2 cm thick, 75% attributed to the freshly fallen litter and the rest to the burnt humus.

Decomposer Arthropods in Soil

Study Site, Sampling and Extraction

Samples of soil have been regularly collected for a period of 20 months from a plantation seeded in 1965. The age of the plantation was 11 years when the work commenced. Samples were collected monthly and the time confined to 0900 and 1100 hrs. 10 sample units were taken at random, on each sampling occasion. A rectangular iron sampler of 5x5x10 cm was used for removing the samples. A total of 200 samples units were collected and examined during the entire period of study. All the samples collected were immediately transferred to polythene bags and labelled, taking as much as possible to prevent loss of moisture. The labelled samples were brought to the laboratory for extraction within 24 hours of their collection. Berlese-Tullgren funnel series were used for the

extraction (Macfadyen, 1955).

Physicochemical factors

Soil samples were collected separately for the study of physiochemical factors.

Soil temperature was measured by an ordinary mercury thermometer at soil surface at 5 cm depth and the temperature of air, one metre above ground level.

Moisture content was measured by the dry weight method. pH and conductivity were measured by a pH metre (Toshniwal Cat. No. CL- 43) and a Elico Conductivity Bridge (Elico Type CM-82). Organic carbon was analysed by the method given by Walkley and Blacks (1934). P_2O_5, K_2O, Fe_2O_3, CaO, MgO and Na_2O were analysed after Piper (1950).

Decomposer Arthropods in litter

Nylon bags (10 cm^2) of three different mesh sizes (3.0 mm^2; 1.0 mm^2 and 0.3 mm^2) were used for the present study. Freshly fallen pine needles were collected at the time of needle fall during April, 1977. The needles were cut into uniform lengths of 5 cm and air dried. 10 gms of air dried litter was placed in each of the nylon bags. 50 litter bags in each mesh size were such prepared and placed along with the litter of the forest floor in the plantation of study site as for soil studies. Thereafter, three bags of each mesh size were collected from the experimental site every 30th day over a period of one year. Immediately, on removal, the litter bags were sealed (Crossley and Hogland, 1962) individually in polythene bags. Microarthropods were then extracted by a modified Tullgren funnel (Macfadyen, 1955). The temperature of the litter was recorded by an ordinary mercury thermometer. The moisture content of the litter was determined by oven drying to a constant weight at 105°C (Piper, 1950).

RESULTS

Sap Sucking Consumer Arthropods

Altogether three aphids were recorded viz. *Cinara attrotibialis* David and Rajasingh, *Eulachnus thunbergii* (Wilson) and *Neomyzus circumflexus* (Buckton). It was observed that *C. attrotibialis* almost always occupied the apex of the seedlings though not in recognisable colonies. They were lethargic creatures. *E. thunbergii* were seen only on the needles and were very active. *N. circumflexus* were first recorded in the two month old seedlings (Reddy *et al*, 1978). They confined themselves in clusters at the distal part of the shoot on the newly flushed needles, with one to two adults and four to five nymphs on each sapling. *C. attrotibialis* and *E. thunbergii* seemed to have no marked preference between current and previous year needles.

The monthly fluctuations in the number of these three species of pine aphids during both the years of study are presented in Fig. 2. In plantations of May, 1975, the aphid population sampling began from March, 1976. It was seen that from March, 1976 till the end of May, 1976, an increase in the number of *C. attrotibialis* was recorded, after which there was a decline in the number upto September. Thereafter a steady increase was recorded upto November, after which a rapid decline

was observed. Thus *Cinara attrotibialis* reached two peaks in one annual cycle (Fig. 2c). The first one in May, with the number of aphids 112 per 20 seedlings and the second during November, the number being 145 per twenty seedlings. Similarly, the lowest record occurred twice during the annual cycle, once in March with the aphid number 49 per twenty seedlings and the other in September, 52 per twenty seedlings. The second annual cycle had an overall trend of population abundance basically similar to that of the first annual cycle. During the second annual cycle, the May peak recorded 94 aphids and the second peak was in November, when the number reached 138. The lowest was observed one in March when the aphid number was 56 and the second one in September when the number was 68, the trend being similar to that of the previous annual cycle. (Fig. 2c).

The monthly population fluctuation of *E. thunbergii* (Wilson) on pine seedlings seeded during the period 1976-78 is presented in Fig. 2b, a perusal of which reveals that the aphid number was minimum in April, (2 per twenty seedlings) with complete absence in March and June. From July, onwards it started increasing gradually reaching a peak the following January, with 58 aphids per twenty seedlings after which a sudden decline was recorded. The number then reached a minimum in April, (7 per twenty seedlings). From May onwards, it started increasing with considerable fluctuation and reached the peak in January (39 per twenty seedlings). This indicates that *E. thunbergii* unlike *C. attrotibialis* reached the peak only once during an annual cycle i.e. in January.

The monthly fluctuation of *N. circumflexus* is presented in Fig. 2a. The species was recorded for the first time in July, and thereafter a gradual increase in the number occurred. The peak of 96 per twenty seedlings was recorded at the end of November, after which a rapid decline occurred reaching a minimum of 20 per twenty seedlings in the third week of April, in the following year and completely disappeared thereafter. The next population was recorded from 1977 seeded plants which showed more or less a similar pattern of fluctuation though less in number. The population number reached a low ebb during the third week of August and second week of September, the number being 2 to 3 per twenty seedlings and reached a peak during the third week of November, when the total population was 48 per twenty seedlings. Total absence was observed during July, last two weeks of September, first week of October, and first week of March, of the second cycle. However, the population was completely nil from the second week of April.

Different environmental factors such as maximum and minimum temperature, rainfall, relative humidity and wind velocity are presented in Fig. 3. The maximum temperature ranged from 14.61±0.13°C to 24.38±0.68°C during the first annual cycle the maximum being recorded in April, and minimum in January, which it was 13.21±0.68°C to 24.46±0.52°C during the second annual cycle, the maximum being recorded in August and minimum in January. During the first year the maximum temperature in April was maintained upto September. It then gradually reached a minimum in January. From then on it gradually increased till it reached the maximum in August and then decreased reaching the minimum in January, the following year. The minimum temperature range was 6.98±0.22°C to 18.43±0.28°C during the first year, and 6.05±0.69°C to 18.89±0.09°C during the second. The minimum temperature gradually increased and reached the peak in July, then decreased gradually to minimum in January. It started increasing gradually reaching the peak in July and gradually decreased to minimum in January. (Fig. 3b).

TABLE II

Aphid	X	Y	Coefficient correlation (r)	Computed "t" of r	Degree of Freedom	Significance	Multiple Correlation
	Abundance	Max. Temp.	– 0.4844	2.599	22	NS	
	Abundance	Min. Temp.	– 0.3402	1.696	22	NS	
Cinara attrotibialis	Abundance	Rel. Humi.	0.2535	1.229	22	NS	0.6146
	Abundance	Rainfall	– 0.1635	0.777	22	NS	
	Abundance	Max. Temp	– 0.8897	9.151	22	P < 0.01	
		Min. Temp.	– 0.8161	6.632	22	P < 0.01	
Eulachnus thunbergii	Abundance	Rel. Humi.	0.0398	0.186	22	NS	0.8436
	Abundance	Rainfall	– 0.5326	2.952	22	P < 0.01	
	Abundance	Max. Temp.	– 0.8818	5.295	8	P < 0.01	
	Abundance	Min. Temp.	– 0.9127	6.325	8	P < 0.01	
Neomyzus circumflexus	Abundance	Rel. Humi.	– 0.6344	2.321	8	P < 0.05	0.9096
	Abundance	Rainfall	– 0.7956	3.719	8	P < 0.01	

NS = Not significant

Table II Coefficient correlation and multiple correlation between the monthly abundance of the three pine aphids and the monthly variation in the various abiotic factors.

Max. Temp. = Maximum Temperature; Min. Temp. = Minimum Temperature; Rel. Humi. = Relative Humidity

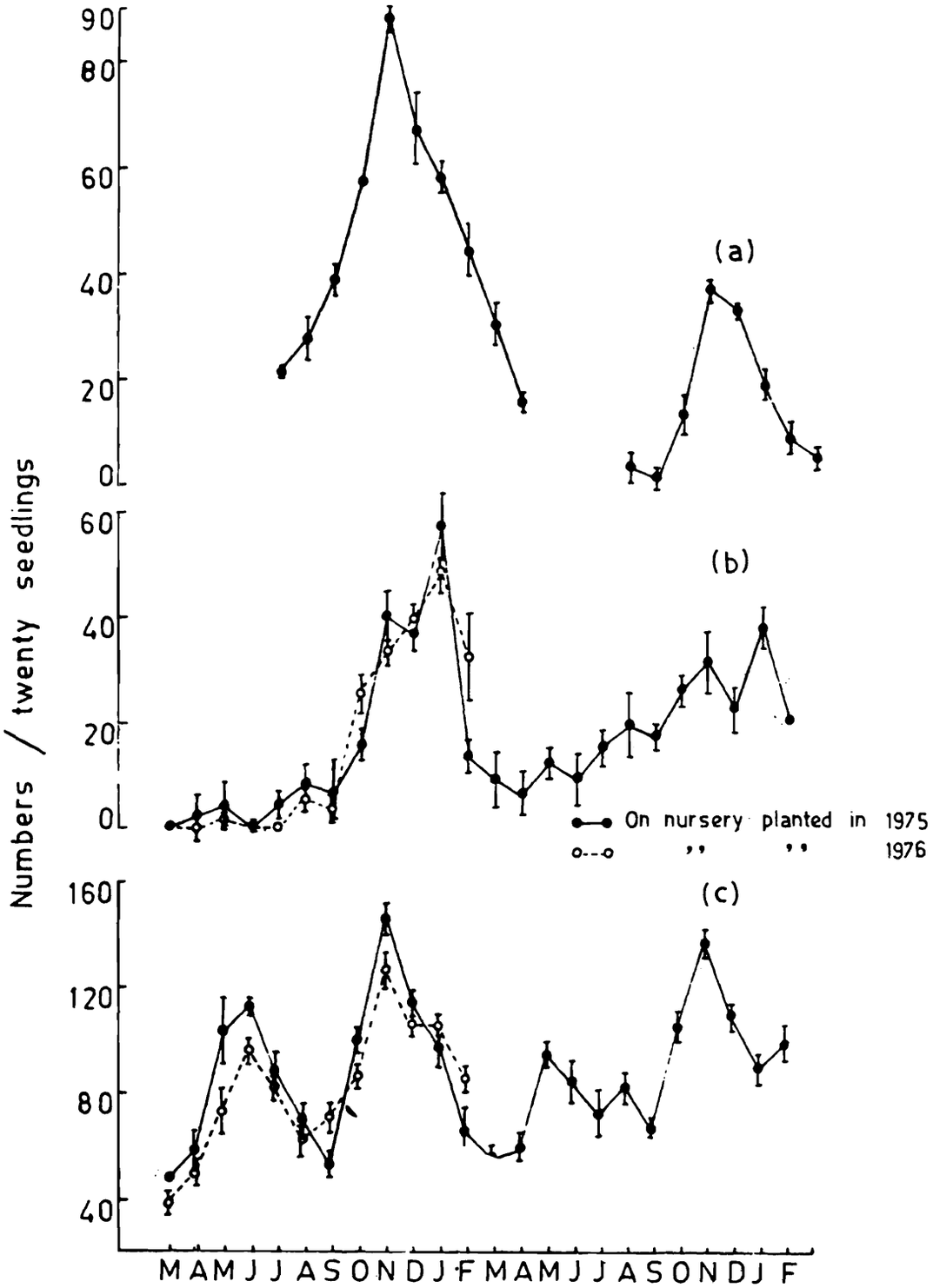


Figure 2 showing the seasonal fluctuation of the three pine aphids during the entire study period.
a *Neomyzus circumflexus* (Buckton); b *Eulachnus thunbergii* Wilson;
c *Cinara attrotibialis* David and Raja Singh

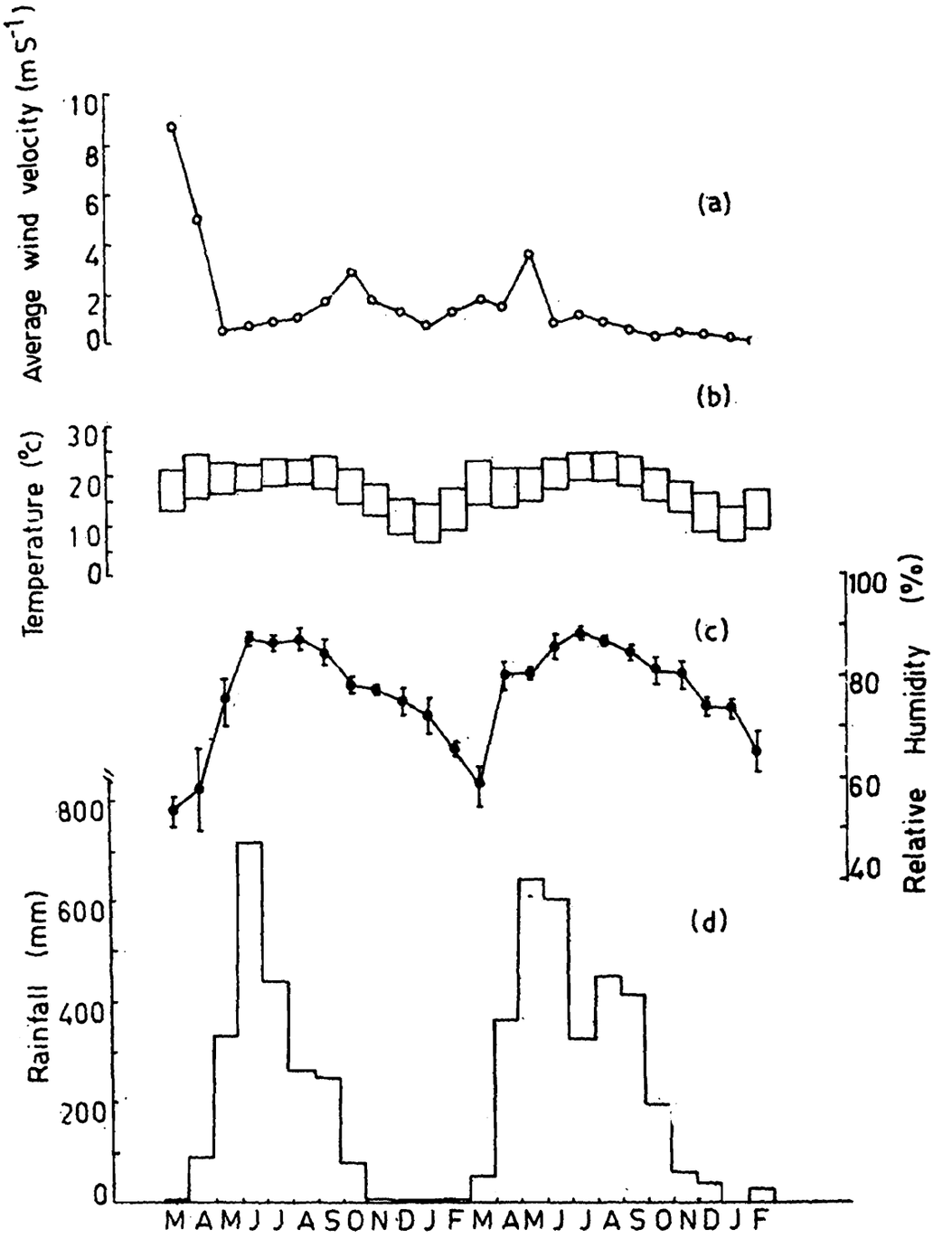


Figure 3 showing seasonal fluctuation in the various abiotic factors during the entire period.

a Average Wind Velocity; b Maximum and Minimum Temperature; c Relative Humidity; d Rainfall

The monthly relative humidity (Fig. 3c) ranged from 53.25±2.57 to 87.42±1.55 percent during the first year, minimum being in March, and the maximum in June and August and 58.39±3.31 to 88.27±1.21 percent during the second year the minimum being recorded in March, and maximum in July. The relative humidity from March, onwards gradually increased reaching the peak in June and August. It then gradually decreased to minimum in March, of the next year. During the second cycle, it showed more or less a similar pattern of fluctuation.

The rainfall ranged from 0 mm to 720.8 mm during the first annual cycle, the maximum being recorded in June, and nil being recorded in January, and 0 to 644.5 mm during the second annual cycle, the maximum being in May, and nil in January. During both the years, it showed more or less a similar type of fluctuation (Fig. 3a). From January it gradually increased with a sudden rise in May, reaching the maximum in June, after which it started gradually decreasing reaching nil in January. During the second year, the sudden increase in the rainfall was recorded in April and it reached the maximum in May. It then gradually decreased with a small increase in August, and was nil in January, of the following year.

Chewing and Mining Consumers

During the present investigation it was seen that insects belonging to fourteen different orders viz. Lepidoptera, Diptera, Coleoptera, Hymenoptera, Hemiptera, Heteroptera, Orthoptera, Dictyoptera, Trichoptera Neuroptera, Arachnida, Dermaptera, Isoptera, Odonata were attracted to the light trap (Fig. 4).

During the first year of study, Lepidoptera was the most abundant group representing 34.81 percent, followed by Diptera 34.39 percent, Heteroptera 6.36 percent, Hymenoptera 5.4 percent, Trichoptera 5.34 percent, Coleoptera and Hemiptera 3.8 percent each, Orthoptera 2.5 percent, Neuroptera 1.51 percent, Dictyoptera 1.04 percent, Arachnida 0.73 percent, Isoptera 0.1 percent, Dermaptera 0.03 percent and Odonata 0.02 percent (Fig. 4). It was seen that Lepidoptera and Diptera collectively represented about 70 percent of the total catch.

During the second year of investigation only 12 orders were recorded. Isoptera and Odonata were completely absent. Diptera dominated the catch representing 49.57 percent followed by Lepidoptera 23.16 percent, Coleoptera 7.35 percent, Hemiptera 6.42 percent, Hymenoptera 3.7 percent, Heteroptera 3.31 percent, Orthoptera 1.95 percent, Trichoptera 1.93 percent, Neuroptera 1.27 percent, Dictyoptera 0.76 percent, Arachnida 0.52 percent and Dermaptera 0.03 percent. Here again, Diptera and Lepidoptera represented more than 70 percent of the total catch (Fig. 4).

A comparison of both the years (Fig. 4) revealed that the overall catch of the first year was larger than that of the second. However, Diptera and Hemiptera caught were more during the second year than that of the first (Fig. 5). The total maximum catch was in the month of May, representing 3069 individuals. It then started decreasing and reached a low ebb in January the following year when only 15 individuals were caught. From February it increased till the maximum number of insects caught was in June, representing 3090 individuals, after which it decreased reaching a minimum once again in January, following the same trend as in the previous years.

TABLE III

Insect Orders	Correlation Coefficient (r)	Computed value of "t"	Degree of freedom	Significance
Lepidoptera	0.3901	1.336	10	NS
Diptera	0.7347	3.421	10	P < 0.01
Coleoptera	0.3016	1.000	10	NS
Hymenoptera	0.7694	3.857	10	P < 0.01
Hemiptera	0.4970	1.825	10	NS
Heteroptera	0.7992	4.200	10	P < 0.01
Orthoptera	0.9030	6.785	10	P < 0.01
Dictyoptera	0.8256	4.642	10	P < 0.01
Trichoptera	0.3835	1.315	10	NS
Neuroptera	0.7398	3.477	10	P < 0.01
Arachnida	0.0697	0.222	10	NS
Total Insects	0.5716	2.195	10	P < 0.05

NS = Not significant

Table III Coefficient correlation between the monthly abundance of various insect orders for entire study period

TABLE IVa

Insect Orders	Max. Temp.	Min. Temp.	Rainfall	Rel. Humi.	Wind Velo.
Lepidoptera	0.5309^{NS}	0.4756^{NS}	0.4378^{NS}	0.0080^{NS}	-0.1844^{NS}
Diptera	0.6255^{*}	0.7119^{**}	0.7663^{**}	0.4812^{NS}	-0.4259^{NS}
Coleoptera	0.4871^{NS}	0.3467^{NS}	0.2645^{NS}	-0.2575^{NS}	0.0076^{NS}
Hymenoptera	0.4865^{NS}	0.5553^{NS}	0.9215^{**}	0.4495^{NS}	-0.2985^{NS}
Hemiptera	0.6319^{*}	0.6025^{*}	0.3512^{NS}	0.1634^{NS}	-0.1441^{NS}
Heteroptera	0.4170^{NS}	0.2111^{NS}	-0.0295^{NS}	-0.4839^{NS}	-0.2797^{NS}
Orthoptera	0.7213^{**}	0.8366^{**}	0.8927^{**}	0.5940^{*}	-0.3882^{NS}
Dictyoptera	0.4522^{NS}	0.3992^{NS}	0.4511^{NS}	-0.0455^{NS}	-0.1525^{NS}
Trichoptera	0.7297^{**}	0.6796^{*}	0.5912^{*}	0.1628^{NS}	-0.2491^{NS}
Neuroptera	0.7093^{**}	0.6316^{*}	0.4728^{NS}	0.0587^{NS}	-0.1808^{NS}
Arachnida	0.3542^{NS}	0.3260^{NS}	0.1176^{NS}	-0.3694^{NS}	0.2619^{NS}
Total Insects	0.6530^{*}	0.6168^{*}	0.5886^{*}	0.1219^{NS}	-0.2251^{NS}

NS = Not significant
* = $P < 0.05$
** = $P < 0.01$

Table IVa Coefficient correlation between the monthly abundance of total insects, various insect orders and monthly variation in the various abiotic factors for the first year of study.

Max. Temp. = Maximum Temperature
Min. Temp. = Minimum Temperature
Wind Velo. = Wind Velocity
Rel. Humi. = Relative Humidity

TABLE IVb

Insect Orders	Max. Temp.	Min. Temp.	Rainfall	Rel. Humi.	Wind Velo.
Lepidoptera	0.5460^{NS}	0.6216^{*}	0.6935^{*}	0.5556^{NS}	0.1083^{NS}
Diptera	0.5455^{NS}	0.6396^{*}	0.7369^{**}	0.6154^{*}	0.0840^{NS}
Coleoptera	0.4742^{NS}	0.5574^{NS}	0.7392^{**}	0.4757^{NS}	0.2428^{NS}
Hymenoptera	0.4736^{NS}	0.5626^{NS}	0.7099^{**}	0.5252^{NS}	0.0567^{NS}
Hemiptera	0.6594^{*}	0.7802^{**}	0.7193^{**}	0.7087^{**}	-0.1829^{NS}
Heteroptera	0.3661^{NS}	0.3668^{NS}	0.7102^{**}	0.4454^{NS}	0.4570^{NS}
Orthoptera	0.5935^{*}	0.7328^{**}	0.7702^{**}	0.7824^{**}	0.1770^{NS}
Dictyoptera	0.4186^{NS}	0.4892^{NS}	0.8052^{**}	0.4832^{NS}	0.6006^{*}
Trichoptera	0.4788^{NS}	0.4203^{NS}	0.3406^{NS}	0.0967^{NS}	0.1139^{NS}
Neuroptera	0.7443^{**}	0.7759^{**}	0.9102^{**}	0.5939^{*}	0.3630^{NS}
Arachnida	0.1322^{NS}	0.2294^{NS}	0.3398^{NS}	0.3887^{NS}	0.1041^{NS}
Total Insects	0.5588^{NS}	0.6474^{*}	0.7506^{**}	0.6095^{*}	0.1294^{NS}

NS = Not significant
* = $P < 0.05$
** = $P < 0.01$

Table IVb Coefficient correlation between the monthly abundance of total insects, various insect orders and monthly variation in the various abiotic factors for the second year of study.

Max. Temp. = Maximum Temperature
Min. Temp. = Minimum Temperature
Wind Velo. = Wind Velocity
Rel. Humi. = Relative Humidity

TABLE Va

Insect Orders	1	2	3	4	5	6	7	8	9	10	11	12
Lepidoptera	489	191	623	361	402	418	352	278	421	220	71	0
	12.78	4.99	16.28	9.44	10.51	10.93	9.20	7.27	11.00	5.75	1.86	0
Diptera	288	296	380	259	522	377	427	378	449	311	72	18
	7.63	7.84	10.06	6.86	13.82	9.98	11.31	10.01	11.89	8.23	1.91	0.48
Heteroptera	3	66	195	111	110	70	40	46	29	15	5	0
	0.43	9.57	28.26	16.09	15.94	10.14	5.80	6.67	4.20	2.17	0.72	0
Hymenoptera	27	35	67	37	51	44	30	32	26	189	52	3
	4.55	5.90	11.30	6.24	8.60	7.42	4.06	5.40	4.38	31.87	8.77	0.51
Trichoptera	16	33	97	61	67	61	67	54	81	61	4	2
	2.65	5.46	16.06	10.10	11.09	10.10	11.09	8.94	13.41	10.10	0.66	0.33
Coleoptera	37	48	119	43	41	28	41	18	34	24	4	0
	8.47	10.98	27.23	9.84	9.38	6.41	9.38	4.12	7.78	5.49	0.92	0
Hemiptera	21	49	47	33	40	48	42	40	14	57	7	1
	5.26	11.21	11.78	8.27	10.03	12.03	10.53	10.03	3.51	14.29	1.75	0.25
Orthoptera	25	44	55	18	29	18	15	25	14	21	9	0
	9.16	16.12	20.15	6.59	10.62	6.59	5.49	9.16	5.13	7.69	3.30	0
Neuroptera	20	11	35	7	15	17	16	14	17	12	5	0
	11.83	6.51	20.71	4.14	8.88	10.06	9.47	8.28	10.06	7.10	2.96	0
Dictyoptera	4	11	24	11	18	20	16	8	3	1	0	0
	3.45	9.48	20.69	6.51	10.65	17.24	13.79	6.90	2.59	0.86	0	0
Arachnida	3	6	3	6	1	2	0	3	6	4	2	0
	8.33	16.67	8.33	16.67	2.78	5.56	0	8.33	16.67	11.11	5.56	0
Isoptera	6	0	3	1	0	0	0	0	1	0	0	0
	54.55	0	27.27	9.09	0	0	0	0	9.09	0	0	0
Dermaptera	0	0	0	2	0	0	1	0	0	1	0	0
	0	0	0	50.00	0	0	25.00	0	0	25.00	0	0
Odonata	0	0	0	1	0	0	0	0	1	0	0	0
	0	0	0	50.00	0	0	0	0	50.00	0	0	0
Total Insects	939	790	1648	950	1296	1103	1047	896	1096	916	230	24
	8.59	7.22	15.07	8.69	11.85	10.09	9.57	8.19	10.02	8.38	2.10	0.22

Table Va — An hourly analysis of the total insects and various insect orders caught in light trap during the first year of the study period. 1–12 represents 1800–0600 hrs. hourly. The top figure for each insect order represents the actual number while the fraction immediately below it represents the percent caught for that hour.

TABLE Vb

Insect Orders	1	2	3	4	5	6	7	8	9	10	11	12
Diptera	117	229	377	572	382	1308	617	207	521	232	143	99
	2.44	4.77	7.85	11.91	7.95	27.23	12.84	4.31	10.85	4.83	2.98	2.06
Lepidoptera	274	107	288	228	265	252	188	191	185	110	60	0
	12.76	4.98	13.41	10.61	12.34	11.73	8.75	8.89	8.61	5.12	2.79	0
Coleoptera	29	73	118	103	48	64	89	64	71	40	4	2
	4.11	10.35	16.74	14.61	6.81	9.08	12.62	9.08	10.07	5.67	0.57	0.28
Hemiptera	45	58	135	94	40	68	63	45	36	14	22	10
	7.14	9.21	21.43	14.92	6.35	10.78	10.00	7.14	5.71	2.22	3.49	1.59
Hymenoptera	13	38	61	48	33	46	20	21	17	36	9	1
	3.79	11.08	17.78	13.99	9.62	13.41	5.83	6.12	4.96	10.50	2.62	0.29
Heteroptera	4	36	36	68	23	42	25	9	21	38	6	0
	1.30	11.69	11.69	22.08	7.47	13.64	8.12	2.92	6.82	12.34	1.95	0
Orthoptera	34	51	21	16	10	17	11	9	1	6	0	4
	18.89	28.33	11.67	8.89	5.56	9.44	6.11	5.00	0.56	3.33	0	2.22
Trichoptera	7	21	13	11	22	46	19	5	14	10	12	1
	3.87	11.60	7.18	6.11	12.15	25.41	10.50	2.76	7.73	5.52	6.63	0.55
Neuroptera	2	14	32	19	14	12	14	7	8	1	1	0
	1.61	11.29	25.81	15.32	11.29	9.68	11.29	5.65	645	0.81	0.81	0
Dictyoptera	0	35	8	4	6	6	1	4	5	0	2	0
	0	49.30	11.27	5.63	8.45	8.45	1.41	5.63	7.04	0	2.82	0
Arachnida	1	7	9	8	12	8	5	8	10	11	1	0
	1.25	8.75	11.25	10.00	15.00	10.00	6.25	10.00	12.50	13.75	1.25	0
Dermaptera	0	0	0	0	0	0	1	0	0	1	0	0
	0	0	0	0	0	0	50.00	0	0	50.00	0	0
Total Insects	526	567	1098	1171	855	1869	1053	570	889	499	260	117
	5.55	5.98	11.59	12.36	9.02	19.73	11.11	6.02	9.38	5.27	2.74	1.23

Table Vb An hourly analysis of the total insects and various insect orders caught in light trap during the second year of the study period

1–12 represents 1800–0600 hrs. hourly. The top figure for each insect order reresents the actual number while the fraction immediately below it represents the percent caught for that hour.

TABLE VI

Months	1st Quarter 1800–2100 hrs	2nd Quarter 2100–2400 hrs	3rd Quarter 2400–0300 hrs	4th Quarter 0300–0600 hrs.	1st Half 1800–2400 hrs	2nd Half 2400–0600 hrs
February	51.68	22.14	18.46	17.20	73.82	26.18
March	21.68	31.47	28.67	18.18	53.15	46.85
April	35.45	36.73	21.61	6.21	72.18	27.82
May	28.42	29.55	32.52	9.51	57.97	42.03
June	24.14	33..33	25.37	17.16	57.47	42.53
July	28.94	36.87	27.13	7.06	65.81	34.19
August	31.85	21.99	35.44	10.72	53.84	46.16
September	24.56	22.95	35.15	17.34	47.51	52.49
October	35.43	22.04	30.55	11.98	57.47	42.53
November	17.77	50.52	20.56	11.15	68.29	31.71
December	42.42	27.27	9.09	21.22	69.69	30.31
January	40.00	26.67	33.33	0	66.67	33.33
February	44.89	29.92	18.10	7.09	74.81	25.19
March	49.99	28.20	12.18	9.63	78.19	21.81
April	29.31	36.44	27.94	6.31	65.75	34.25
May	27.51	26.56	31.55	11.38	57.07	42.96
June	20.36	42.94	30.51	6.19	63.03	36.70
July	21.69	42.50	29.57	6.24	64.19	35.81
August	25.93	28.35	33.78	11.94	54.28	45.72
September	25.29	29.78	32.28	12.65	55.07	44.93
October	20.79	35.91	23.46	19.84	56.70	43.30
November	38.08	32.39	18.85	10.68	70.47	29.53
December	62.92	11.15	18.51	7.42	74.07	25.93
January	60.00	20.00	13.34	6.66	80.00	20.00

Table VI Percent of total insects caught in light trap, during the different quarters and halves of the night, seasonally for the entire period of study.

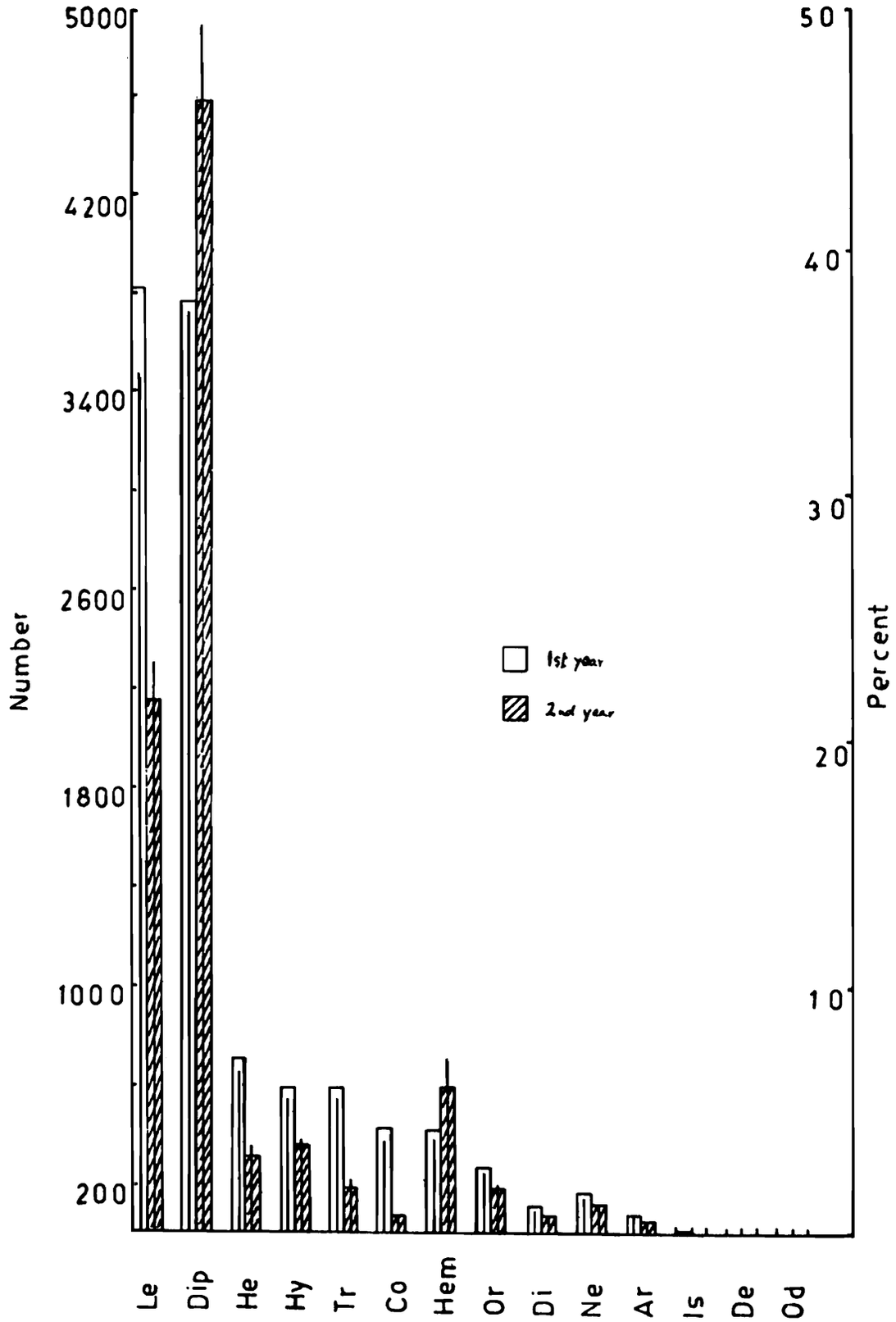


Figure 4 showing the qualitative and quantitative composition of the various insects caught during the entire study period.

Le = Lepidoptera; Or = Orthoptera; Dip = Diptera; Dic = Dictyoptera;
Het = Heteroptera; Ne = Neuroptera; Hy = Hymenoptera; Ar = Arachnida;
Tr = Trichoptera; Is = Isopoda; Co = Coleoptera; De = Dermaptera;
Hem = Hemiptera; Od = Odoflata

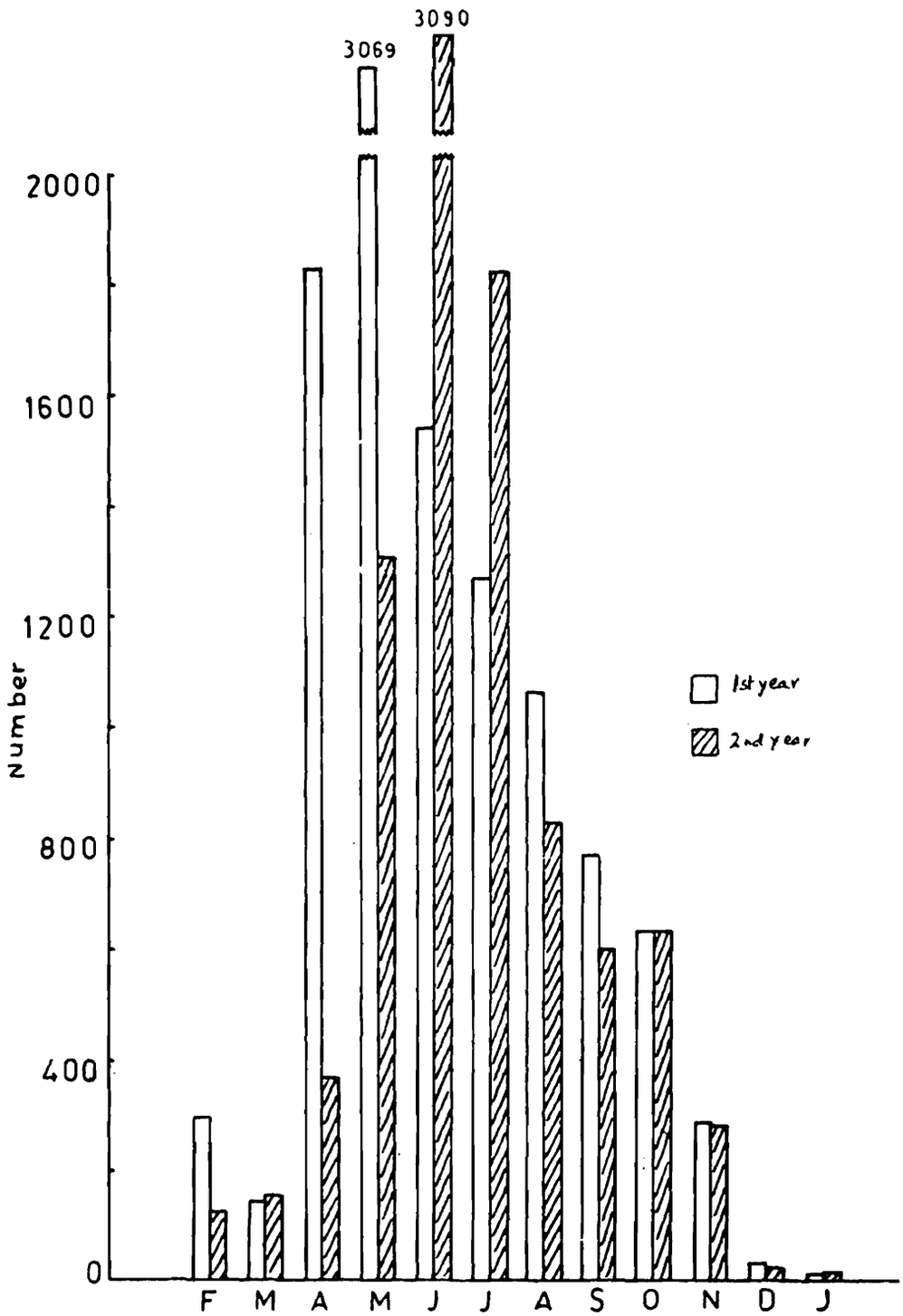


Figure 5 showing the seasonal fluctuation of the total insects caught in light-trap during the entire study period.

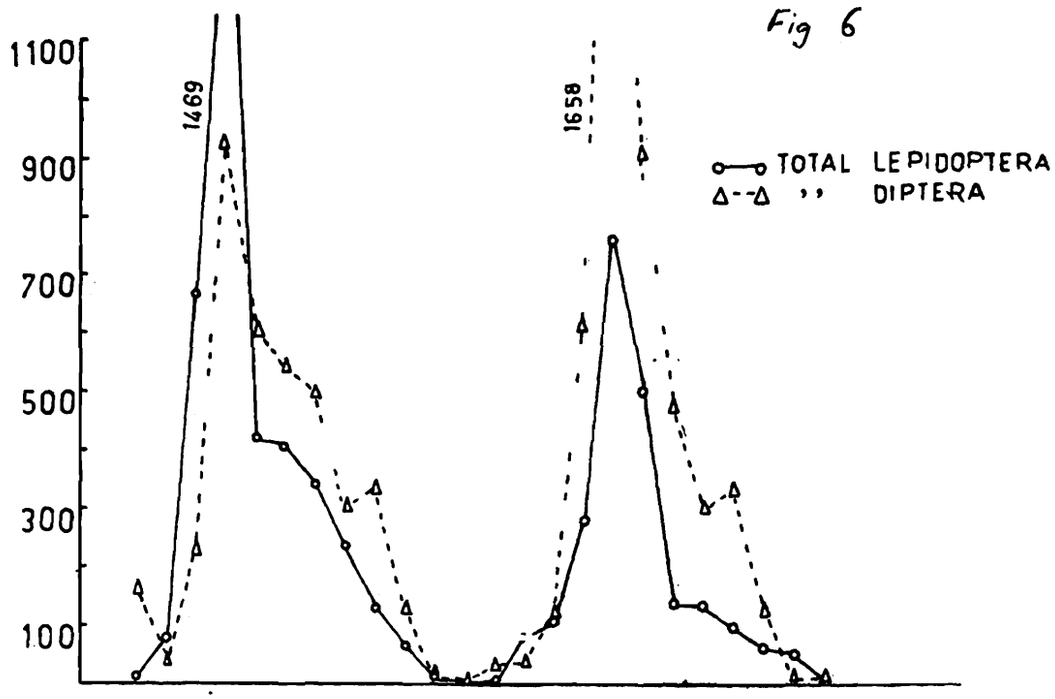


Figure 6 showing the seasonal fluctuation of total Lepidoptera and total Diptera caught in light trap during the entire study period.

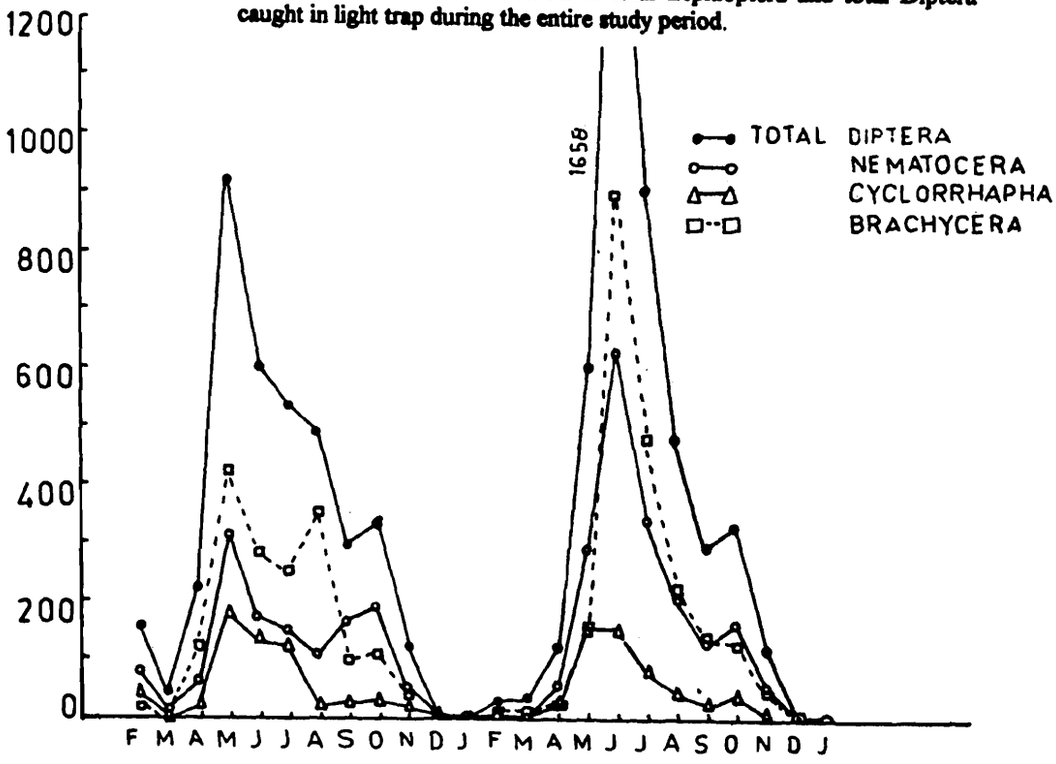


Figure 7 showing the seasonal fluctuation of Brachycera, Nematocera and Cyclorrhapha caught in light-trap during the entire study period.

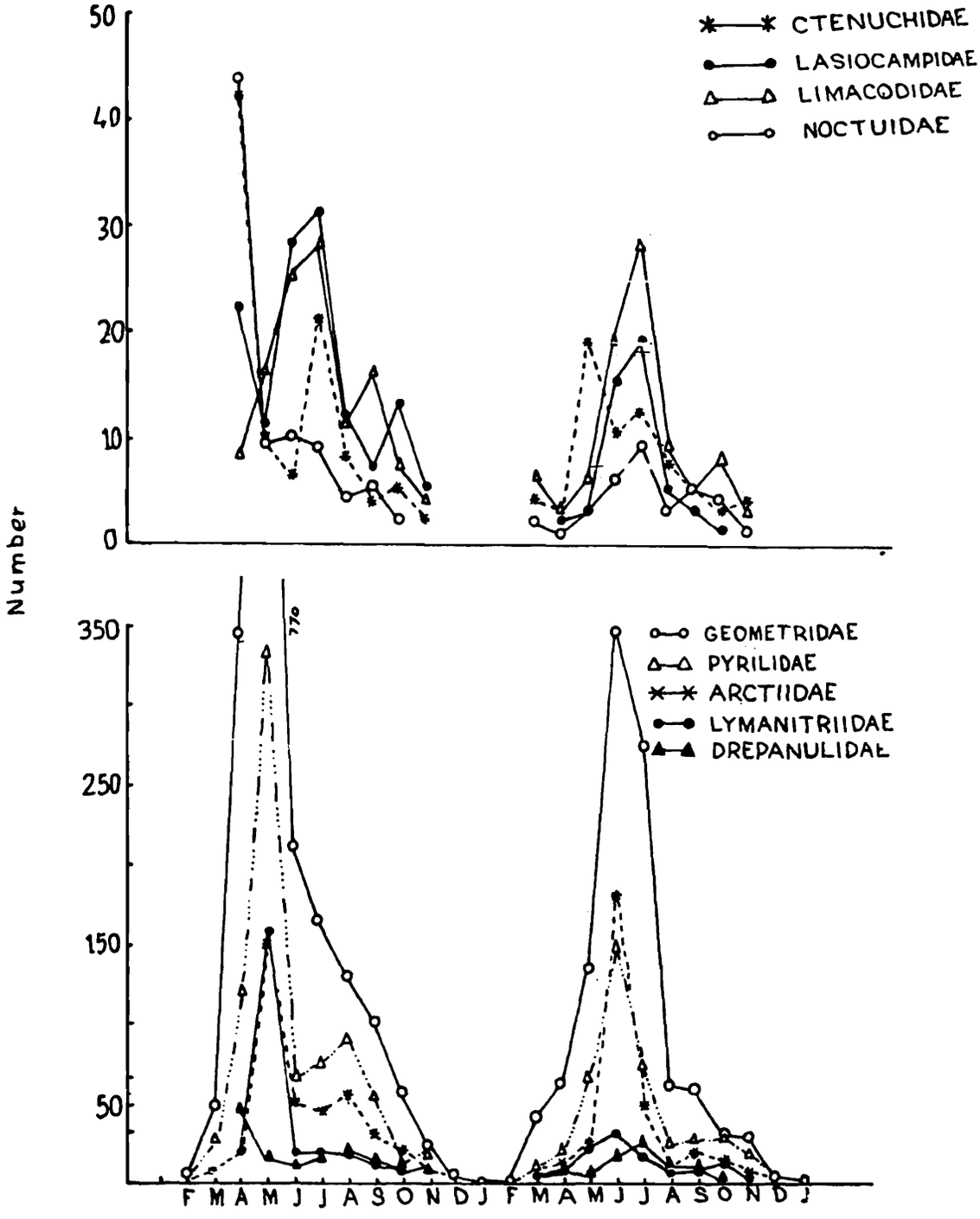


Figure 8 showing the seasonal fluctuation of Geometridae, Pyralidae, Arctiidae, Lymantriidae, Ctenuchidae, Limacodidae, Drepanulidae, Noctuidae and Lasiocampidae caught in light-trap during the entire study period.

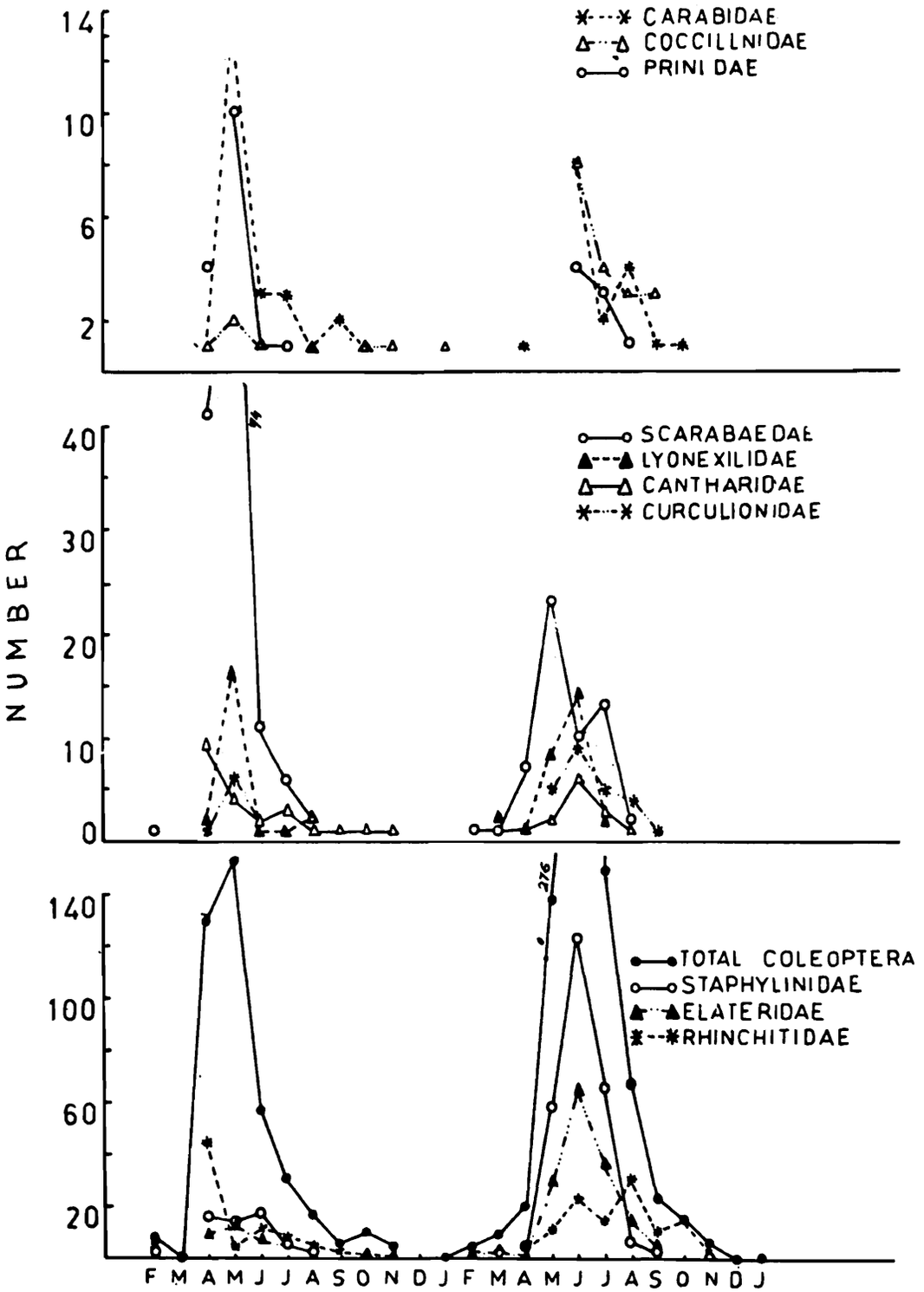


Figure 9 showing the seasonal fluctuation of total Coleoptera, Scarabaedae, Elateridae, Rhinchitidae, Staphylinidae, Cantharidae, Curculionidae, Prinidae, Carabidae, Coccilinidae, Lyonexilidae, Dermisticdae, Cleridae and Silvaniedae caught in light-trap during the entire study period.

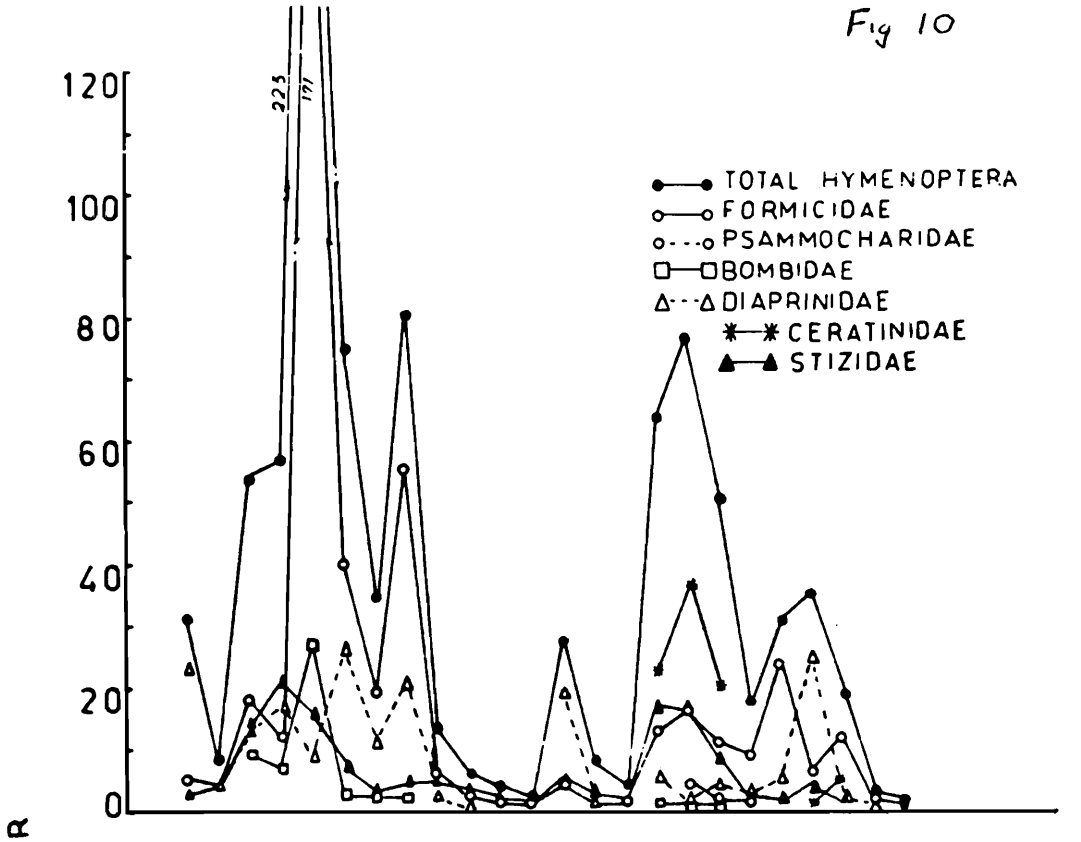


Figure 10 showing the seasonal fluctuation of total Hymenoptera, Formicidae, Diaprinidae, Ceratinidae, Bombidae, Stizidae and Psammocharidae caught in light-trap during the entire study period.

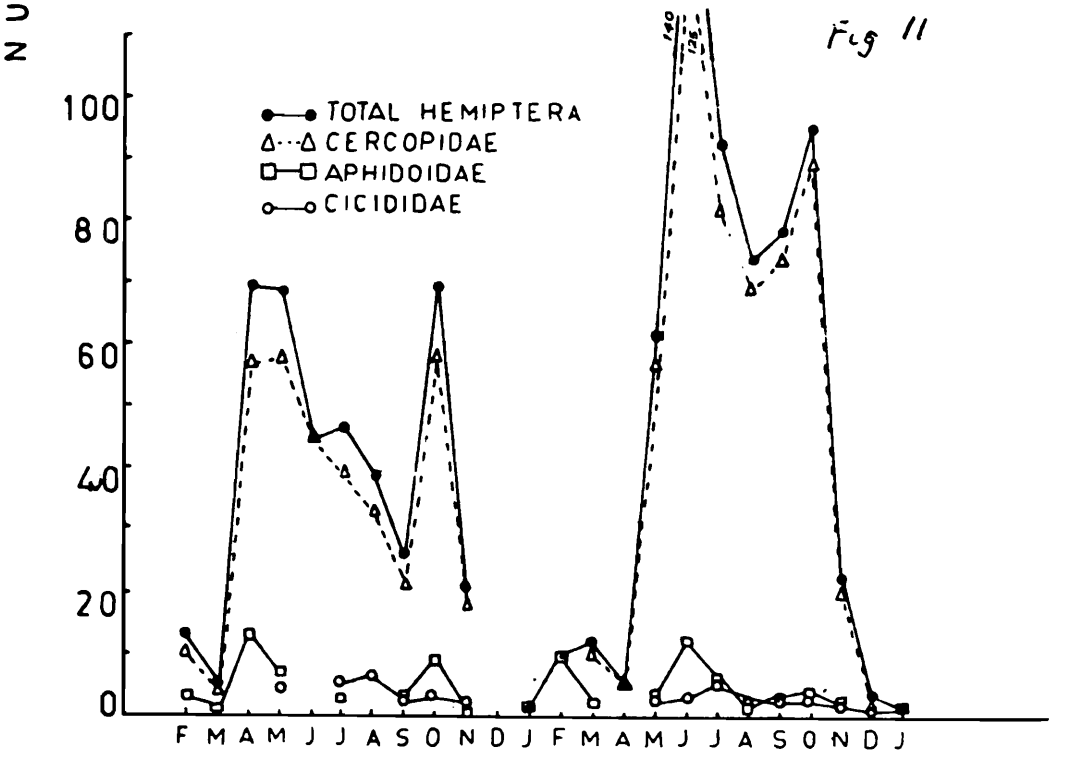


Figure 11 showing the seasonal fluctuation of total Hemiptera, Cercopidae, Cicididae and Aphidoidae caught in light-trap during the entire study period.

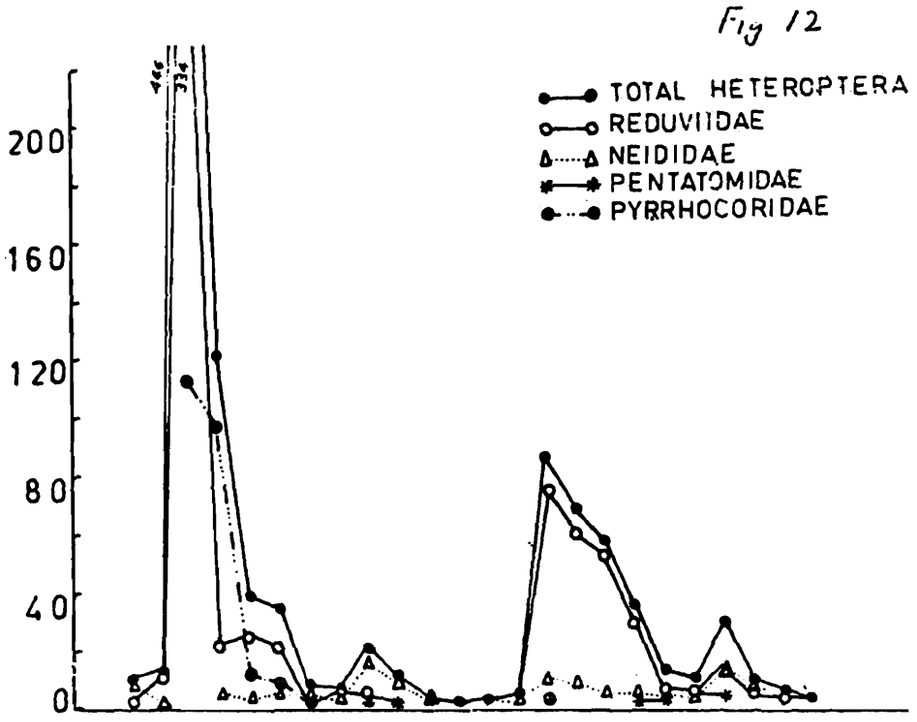


Figure 12 showing the seasonal fluctuation of total Heteroptera, Reduviidae, Pyrrhocoridae, Neididae andPentatomidae caught in light-trap during the entire study period.

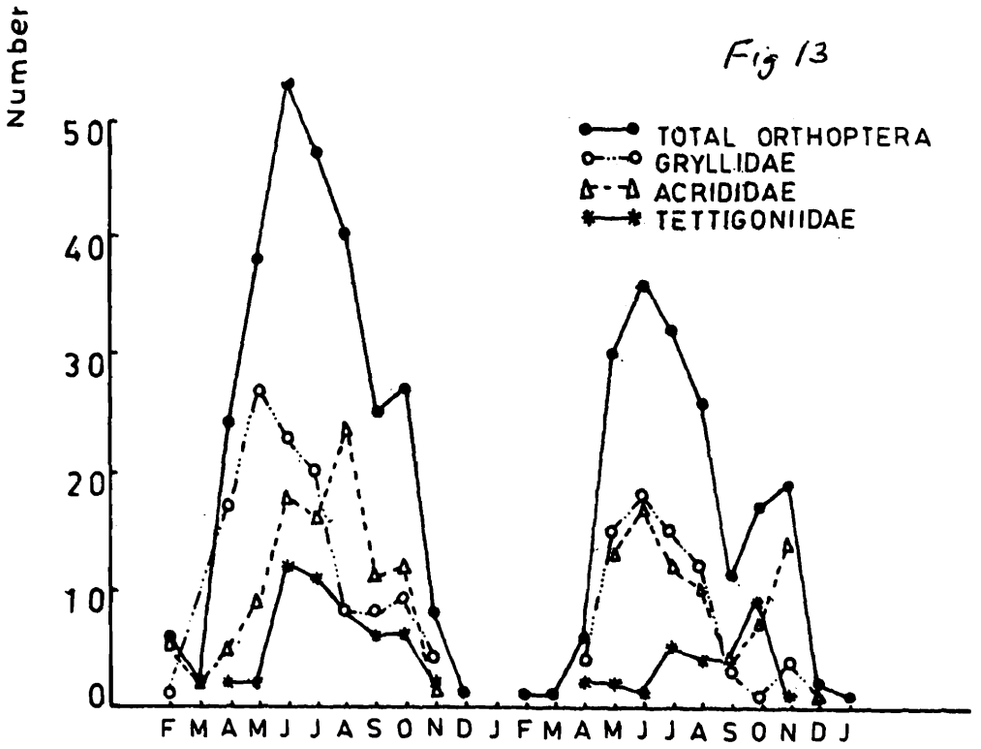


Figure 13 showing the seasonal fluctuation of total Orthoptera, Gryllidae, Acrididae and Tettigoniidae caught in light-trap during the entire stuudy period.

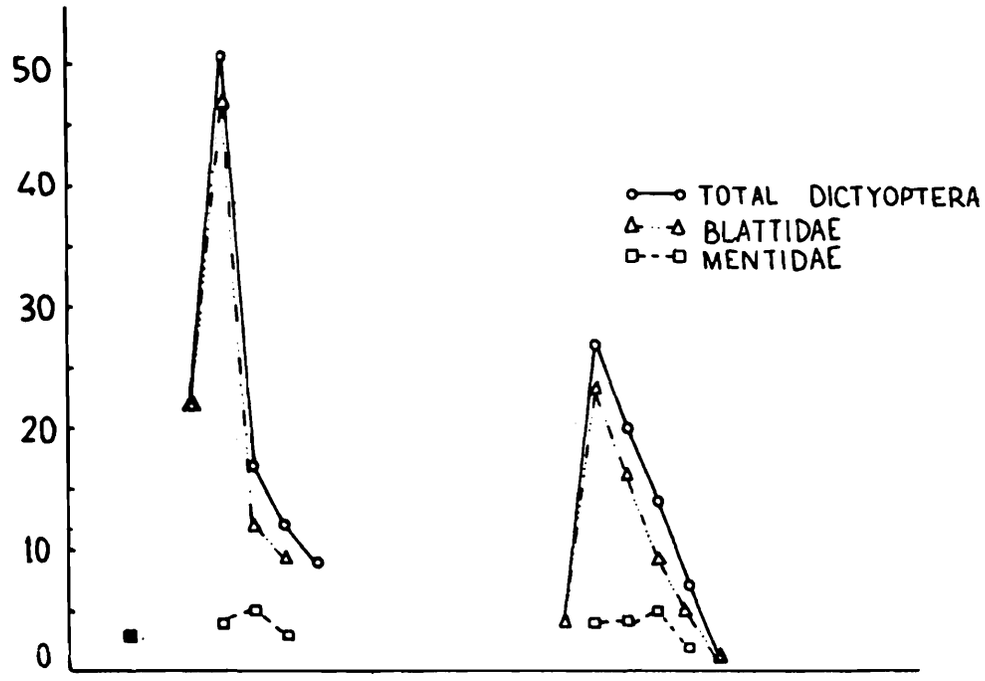


Figure 14 showing the seasonal fluctuation of total Dictyoptera, Blattidae and Mantidae caught in light-trap during the entire study period.

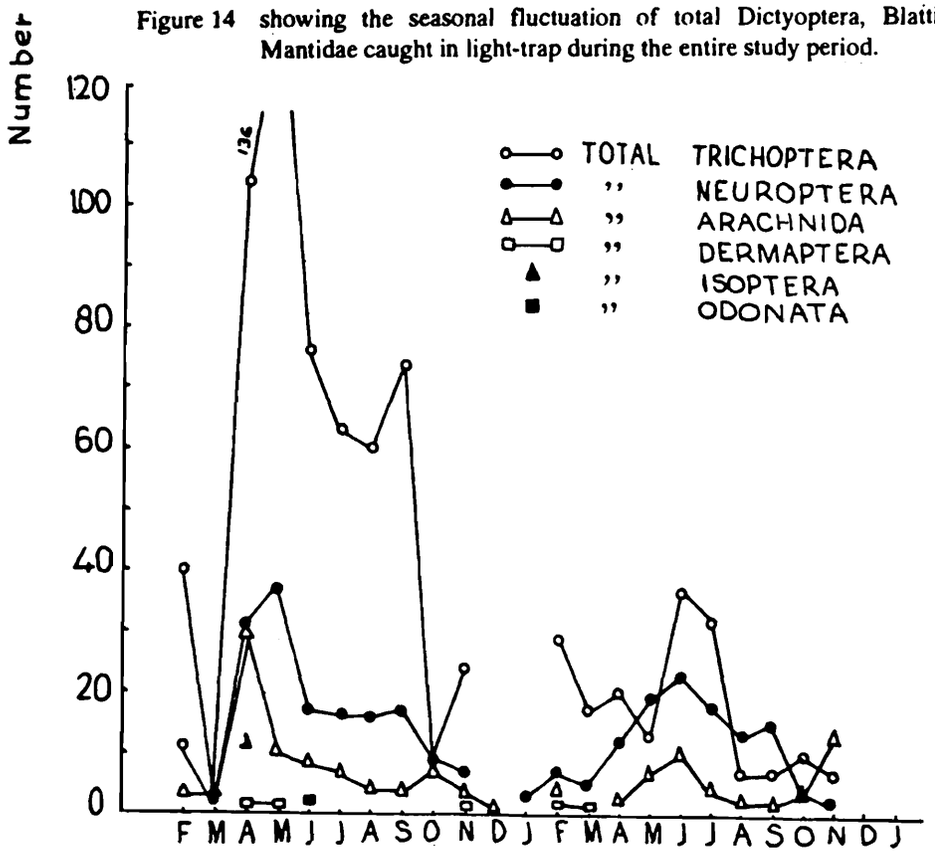


Figure 15 showing the seasonal fluctuation of Trichoptera, Neuroptera, Arachnida, Dermaptera, Isoptera and Odonata caught in light-trap during the entire study period.

The relationship between the monthly abundance of different orders of insects for both the years is presented in Table-III. A highly positive significant relationship ($P < 0.01$) for the orders Diptera, Hymenoptera, Heteroptera, Orthoptera, Dictyoptera and Neuroptera existed. The relationship was positively significant at $P < 0.05$ level for the total catch. No relationship was seen for Lepidoptera Hemiptera, Trichoptera and Arachnida.

An analysis of the relationship between the environmental factors (Fig. 3), such as temperature, rainfall, humidity and wind velocity and the total number of insects caught is presented in Table IVa, b. The maximum temperature was positively related ($P<0.05$) with the total insect catch for the first year whereas no significance existed during the second. However, the minimum temperature showed a positive correlation ($P<0.05$) for both the years. Though rainfall and the total insect catch had a positive significant relationship for both the years, the correlation was greater during the second year ($P<0.01$) than in the first year ($P<0.05$). Relative humidity also had a positive relationship with the total insect catch during the second year ($P<0.05$), whereas no relationship was seen during the first. The insect catch had no significant relationship with wind velocity during both the years of study.

An hourly analysis of the catch is presented in Table-Va, b which revealed that during the first year it recorded maximum during 2000-2100 hrs., representing 15.07 percent of the total nights insect catch, while the minimum was during the early morning hours (0500-0600 hrs.) representing 0.22 percent. During the second year, the maximum (14.73%) occurred during 2300-2400 hrs. and the minimum was again during 0500-0600 hrs. with 1.23%.

A further analysis was made by dividing the night into halves and quarters to see the optimum activity period of the insects (Table-VI). This revealed that the first two quarters of the night viz. 1800-2100 hrs. and 2100-2400 hrs., recorded a maximum catch of 33.71% and 30.24% respectively, revealing that the first half of the night had the maximum number of insects caught.

However, for each month the maximum during different quarters of the night varied. During February, October and December of the first year, till March, and from November, to January of the following year, the maximum insect catch was confined to 1800- 2100 hrs. whereas in April, June, July and November and April, June, July and October of the first year of the study, the maximum catch was recorded during 2100-2400 hrs. and in May, August, September of the first year, the maximum insect catch was confined to 2400-0300 hrs. The minimum catch was encountered during 0300-0600 hrs. for all the months except December of the first year.

Diptera

Diptera was one of the most abundant group of insects caught in the present light trap, representing a total of 8382 individuals. During the first year this order was next only to Lepidoptera constituting 34.39 percent of the total insect catch (Fig. 4). However, during the next year Diptera exceeded Lepidoptera and constituted 49.57 percent of the total insect catch (Fig. 4). The seasonal abundance of total Diptera is presented in Fig. 6 and different suborders in Fig. 7. The former figure revealed that during the first year, Diptera trapped were maximum comprising 926 individuals in May, and gradually decreased with a small peak of increase in October and reached its low ebb in January, representing only four individuals. From May of the next year onwards, the abundance

gradually increased to reach its peak of abundance in June, representing 1958 individuals. Once again it decreased however, with a slight increase in October, and reached its lowest ebb in January, representing only 5 individuals (Fig. 6).

An analysis of the relationship between the monthly relative abundance of Diptera and various environmental factors is presented in Table-IV which revealed that the maximum temperature had a positive significant correlation ($P<0.05$) with the Dipteran catch in the first year of the study, whereas no significant relationship existed during the second. The relationship between the minimum temperature and Diptera caught was positively significant at $P<0.01$ and $P<0.05$ levels during the first and second years respectively. The rainfall had a positive correlation, significant at $P<0.01$ level during both the years. The wind velocity had no relation with seasonal Diptera abundance, whereas the relative humidity had a positive correlation with the Diptera abundance, significant at $P<0.05$ level also during the first year and no significant relationship during the second.

In the present investigation, Diptera caught in the light trap were identified only upto the sub-order level due to limitations of species identification expertise. The Diptera was represented by all the three sub-orders viz. Brachycera, Cyclorrhapha and Nematocera.

Among the three sub-orders Brachycera was the most dominant group representing 3903 individuals, 46.56 percent of the total catch, followed by Nematocera representing 3261 individuals, 38.91 percent of the total catch. Cyclorrhapha was caught minimum which represented 1218 individuals, 14.53 percent of the total catch. The relative monthly abundance of Brachycera, Cyclorrhapha and Nematocera are presented in Fig. 7 which revealed that during the first year Brachycera had its peak of abundance in May, representing 424 individuals (10.86 percent). Then it started decreasing with a small peak of abundance in August representing 355 individuals (9.1 percent) making its complete disappearance in December. From January of the next year onwards, it reappeared and gradually increased till it reached a peak in June, representing 895 individuals (22.93 percent) and then it gradually decreased reaching its lowest in January at the end of the entire study period representing only 2 individuals (0.05 percent).

Nematocera had its peak abundance in May, representing 317 individuals (9.72 percent). From June it started decreasing with a slight increase in September reaching its second peak of abundance in October representing 190 individuals (5.85 percent). Then it decreased reaching its minimum in January representing only 3 individuals (0.09 percent). From February of the next year onwards it started increasing gradually and reached its maximum abundance in June representing 626 individuals (19.21 percent). Then it started decreasing gradually with a small peak of increase in October representing 159 individuals (4.88 percent) and reached its minimal in January at the end of the study period representing only 2 individuals (0.06 percent).

Cyclorrhapha caught was maximum in May representing 185 individuals (15.19 percent). It then started decreasing with a slight increase in October and disappeared completely in January. From February onwards it started increasing gradually reaching its peak in May and June with 155 individuals (12.78 percent). Then it started decreasing with a slight increase in October and disappeared completely in December with a negligible number (0.08 per cent) in January at the

conclusion of the study.

An analysis of hourly abundance of Diptera revealed that in the first year they were caught maximum during 2200-2300 hrs. representing 13.82 percentage of total night catch followed by the period 0200-0300 hrs. representing 11.89 percent. The least catch was recorded during the hours 0500-0600, which represented only 0.48 percentage. However, during the second year it was seen that they reached the peak of their abundance during 2300-2400. hrs. representing 27.23 percent followed by 2400-0100 hrs. representing 12.84 percent (Table-IV a, b). The minimum hourly catch was recorded during 0500-0600 hrs. which represented only 2.06 percentage of total night's catch.

Lepidoptera

The monthly fluctuation of the order Lepidoptera (Fig. 6) and its families are presented in Fig. 8. The months May and June of the two years recorded the most abundant, represented by 1469 and 757 individuals respectively. From June, the total Lepidoptera caught decreased gradually reaching a minimum in January, when only 3 individuals were caught. It started increasing gradually thereafter and reached the peak again in June of the next year and declined till the minimum was observed in January.

An analysis of the relationship between the total moth catch and the different environmental factors is presented in Table IV a, b. The maximum temperature during both the years and minimum temperature in the first year had no significant relationship with the Lepidoptera catch. However, the minimum temperature showed a significant relationship ($P < 0.05$) during second year of study. The relationship between the total rainfall and Lepidoptera caught was positively significant ($P < 0.05$) during the second year. But there was no significant relationship during the first year. There was no relationship either between the wind velocity or relative humidity and total Lepidoptera.

The order Lepidoptera was represented by nine families - Geometridae, Pyralidae, Arctiidae, Lymantriidae, Ctenuchidae, Limacodidae, Drepanulidae, Noctuidae and Lasiocampidae.

Family Geometridae represented peak numbers in May, (770 individuals) and June, (337 individuals), during the study period. From June, onwards it started decreasing gradually and disappeared during January-February. It reappeared in March, and reached the peak in June, thereafter declining till it reached the lowest in January, of the following year. In this family *Acidalia* Sp. was the most dominant followed by *Craspedia remotata* Guenea.

The family Geometridae followed the family Pyralidae in abundance (Fig. 8). The family Pyralidae represented two peaks, the larger in May, and the smaller in August, numbering 330 and 89 individuals respectively. It was minimum in February, with only two individuals. During the second year this family was maximum in June, representing 146 individuals. Thereafter the number of Pyralidae moths fluctuated. *Sylepta lunalis* Guenee was the most dominant species followed by *Thliptoceras cascale* Swinhoe among this family.

The family Arctiidae was highest in May and August of the first year and June of the next year representing 150, 54 and 176 individuals respectively (Fig. 8). The minimum number was recorded

during February and December, January and February, and January of the following year represented by only one individual. In this family *Asura undalosa* Walker was found to be the most dominant species followed by *Miltochrista strigivenata* (Walker) and *Eilema nigripes* Hampson.

The family Lamantriidae was the next dominant group. This family showed peak periods of abundance in May of the first year and in June during the second year representing 157 and 30 individuals respectively. The minimum number was recorded during February and March, November to February of the first year and December and January in the second. *Euproctis divisa* Walker was the most dominant species.

The family Noctuidae represented peak periods of abundance in April and July, numbering 47 and 24 individuals of the first and second year respectively (Fig. 8). The minimum number was recorded in October and February. This family was completely absent during February and March and December and January, November and December and January of the second year. *Bleptina* sp. nr. *hadenalis* Moore was the most dominant species.

The family Limacodidae represented its peaks of abundance in July in both the years numbering each time 28 individuals. The minimum number was recorded in November, April and November, representing 4 and 3 individuals respectively. The family was completely absent in February and March, December to February and December and January of the next year. *Lenodora* Sp. was the most dominant group followed by *Thosea cana* Walker.

The family Lasiocampidae was maximum during July representing 31 and 19 individuals in the first and second years respectively. The minimum number was recorded during November and October and was completely absent during February and March in the first year, December to March, November to January of the next year.

The family Drepanulidae was represented by *Drepana pallida* Moore. It was recorded maximum in April with a larger peak (44 individuals) and June and July of the next year with smaller peaks (10 and 9 individuals respectively). It was completely absent during February and March, November, February of the first year and December to January of the next year.

The family Ctenuchidae was listed by *Eressa affinis* Moore which was recorded maximum in April and May with large peaks, and in July with small peaks. This family was recorded minimum during November, April and October and completely absent during February and March, December of both the years, February and December and January of the second year.

An analysis of hourly catches of Lepidoptera presented in Table- Va, b, revealed that the catch was highest during 2000-2100 hrs. representing 16.28 percent and 13.41 percent of the total nights catch of the first and second year of study respectively. The lowest catch was recorded during 0400-0500 hrs. representing only 1.86 percent and 2.76 percent in the first and second year of the study respectively. The moth catch was completely nil during 0500-0600 hrs.

Coleoptera

Coleoptera was represented by 426 (3.8%) individuals during the first year and 681 (7.35%)

during the second year (Fig. 4). Monthly relative abundance of Coleoptera with it families is presented in Fig. 9, a perusal of which revealed that the peak abundance occurred during May, representing 153 individuals. It was absent during March and December. It reappeared again in January and gradually increased reaching its peak in the month of June of the next year representing 275 individuals. It then gradually decreased representing the minimum catch in the month of December, numbering only 3 individuals and completely disappeared in January at the end of the study period.

An analysis of relationship between the total abundance of Coleoptera and various environmental factors (Table-IVa, b) revealed that the maximum and minimum temperatures, relative humidity and wind velocity had no significant correlation during both the years of study. The total monthly rainfall also had no significant relationship with the Coleoptera catch during the first year of study. However, the relationship was positively significant ($P<0.01$) for the following year.

Coleoptera was represented by the families : Scarabaeidae, Elateridae, Rhinchitidae, Staphylinidae, Cantharidae, Curculionidae, Chrysomelidae, Prinidae, Carabidae, Coccilinidae, Lyonexilidae, Dermisticdae, Cassodidae, Cleridae, Silvaniedae.

Family Staphylinidae was the most dominant group representing 319 individuals (28.28%) followed by Rhinchitidae representing 203 individuals (18.00%), Elateridae representing 197 individuals (17.46%) and Scarabaeidae representing 193 individuals (17.11%). The remaining families of Coleoptera were very poorly represented in the catch (Fig. 9).

Staphylinidae was at its peak of abundance in June, representing 17 and 122 individuals for the first and second year respectively. From July, it started decreasing with complete disappearance in December and January and again it increased in number from March of the next year reaching its peak in June. Then it started decreasing and disappeared completely in December and January.

Rhinchitidae was maximum in April, representing 45 individuals. Then it started decreasing with a slight increase in June and fell thereafter. It increased again from February, reaching its peak in June, representing 23 individuals in the next year. It was completely absent in March of the first year and in December and January, for both the years.

Elateridae represented its peak of abundance in May, representing 13 individuals. Then it gradually decreased till it disappeared in December and January. It made its appearance in February and with a gradual increase reached its peak in June of the next year representing 65 individuals. From July, it decreased gradually in number and disappeared thereafter.

Scarabaeidae was the only family which was more in the first year than that of the second. It was at its peak of abundance in May of both years representing 74 and 23 individuals. From June of the first year and July of the second onwards it decreased gradually. It was completely absent from September to January, during both the annual cycles. The remaining families represented maximum in May and June, but were not represented in numbers enough regularly to show any seasonally significant change.

An analysis of hourly abundance of Coleoptera (Table-Va, b) revealed that they were most abundant during 2000-2100 hrs. representing 27.23 percent in the first year and 16.74 percent of the

total night catch in the second year, followed by 1900-2000 hrs. in the first year representing 10.98 pecent and 2100-2200 hrs. in the second year representing 14.61 pecent. The least catch was recorded during 0500-0600 hrs. which was nil in the first year and 0.28 percent in the second year.

Hymenoptera

Hymenoptera represented 592 (5.4 percent) and 343 (3.7 percent) during the first and second years respectively (Fig. 4). The monthly abundance of Hymenoptera is presented in Fig. 10, a perusal of which revealed the gradual increase from March, reaching a peak in June, representing 223 individuals (38.01 percent). From July, it started decreasing with a small peak of increase in September, representing 83 individuals (14.02 percent) reaching the minimum in January, representing 2 individuals (0.34 percent). The next year this group reached the peak of abundance again in June representing 78 individuals (22.74 percent) with two small peaks of increase in February and October, representing 28 (8.16 percent) and 36 (10.5 percent) individuals respectively.

An analysis of relationship between the monthly total abundance of Hymenoptera and the different environmental factors (Table- IVa, b) revealed that the minimum and maximum temperature, relative humidity and wind velocity showed no relationship with the monthly Hymenopteran abundance during both the years of study. However, the Hymenopteran fauna showed a strong positive correlation ($P < 0.01$) with total rainfall during both the years.

Hymenoptera comprised of the families Formicidae, Diaprinidae, Vipioniidae, Ceratinidae, Bombidae, Stizidae, Psammocharidae and their seasonal abundance are presented in Fig. 10. Catches of Formicidae represented 62.14 percent of the total number of Hymenoptera caught in the trap followed by Diaprinidae representing 20.32%, and Ceratinidae representing 9.20%.

Formicidae showed its peak period of abundance in June, representing 171 individuals (18.28%) of the total Hymenoptera. Then it started decreasing with a small peak of increase in September and reached minimum in December and January, representing only 1 individual. In the next year it increased with a slight peak in September, representing 24 individuals. From October, it gradually decreased reaching a low ebb in January, when it was only 1 individual.

Diaprinidae was caught maximum during July of the first year and October of the second year representing 26 individuals (2.78%) and 25 individuals (2.67%) respectively. This family was completely absent during December and January for both the years.

Ceratinidae was maximum in June of the second year representing 37 individuals (3.9%). The remaining families were not represented in numbers large enough to show any seasonally significant changes.

An hourly analysis of abundance of Hymenoptera caught revealed that in the first year of the study period they were maximum during 2000-2100 hrs. representing 11.30 percent of the total night's catch, followed by 2200-2300 hrs. representing 8.60 percent. In June, at 0300-0400 hrs. an army of Formicidae, 150 in numbers were caught which increased the total catch of the hour to 31.87% of total nights catch (Table-Va, b) an unusual phenomenan observed during the entire period of study. The minimum catch was recorded during 0500-0600 hrs. representing 0.51 percent. In the

second year, the maximum catch was recorded during 2000-2100 hrs. representing 17.70 percentage of total night catch, followed by 2100-2200 hrs. representing 13.99 percent. The minimum catch was recorded during the hours 0500- 0600 hrs. represented only by 0.29 percent.

Hemiptera

Hemiptera represented 420 (3.8%) individuals in the first year and 595 (6.42%) during the second year (Fig. 4). The monthly relative abundance of total Hemiptera caught is presented in Fig. 11, a perusal of which revealed that during the first they were in peak abundance during April-May, representing 70 (16.67%) individuals and during October with about 75 (17.86%) individuals. The least catch of Hemiptera was recorded in January. During the second year from February, it started increasing reaching the maximum in June, representing 140 (23.58%) individuals. Then it decreased in number with a small peak of increase in October, representing a catch of 93 (15.63%) individuals. The least catch was recorded in January, representing only 1 individual (0.17%).

An analysis of relationship between monthly relative abundance of Hemiptera and various environmental factors (Table-IVa, b) revealed that maximum temperature had a positive correlation ($P<0.05$) with the seasonal abundance of Hemiptera. The minimum temperature also had a positive relationship, being significant at $P<0.05$ level in the first year and at $P<0.01$ level during the second. The total rainfall and relative humidity also showed a positive significant correlation ($P<0.01$) in the second year whereas, no relationship was seen during the first year. The wind velocity showed no relationship with their seasonal abundance in both the years.

The order Hemiptera was represented by Cercopidae, Cicididae and Aphidoidae. Cercopidae was the most dominant group representing 877 individuals (87.39%) of the total hemiptera caught, followed by Aphidoidae representing 87 individuals (8.67%) and Cicididae represented only 40 individuals, 3.98%.

The family Cercopidae had its peak of abundance in April, May and October, representing 58 individuals (5.78%) each time. In the second year, the peak periods of abundance were in June and October, representing 125 individuals (12.45%) and 90 individuals (8.96%) respectively. This group was entirely absent during December to February and January of the second year. The relative peaks of Cercopidae abundance therefore reflected the relative abundance of the entire order. The other two families trapped were too few to show any significant seasonal variations.

An hourly analysis of Hemiptera presented in Table-Va, b, revealed that in the first year the maximum catch was recorded during 0300-0400 hrs. representing 14.29 percent of the total night catch followed by 1900-2000 hrs. representing 11.21 percent. The catch was recorded during 0500-0600 hrs. which represented only 0.25 percent. During the second year the maximum catch was recorded around 2000-2100 hrs., which represented 21.43 percent of the total night catch followed by 2100-2200 hrs., representing 14.92 percent. The least catch was recorded at 0500- 0600 hrs. which represented 1.59 percent of the total night catch.

Heteroptera

Heteroptera represented 698 (6.36%) individuals during the first year and 307 (3.31%) during the

second (Fig. 4). The monthly total relative abundance of Heteroptera is represented in Fig. 12, a perusal of which revealed that during the first year the catch was maximum in April, representing 446 (63.61%) individuals. It then decreased till it again rose with a negligible peak of increase in October and reached a low ebb in January. From February of the following year it gradually started increasing reaching its peak of abundance again in April, representing 84 individuals or 27.36% of the total catch of that year. Then it started gradually decreasing and before it reached the minimum in January, representing 2 individuals (0.65%) of the total catch of the year, it again had a small peak in October, representing 28 individuals (9.12%).

An analysis of relationship between total monthly relative abundance of Heteroptera and various environmental factors (Table-IVa, b) revealed that the variation in maximum and minimum temperature, relative humidity and wind velocity showed no significant correlation with the monthly abundance of Heteroptera during both the years. The total rainfall had no significant relationship with the Heteroptera catch during the first year, but was positively significant ($P<0.01$) during the second year.

The group Heteroptera was represented by the families Reduviidae, Pyrrhocoridae, Neididae, Pentatomidae and Hydrometridae. Reduviidae was the most dominant group representing 669 individuals, 65.72% of the total Heteroptera catch, followed by Pyrrhocoridae representing 235 individuals (23.08%), Neididae represented 105 individuals (10.31%), by Pentotomidae and Hydrometridae representing 9 (0.88%) and 1 (0.18%) individuals respectively.

The monthly abundance of Reduviidae is presented in Fig. 12, a perusal of which revealed that Reduviidae was at its peak abundance in April, of both the years representing 334 (32.81%) and 74 (7.27%) individuals. From April, the population gradually decreased with negligible peak of increase in June, representing 24 individuals (2.36%) and disappeared completely in December, From January of the next year, it gradually started increasing with the peak of abundance in April. Then it gradually decreased reaching the minimum in January, representing only 2 (0.2%) individuals.

Pyrrhocoridae was caught maximum in April, then it gradually decreased and disappeared from November. In the next year, the family was not represented in numbers large enough to show any seasonal significant changes.

The relative peaks of Reduviidae and Pyrrhocoridae abundance therefore reflect the relative abundance of the order Heteroptera. The remaining three families trapped were too few in numbers to show any seasonal significant changes.

An hourly analysis of Heteroptera caught revealed that in the first year, this group was trapped maximum at 2000-2100 hrs. representing 28.26 percent of total night catch followed by 2100- 2200 hrs. representing 16.09 percent. The minimum number was caught during 0400-0500 hrs. representing 0.72 percent, and nothing was caught during 0500-0600 hrs. During the second year, the maximum Heteroptera were caught at 2100-2200 hrs. representing 2.08 percent and minimum during 0400-0500 hrs. representing 1.95 percent. Again nothing was caught during 0500- 0600 hrs.

Orthoptera

Orthoptera represented 273 (2.5%) individuals in the first year and 181 individuals (1.95%) during the second (Fig. 4). The monthly total abundance of this group is represented in Fig. 13, a perusal of which revealed that in the first year this group reached the peak of their abundance in June, representing 53 individuals (19.41%) of the total yearly catch. Then it decreased with a negligible increase in October, representing 27 individuals (9.89%) and reached its minimum in December, representing only 1 individual (0.37%) with total disappearance in January. Then the number gradually increased and reached the maximum in June, the next year representing 36 individuals (19.89%). It then started decreasing with a slight increase in November, representing 19 individuals (10.5%) and reached its minimum in January, representing only 1 individual (0.55%).

An analysis of relationship between total monthly abundance of Orthoptera and different environmental factors (Table-IVa,b) revealed that minimum temperature had a very strong correlation ($P<0.01$) with seasonal abundance of Orthopteran fauna during both years. The maximum temperature showed a positively significant relationship during both the years, but the significance was at $P<0.01$ level in the first year and at $P<0.05$ level during the second. The total rainfall showed positive correlation significant at $P<0.01$ level for both the years. The wind velocity showed no correlation at all. However the relative humidity was significant at $P<0.05$ level in the first year and at $P<0.01$ level in the second year.

The order Orthoptera was represented by families Gryllidae, Acrididae and Tettigoniidae. Family Gryllidae was the most dominant group representing 191 individuals (42.16%) of the total orthopteran catch, followed by Acrididae representing 185 individuals (40.84%) and Tettigoniidae represented 77 individuals (17.00%).

The family Gryllidae was caught maximum during May, representing 27 individuals (5.96%). Then it gradually started decreasing, finally making its disappearance in December to March of the next year. It reappeared in April and reached the maximum in June, representing 18 individuals, 3.97% of total Orthoptera catch. Then it started decreasing, reaching its minimum in December, represented by only 1 individual (o.22%), and finally disappeared in January.

An hourly analysis of total Orthoptera caught revealed that during the first year they were caught maximum at 2000-2100 hrs. representing 20.15 percent followed by 1900-2000 hrs. representing 16.12 percent. During the second year, the maximum catch was recorded during 1900-2000 hrs. representing 28.33 percent followed by 1800-1900 hrs. representing 18.89 percent. The least catch was recorded at 0400-0500 hrs. representing 3.3 pecent, with complete disappearance at 0500-0600 hrs. In the second year the least catch was recorded during 0200-0300 hrs. (0.56%) with a complete disappearance at 0400-0500 hrs.

Dictyoptera

Dictyoptera represented 114 individuals in the first year and 70 individuals in the second year which are 1.04% and 0.76% of the total yearly catch of insects (Fig. 4). The monthly fluctuation of total Dictyoptera is presented in Fig. 14, a perusal of which revealed that in the first year they were present only in February and from April to August. They were trapped maximum in May,

representing 51 individuals, 44.74% of the total Dictyoptera caught and minimum in February, representing only 3 individuals, 2.63% of the total yearly catch of Dictyoptera. In the next year, they were only trapped from April to September, showing the peak of their abundance in May, representing 27 individuals, 38.57%. They were recorded minimum in September, representing only 2 individuals, (2.86%).

An analysis of relationship between the monthly abundance of Dictyoptera and the various environmental factors (Table-IVa,b) revealed that the variation in maximum and minimum temperatures and relative humidity had no correlation with the abundance of Dictyoptera. The total rainfall showed a positive significant correlation ($P<0.01$) with the seasonal Dictyoptera abundance during the second year and no relationship in the first year. The wind velocity also showed a positive significant correlation ($P<0.05$) with Dictyoptera abundance only in the second year.

The order Dictyoptera was represented by two families Blattidae and Mantidae, the former representing 157 individuals, 83.96% of the total dictyopteran catch, the latter representing 30 individuals representing 16.04% of total Dictyoptera catch.

The monthly population fluctuation of Blattidae and Mantidae, is represented in Fig.14 which revealed that Blattidae appeared in April and reached its peak of abundance in May, representing 47 individuals, 26.13% of the total Dictyopteran catch and minimum was recorded in July and August, each month representing 9 individuals (4.81%). Then it reappeared in April of the next year and reached its peak of abundance in May, representing 12.3% of the total dictyoptera catch. The minimum catch recorded was in September, representing only one individual, (0.53%). The relative peaks of Blattidae abundance therefore reflected the relative abundance of the total order Dictyoptera.

Mantidae was recorded only in February and from May to July of the first year and from May to August of the second. They were represented in numbers too few to show any significant seasonal variations.

An hourly analysis of Dictyoptera caught revealed that they recorded maximum during 2000-2100 hrs. representing 20.69 percent of total night catch and minimum at 0300-0400 hrs. which represented only 0.86 percent during the first year. The maximum catch recorded in the second year was during 1900-2000 hrs. representing 49.3 percent followed by 2000-2100 hrs. representing 11.27 percent of the total night catch and minimum catch was recorded during 2400-0100 hrs. representing 1.41 percent while no catch was recorded during 1800-1900 hrs., 0300-0400 hrs. and 0500-0600 hrs

Trichoptera

Trichoptera represented 589 individuals in the first year and 179 individuals during the second which represented 5.39% and 1.93% of the total yearly insects caught respectively (Fig. 4). The monthly fluctuation of Trichoptera is presented in Fig. 15, a perusal of which revealed that they were caught maximum in May, representing 136 individuals, 23.09% of the total yearly catch of Trichoptera. Then it gradually decreased with a slight increase in number in September, representing 74 individuals, (12.56%) and reached a minimum in October, representing 9 individuals, (1.53%). The next year it appeared in February, and had its peak of abundance in June, representing 37 individuals, (20.67%). The minimum number was recorded in November, representing 7 individuals,

3.91% of total Trichoptera catch. This group was completely absent in December and January of both the years.

An analysis of relationship between the monthly abundance of Trichoptera and various environmental factors (Table IVa, b) revealed that the variation in maximum and minimum temperatures, total rainfall showed a positive correlation ($P<0.01$) with the monthly abundance of Trichoptera during the first year of study whereas no significant relationship during the second. The wind velocity and relative humidity had no correlation with their seasonal abundance.

An hourly analysis of abundance of Trichoptera (Table Va, b) revealed that in the first year they were most abundant at 2000- 2100 hrs. representing 16.06 percent of the total night's catch followed by 0200-0300 hrs. representing 13.41 percent and the least was recorded at 0500-0600 hrs. representing 0.33 percent only. During the second year they were most abundant at 2300-2400 hrs. representing 25.41 percent followed by 2200-2300 hrs. representing 12.15 percent. The least catch was recorded at 0500- 0600 hrs. representing only 0.55 percent.

Neuroptera

Neuroptera represented 166 individuals during the year and 118 individuals in the second which constituted 1.51% and 1.27% of the total yearly catch of insects respectively (Fig. 4). The monthly fluctuation of Neuroptera is presented in Fig. 15, a perusal of which revealed that they were caught maximum in May, representing 37 individuals, (22.29%) of the total yearly catch of Neuroptera. Then they started decreasing reaching a minimum in January, representing 3 individuals, (1.81%). From February, of the next year onwards it increased gradually and reached its peak of abundance in June, representing 23 individuals, (19.44%). It then started decreasing and reached the minimum in November, representing only 2 individuals (1.69%). In both the years there was a slight peak during September. They were completely absent during December, of the first year and January, of the second year. An analysis of relationship between the monthly abundance of Neuroptera and various environmental factors (Table IVa, b) revealed that the variations in maximum and minimum temperature showed a strong positive correlation ($P<0.01$) with the seasonal abundance of Neuroptera for both the years. The rainfall and relative humidity had a positive correlation with Neuroptera abundance only during the second year. The wind velocity had no relation with their abundance during both the years of study.

An hourly analysis of abundance of Neuroptera (Table Va, b) revealed that in both the years of study they were most abundant at 2000-2100 hrs. representing 20.71 percent and 25.81 percent respectively and the minimum was recorded during 0400-0500 hrs. which represented 2.96 percent and 0.81 percent respectively. They were completely absent during the 0500-0600 hrs.

Arachnida

The group Arachnida represented 80 individuals in the first year and 48 individuals during the second which constituted 0.78% and 0.52% of the total yearly catch of Arachnida respectively (Fig. 4). The monthly population fluctuation of Arachnida is presented in Fig. 15, a perusal which

revealed that they were at their peak of abundance in April, representing 29 individuals, 36.25% of the total yearly catch of Arachnida. They then gradually decreased with a small peak of increase in October, representing 7 individuals, (8.75%) and reached minimum in December, representing only 1 individual, (1.25%). Arachnida was completely absent in January. The next year they represented a small peak of abundance in June, representing 10 individuals, (20.83%). Then it decreased till September and increased thereafter reaching the maximum peak catch in November, representing 13 individuals, 27.08% of the total yearly Arachnid catch. The minimum was recorded in April, August and September, each month representing 2 individuals, 4.17%. They were completely absent during January, March, December, of the first year and January, of the second year of study.

An analysis of relationship between monthly abundance of Arachnida and various environmetal factors (Table IVa, b) revealed that the variation in all the environmental factors under study showed no significant correlation with the seasonal variation of Arachnida.

An hourly analysis of abundance of Arachnida (Table Va, b) revealed that in the first year they were maximum at 1900-2000 hrs., 2100-2200 hrs. and 0200-0300 hrs. representing in each hour 16.67 percent of the total night's catch. The minimum catch was recorded during 2200-2300 hrs. representing only 2.78 percent. They were completely absent during 2400-0100 hrs. and 0500-0600 hrs. In the next year they represented maximum number during 2200-2300 hrs. comprising 15.00 percent of the night's total catch, followed by 0300-0400 hrs. representing 13.75 percent. The minimum was recorded during 1800-1900 hrs. and 0400-0500 hrs. representing only 1.25 percent. They were completely absent during 0500-0600 hrs.

Dermaptera

Dermaptera represented only 3 individuals in both the years of study (0.03%) of the total catch of insects (Fig. 4). They were recorded in April, May and November, each month representing one individual (Fig. 15). In the second year they were present only in February and March. The former representing 2 individuals, while the latter only one. They were caught at 2100-2200 hrs. in April and November, 0300-0400 hrs. in May and 2400-0100 hrs. and 0300-0400 hrs. in February. They were too low in number to draw any conclusion regarding their hourly activity.

Isoptera

Isoptera, during the entire study period were caught only in April, of the first year representing 11 individuals, 0.1% of the total yearly insect catch (Fig. 4). They were caught maximum at 1800-1900 hrs. representing 6 individuals, 54.5% of the total catch, followed by 0200-2100 hrs. representing 3 individuals, 27.27%, at 2100-2200 hrs. and 0200-0300 hrs. each hour representing only one individual (9.09%).

Odonata

Odonata was represented by only two individuals (0.02%) of the total insect catch (Fig. 4). They were recorded only in June, of the first year during the entire study period at 2100-2200 hrs. and 0200-0300 hrs. each hour representing one individual. They were also too low in number to draw any

conclusion regarding their hourly activity.

Decomposer Arthropods

The term "microarthropods" as used in the present investigation designated all arthropods extracted from soil (Price, 1973). These ranged in size from less than 0.4 mm for most prostigmatids, including the juveniles of Acarina to 7 mm as in Diplopoda and Chilopoda. The extracted soil fauna were counted and sorted only upto family in Collembola ad higher taxonomic levels for the others.

The abundant groups of soil fauna encountered in the present study were Acarina and Collembola (Fig. 16) followed by less commonly occurring groups like Protura, Diplura, Chilopoa, Diplopoda, Symphyla, Isopoda, Thysanoptera, Hemiptera, Araneidae, Pauropoda, Formicidae, Microcoleoptera adults and larvae, Calanoids and Diptera larvae. Five families of Collembola recorded were Isotomidae, Entomobryidae, Onychiuridae, Sminthuridae and Hypogastruridae. The group Acarina composed of Prostigmata, Mesostigmata and Cryptostigmata sub-orders. Members of the sub- order Astigmata were not encountered during the entire study period.

The quantitative composition of different groups of microarthropods for the period of investigation is presented in Fig. 16. The present investigation was carried out for a total period of 20 months beginning September, 1976. The first annual cycle was complete while the second consisted of only 8 months. Since both annual cycles could not be compared as such, the first eight months of the previous annual cycle was compared to the eight months of the second annual cycle.

When so done it was seen that the abundance of microarthropods was much more during the latter than in the former. Collembola and Acarina constituted 89.54% of the total soil arthropod population for the entire study period. Among these two, Collembola, was the most dominant group constituting 58.42%. Among Collembola, Isotomidae was the most dominant group and recorded 49.18% of the total microarthropod population followed by Entomobryidae (4.13%), Sminthuridae (2.53%), Onychiuridae (1.89%) and Hypogastruridae (0.32%). Among Acarina, Prostigmata was the most dominant group comprising of 16.54% of the total microarthropod fauna, followed by Cryptostigmata constituting 11.11% and Mesostigmata 3.44%. Apterygota which constitute Collembola, Protura and Diplura formed 59.9% of the total microarthropod population. The group Myriapoda represented by Diplopoda, Chilopoda, Symphyla and Pauropoda constituted 1.6% of the total microarthropod population. The other groups such as Hymenoptera (Formicidae), Isopoda, Coleoptera adults and larvae, Thysanoptera, Hemiptera, Calonoids, Araneida, Diptera larvae constituted 1.23%, 0.63%, 0.48% and 0.06%, 0.42%, 0.42%, 0.27%, 0.12% and 0.06% of the total arthropod population respectively.

Seasonal Fluctuation

Fig. 17 represents the seasonal abundance of the total soil microarthropods during the period of investigation. The total microarthropod population ranged from $208X10^2/m^2$ to $1600X10^2/m^2$, maximum during the month of July and minimum in the month of September for the first year of study. The month of April, had a peak representing $1356X10^2/m^2$. But during the second cycle the minimum number of $240X10^2/m^2$ was in the month of April and the maximum occurred in the month of November, representing $836X10^2/m^2$.

TABLE VIIa

Physical Factors	Total Micro–Arthropos	Total Collembola	Total Acarina	Total Myriapoda	Arthopods other than Collembola and Acarina	Apterygota
Air Temp.	0.2775^{NS}	0.4363^{*}	-0.5212^{*}	-0.1852^{NS}	-0.3903^{NS}	0.4278^{NS}
Temp. at Soil Surface	0.1964^{NS}	0.3408^{NS}	-0.4655^{*}	-0.4158^{NS}	-0.3898^{NS}	0.3318^{NS}
Temp. at 5cm depth	0.2563^{NS}	0.4120^{NS}	-0.5318^{*}	-0.1692^{NS}	-0.3113^{NS}	0.4080^{NS}
Soil Moisture	0.1437^{NS}	0.3217^{NS}	-0.6899^{**}	-0.3274^{NS}	-0.0505^{NS}	$0..3214^{NS}$
Rainfall at previous month	0.4580^{*}	0.5950^{**}	-0.5444^{*}	-0.1903^{NS}	-0.0214^{NS}	0.5961^{**}
pH	0.0922^{NS}	0.8769^{**}	0.2696^{NS}	0.6300^{**}	0.1361^{NS}	-0.4335^{NS}
Conductivity	0.1849^{NS}	0.1180^{NS}	0.2309^{NS}	0.4292^{NS}	0.1316^{NS}	-0.4260^{NS}
Organic Carbon	0.1794^{NS}	0.2610^{NS}	-0.1710^{NS}	-0.1225^{NS}	-0.5329^{*}	-0.5412^{*}
P_2O_5	0.1133^{NS}	0.1972^{NS}	-0.1732^{NS}	-0.0052^{NS}	-0.5648^{**}	0.4890^{*}
K_2O	-0.0781^{NS}	-0.1552^{NS}	-0.1377^{NS}	-0.2778^{NS}	-0.4018^{NS}	-0.3290^{NS}
Fe_2O_3	-0.0453^{NS}	-0.0706^{NS}	0.3922^{NS}	-0.2842^{NS}	0.2526^{NS}	-0.1929^{NS}
CaO	-0.4221^{NS}	-0.4307^{*}	-0.3069^{NS}	0.0502^{NS}	-0.1306^{NS}	-0.4295^{NS}
MgO	-0.3600^{NS}	-0.3445^{NS}	-0.1494^{NS}	-0.0533^{NS}	0.3105^{NS}	-0.3316^{NS}
Na_2O	0.0680^{NS}	0.1349^{NS}	-0.2187^{NS}	0.0373^{NS}	-0.1580^{NS}	0.1429^{NS}

NS = Not significant

* = $P < 0.05$

** = $P < 0.01$

Table VIIa Coefficient correlation beetween the monthly abundance of total microarthropods, total Collembola, total Acarina, Myriapoda, insects other than Collembola and Acarina and various physico–chemical factors.

TABLE VIIb

Physical Factors	Entomobryidae	Isotomidae	Sminthuridae	Prostigmata	Mesostigmata	Cryptostigmata
Air Temp..	-0.2219^{NS}	0.4417^{*}	0.3670^{NS}	-0.4344^{*}	-0.4457^{*}	-0.3455^{NS}
Temp. at soil surface	-0.2297^{NS}	0.3532^{NS}	0.2477^{NS}	-0.3967^{NS}	-0.3975^{NS}	-0.2981^{NS}
Temp. at 5cm depth	-0.0163^{NS}	0.4067^{NS}	0.4309^{NS}	-0.3908^{NS}	-0.4725^{*}	-0.4193^{NS}
Soil Moisture	0.1007^{NS}	0.3170^{NS}	0.3926^{NS}	-0.4612^{*}	-0.3371^{NS}	-0.7070^{**}
Rainfall at previous month	0.1080^{NS}	0.5859^{**}	0.3986^{NS}	-0.3840^{NS}	-0.3546^{NS}	-0.4989^{*}
pH	-0.0701^{NS}	0.5618^{**}	-0.0139^{NS}	0.0631^{NS}	0.4910^{*}	0.3497^{NS}
Conductivity	-0.1318^{NS}	0.1394^{NS}	-0.2127^{NS}	0.2390^{NS}	-0.1157^{NS}	0.2135^{NS}
Organic Carbon	-0.2526^{NS}	0.2561^{NS}	0.3340^{NS}	-0.3983^{NS}	-0.4491^{*}	0.3393^{NS}
P_2O_5	-0.3518^{NS}	0.1988^{NS}	0.2938^{NS}	-0.3546^{NS}	-0.5617^{**}	0.3170^{NS}
K_2O	-0.1857^{NS}	-0.0153^{NS}	0.3739^{NS}	-0.3246^{NS}	-0.1625^{NS}	0.3397^{NS}
Fe_2O_3	0.3806^{NS}	-0.0762^{NS}	-0.3781^{NS}	0.5555^{**}	0.3807^{NS}	0.6991^{**}
CaO	0.1591^{NS}	-0.4466^{*}	0.2622^{NS}	-0.0294^{NS}	0.2355^{NS}	-0.5408^{*}
MgO	0.4973^{*}	-0.3744^{NS}	-0.1384^{NS}	-0.0742^{NS}	0.1969^{NS}	-0.2927^{NS}
Na_2O	0.1471^{NS}	0.1191^{NS}	0.2274^{NS}	-0.1558^{NS}	-0.3482^{NS}	-0.1230^{NS}

NS = Not significant

* = $P < 0.05$

** = $P < 0.01$

Table VIIb Coefficient correlation between the monthly abundance of Isotomidae, Entomobryidae, Sminthuridae, Prostigmata, Mesostigmata, Cryptostigmata and various physico–chemical factors.

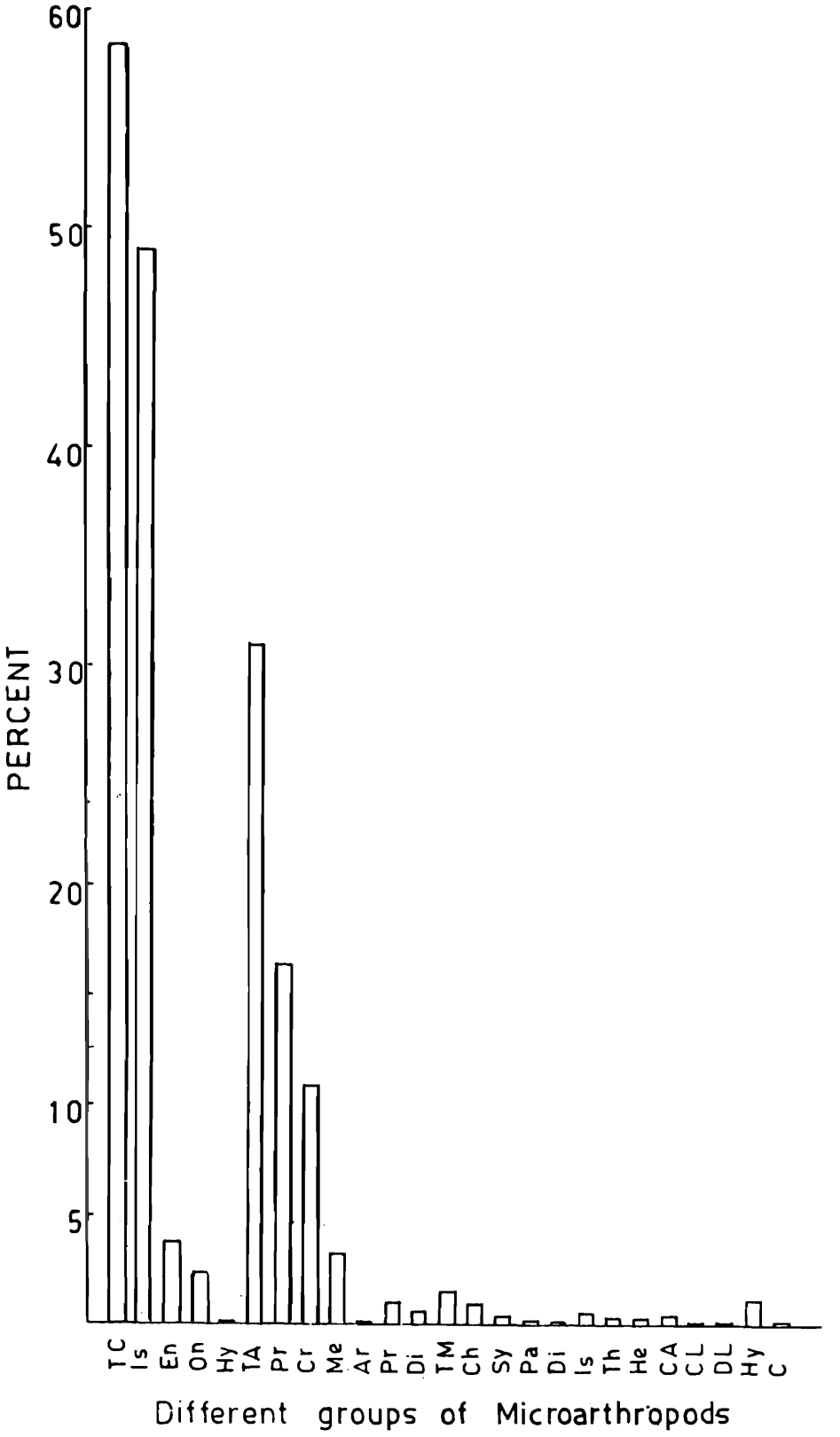


Figure 16 showing the qualitative and quantitative composition of the various microarthropod groups found in the soil during the entire study period.

TC = Total Collembola; TM = Total Myriapoda; Is = Isotomidae; Ch = Chilopoda;
En = Entomobryidae; Sy = Symphyla; On = Onychiuridae; Pa = Pauropoda;
Hy = Hypogastruridae; Di = Diplopoda; TA = Total Acarina; Iso = Isopoda;
Pr = Prostigmata; Th = Thysanoptera; Cr = Cryptostigmata; He = Hemiptera;
Me = Mesostigmata; CA = Coleoptera Adults; Ar = Araneidae; DL = Diptera Larvae;
Pro = Protura; Hy = Hymenoptera; Dip = Diplura; C = Calanoids

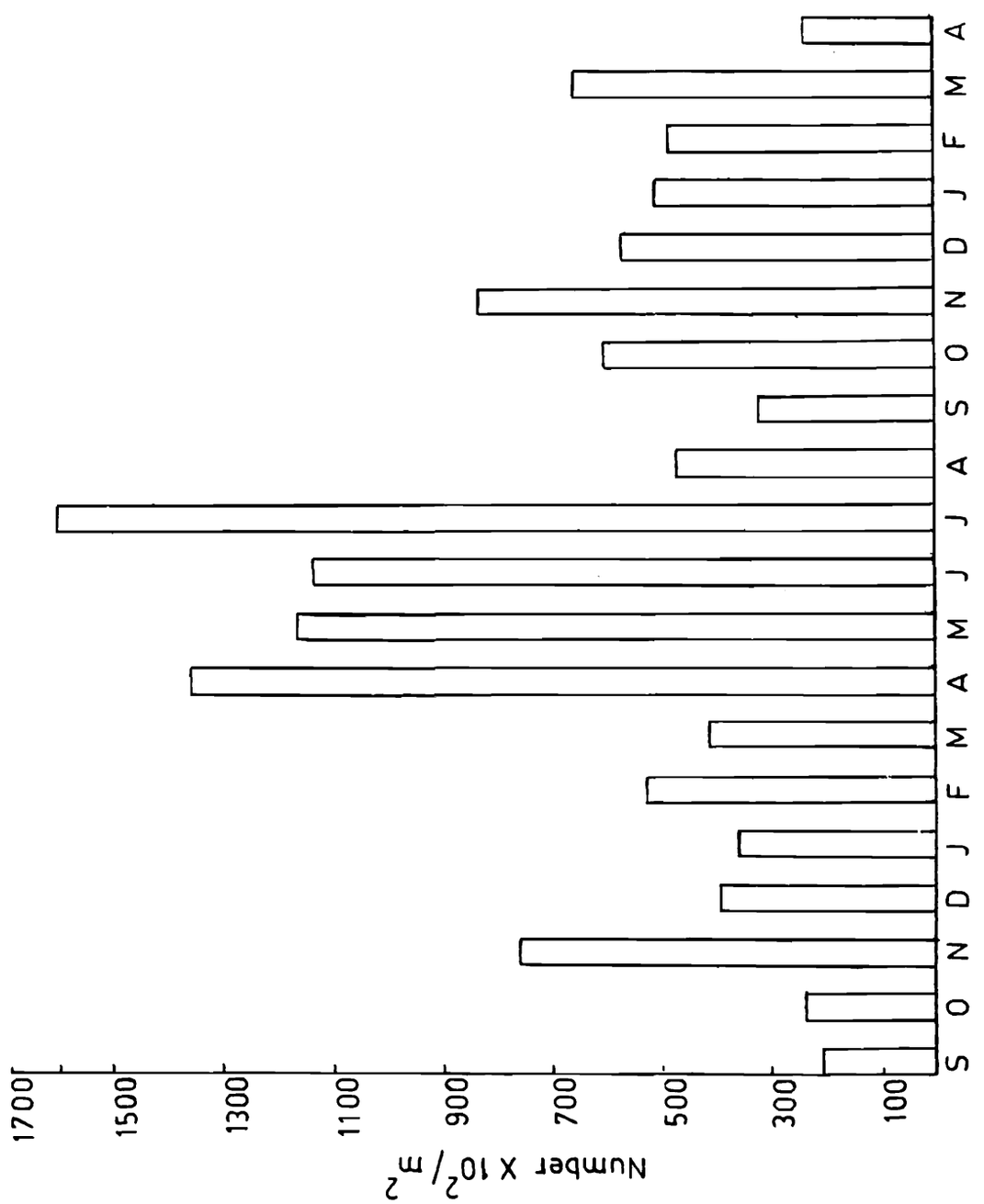


Figure 17 showing the seasonal fluctuation of total microarthropods found in the soil during the entire study period.

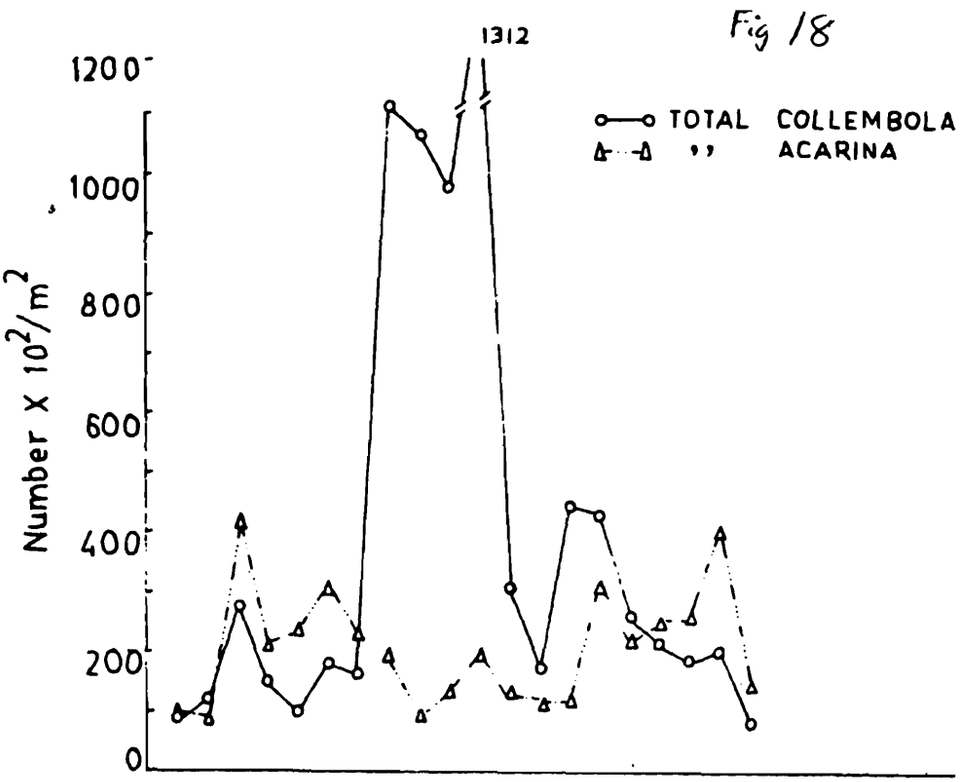


Figure 18 showing the seasonal fluctuation of total Collembola and Acarina found in the soil during the entire study period.

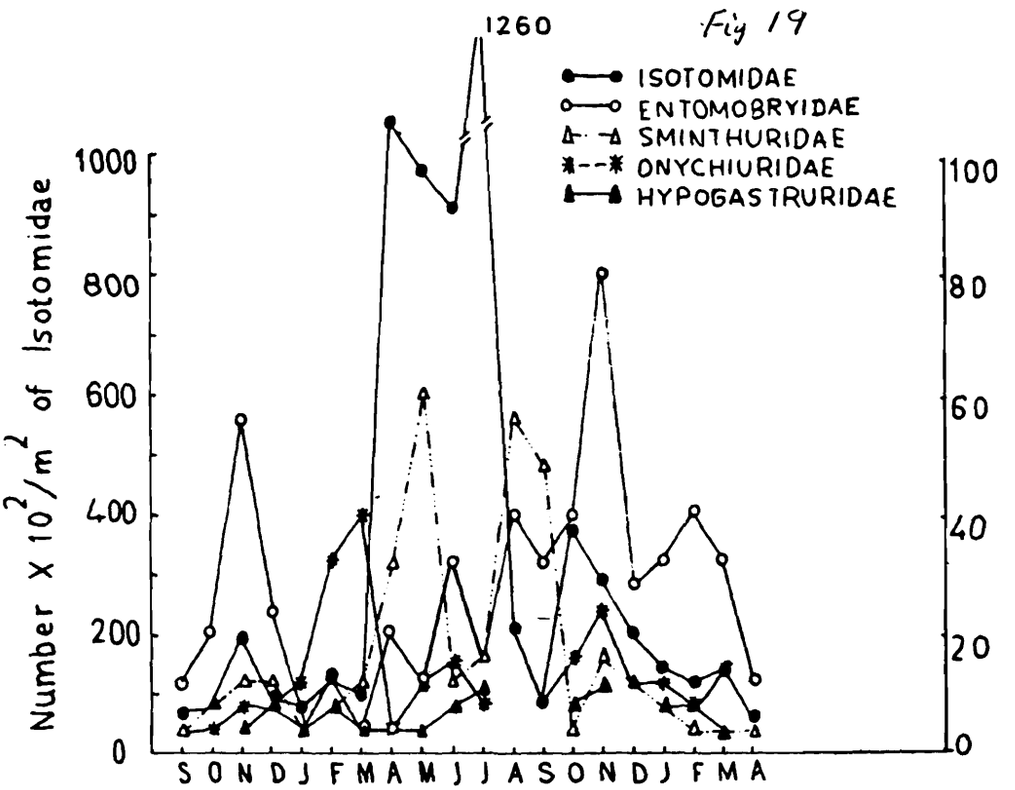


Figure 19 showing the seasonal fluctuation of Isotomidae, Entomobryidae, Onychiuridae and Hypogastruidae found in the soil during the entire study period

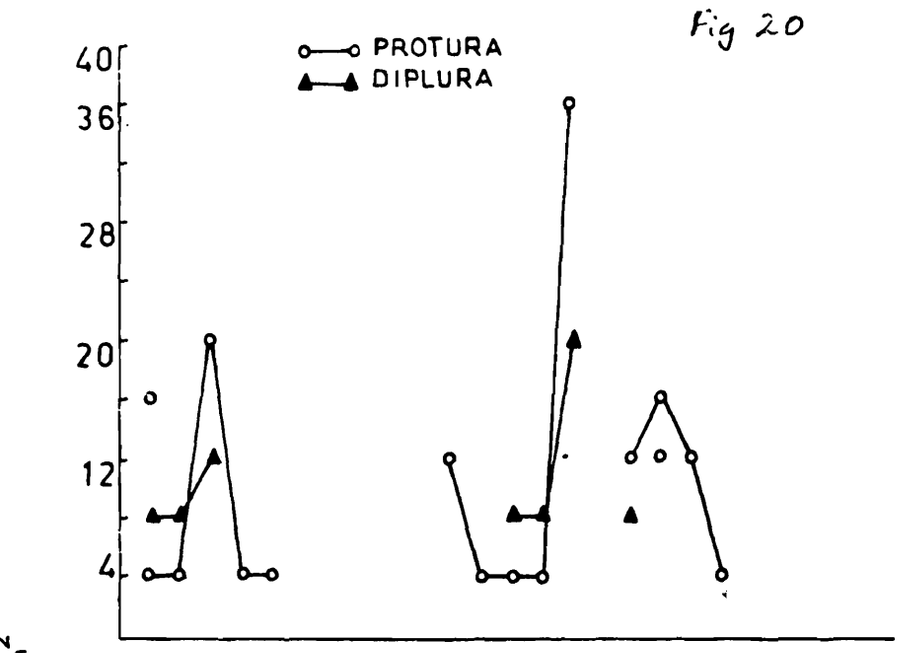


Figure 20 showing the seasonal fluctuation of Protura and Diplura found in the soil during the entire study period.

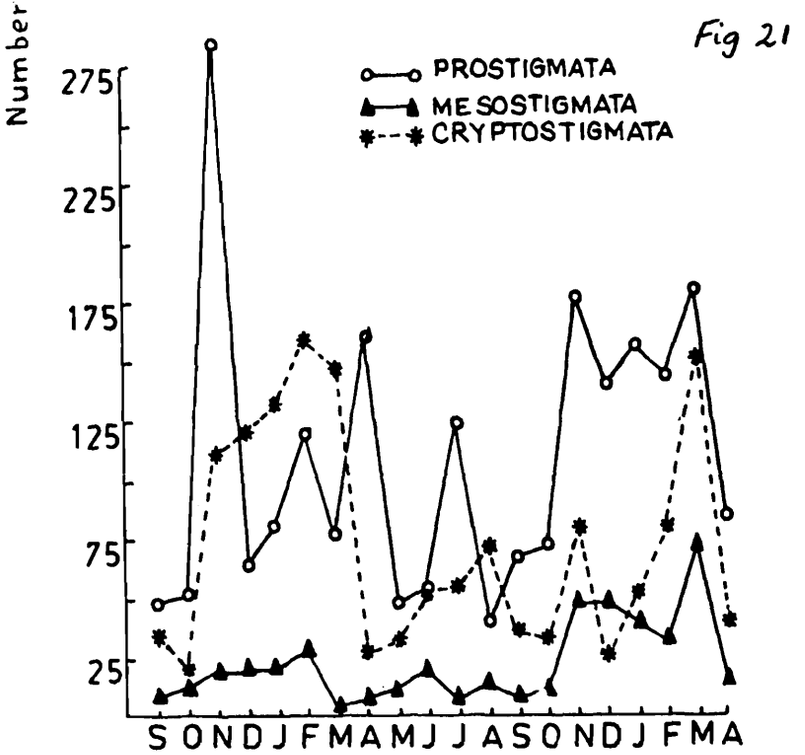


Figure 21 showing the seasonal fluctuation of Prostigmata, Mesostigmata and Cryptostigmata found in the soil during the entire study period.

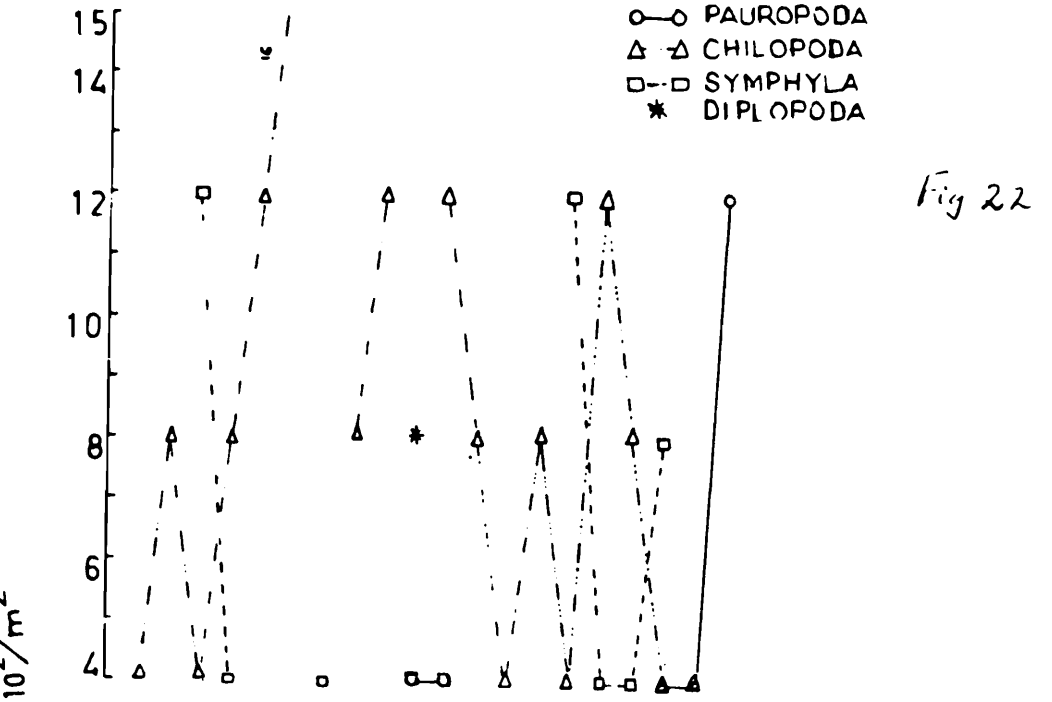


Figure 22 showing the seasonal fluctuation of Pauropoda, Diplopoda, Chilopoda and Symphyla found in the soil during the entire study period.

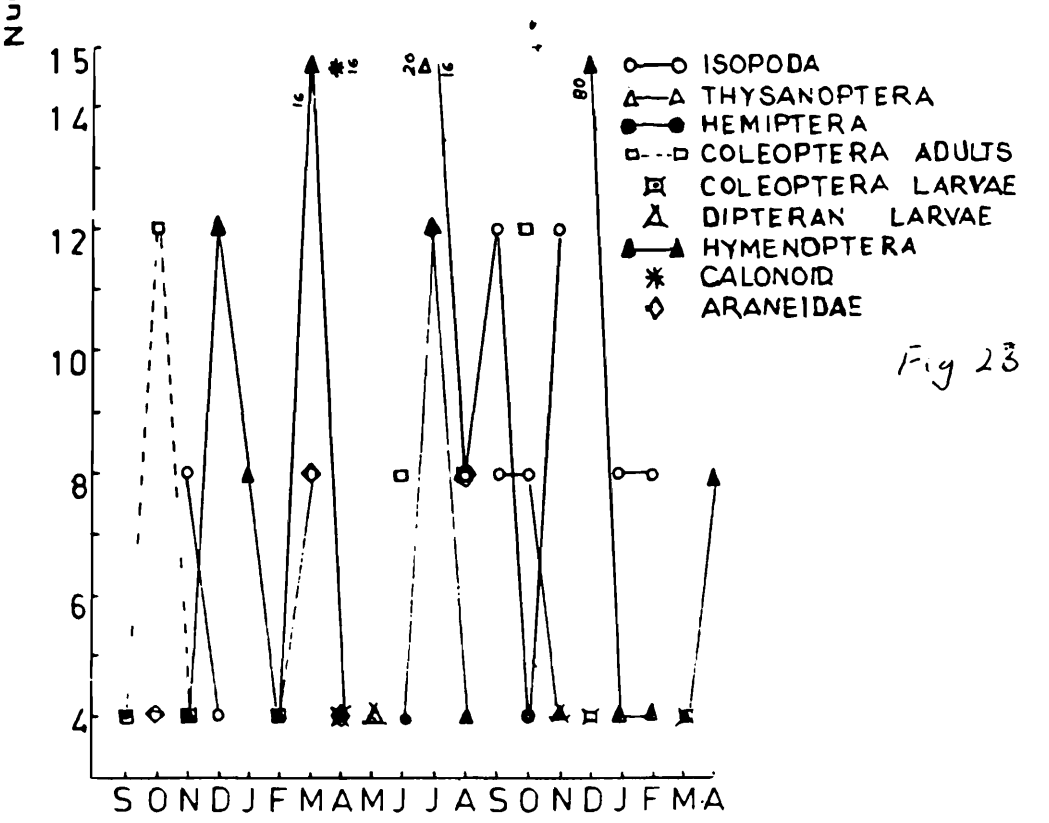


Figure 23 showing the seasonal fluctuation of Hymenoptera, Isopoda, Araneidae, Thysanoptera, Hemiptera, Coleoptera, Diptera and Calanoids found in the soil during the entire study period.

The seasonal abundance of the total Collembola (Fig. 18) represented by all the five families (Fig. 19) reached the peak of abundance in the month of July, ($1312X10^2/m^2$) and minimum in the month of September. Besides that it had another smaller peak during the months of April and May. During the second year of investigation, the Collembola population was maximum in the month of October, and minimum in the month of April. The family Isotomidae was the most predominant group. The seasonal abundance of this family presented in Fig. 19 revealed that the number was minimum in the month of September, and the abundance fluctuated upto the month of March, and suddenly increased in the month of April, reaching a small peak of $1052X10^2/m^2$ and then with a slight decrease in the month of May-June, reached the largest peak in the month of July, representing $1260X10^2/m^2$. Then it suddenly decreased to $208X10^2/m^2$. During the second year of investigation, the population fluctuation did not follow the previous year. The minimum number was recorded in the month of April and September, representing $56X10^2$ and $80X10^2/m^2$ respectively and maximum in the month of October representing $372X10^2/m^2$.

Therefore, relative peaks of Isotomidae reflected the relative abundance of the total Collembola group and also the relative abundance of the total microarthropods.

The family Entomobryidae was the next dominant group. The family did not show any significant seasonal variation (Fig. 19). The maximum number was recorded in the month of November, representing $56X10^2/m^2$ followed by August, representing $40X10^2/m^2$ and was recorded minimum during the month of January and March. During next year of investigation the maximum number recorded was in the month of November, representing $80X10^2/m^2$ individuals and minimum in the month of April.

The family Sminthuridae was next to Entomobryidae in order of abundance. The monthly catches of this family also did not show any significant variation (Fig. 19). The peaks recorded was in the month of May and August, representing $60X10^2/m^2$ and $56X10^2/m^2$ respectively. The minimum number was recorded during the months of September, and January. During the second cycle, the maximum numbers recorded were in the month of August and minimum in the months of February, March and April.

The families Onychiuridae and Hypogastruridae were too few to detect changes in seasonal abundance. The peak numbers $32X10^2$ to $40X10^2/m^2$ in case of Onychiuridae was recorded during the month of March and in November, respectively.

The group Acarina was the second major group of soil microarthropods (Fig. 16). The group was represented by three sub-orders. The seasonal abundance of total Acarina presented in the Fig. 18, revealed that the abundance ranged from $84X10^2/m^2$ to $416X10^2/m^2$, the minimum in the month of October, followed by a sudden increase in the month of November, reaching the maximum. A second peak of abundance, $308X10^2/m^2$ was recorded in the month of February. During the second year of investigation, the minimum number of Acarina recorded was in the month of September, with, $112X10^2/m^2$ in the month of November. In the month of March, the population of Acarina reached the maximum representing $40X10^2/m^2$.

Among the Acarina group, Prostigmata was the most dominant group (Fig. 21). It's population reached the maximum in the month of November, representing $284X10^2/m^2$ and minimum in the

month of August, $40X10^2/m^2$ (Fig. 21). A small peak representing $160X10^2/m^2$ was recorded in the month of April. During the second year, the minimum number recorded was in the month of September and maximum in the months of November, and March. The relative peaks of Prostigmata abundance therefore reflected the relative peaks of abundance for the total Acarina.

Cryptostigmata was next to Prostigmata in order of abundance among the Acarina. The Cryptostigmata mites recorded were minimum in the month of October, representing $20X10^2/m^2$ and suddenly increased in the month of November, (Fig. 21) and gradually reached the peak in the month of February. Then it gradually started decreasing with a small peak in the month of August. During the second year the number gradually increased from the month of August and reached a small peak in the month of November, representing $80X10^2/m^2$. It then suddenly decreased to a minimum in the month of December, representing $24X10^2/m^2$. From January, onwards it gradually started increasing and reached the peak in the month of March of the second cycle representing $152X10^2/m^2$, after which is decreased.

The Mesostigmata were too few to reflect any significant change in their seasonal abundance.

Collembola along with Protura and Diplura constituted the Apterygota group. During the present investigation Collembola were the most prominent group of Apterygota (Fig. 18). They constituted 97.53% of the total Apterygota. The next dominant group was Protura. The seasonal abundance of Protura during the first year more or less followed that of the second year. The Proturans were recorded maximum in the month of November representing $20X10^2/m^2$ and were recorded nil during the period from February to June. During the second year, the number reached maximum in the month of November representing $36X10^2/m^2$ and were minimum during the months of August, September and October and April (Fig. 20).

The Diplura were represented by very negligible numbers. They were recorded maximum in the month of November representing $12X10^2/m^2$ and were nil from the months of January to August. During the second year of investigation, the maximum Diplura population was recorded in the month of November and decreased to minimum in the month of February. But in the month of March, it again showed a peak representing $16X10^2/m^2$ and then decreased to $4X10^2/m^2$ in the month of April (Fig. 20).

The group Myriapoda during the present investigation was represented by Chilopoda, Diplopoda, Symphyla and Pauropoda. The total Myriapoda represented 1.6 percent of the total population (Fig. 16). The seasonal abundance of total Myriapoda presented in Fig. 22 revealed no significant fluctuations. These were maximum in the month of February representing $24X10^2/m^2$ and minimum during the months of September and March. They further showed a small peak in the month of July representing $20X10^2/m^2$. During the second year they were in an increased state of abundance from November, to April and were recorded nil in the month of April. The group Chilopoda were represented by very few individuals to detect any change in the monthly fluctuation. The family Symphyla though represented by very negligible numbers, its maximum was distinct, and recorded during both the years during the month of November. The group Pauropoda were also recorded in very negligible numbers. They were recorded only in June and July, of the first year and from January to March, in the second during the entire period of investigation. The group Diplopoda was

recorded only in June, of the first year for the entire study period.

The other groups Formicidae, Isopoda, Thysanoptera, Hemiptera, Coleoptera were very poorly represented (Fig. 23), and were so few to allow detection of any change in the seasonal abundance. However, these groups when collectively represented as miscellaneous, they exhibited considerable variation in monthly fluctuations (Fig. 23). The miscellaneous group was maximum in the month of July representing $64x10^2/m^2$ and minimum in the month of May. During the succeeding year, this group was represented maximum in December and minimum in April. The maximum number represented during December, was due to the colony of Hymenoptera which represented nearly 87% for that month (Fig. 23).

Physical factors

The seasonal variation in physical factors undertaken for the study period is represented in Fig. 24. The temperature of the air inside the forest canopy, temperature at soil surface and at 5 cm depth of the soil, during the period of study varied considerably, the range being 17°C to 25.5°C, 16°C to 25.5°C and 14°C to 24°C respectively. The maximum air temperature and temperature at soil surface was recorded during July to September and minimum during December of both the years. Temperature at 5 cm depth recorded maximum in the month of August and minimum in December both the years. All these temperatures showed a definite trend of decrease starting from September, reaching the minimum in the month of December. From January onwards a gradual increase was recorded reaching the maximum during July, August and September (Fig. 24a).

The monthly variation in the percentage of moisture content of the soil (Fig. 24a) showed a considerable variation. It ranged from 12.00% to 44.67%. The maximum percentage of moisture content recorded was during October and the minimum during January. Besides that a few smaller peaks were seen during the months of May, August, October, of the first year and February in the second year of study.

The pH of the soil was acidic, ranging from 4.47 to 6.47 units. The maximum pH was recorded in the month of February, and minimum in the month of October. Besides that, the pH showed another peak of increase during the month of March, of the second year. The monthly variation in pH during the present study was considerable (Fig. 24b).

The conductivity ranged from 14.88 to 41.3 mmhos/cm^2. The minimum conductivity was recorded in the month of May and maximum in the month of July. A second peak of increase was recorded in the month of February of the second year representing 37.45 mmhos/cm^2.

Chemical factors

Phosphorus (P_2O_5) ranged from 3.6 to 29.6 pound per acre, the maximum being in the month of March and minimum in the month of February the following year (Fig. 25a). Pottasium (K_2O) was very abundant comparatively and ranged from 140 pounds per acre to 650 pounds per acre, the maximum being in the month of August and minimum in the month of November. A few smaller peaks were recorded during the months of January, March and June of the first year and March in the second year (Fig. 25a). The percentage of organic carbon ranged from 2.25% to 4.58%, the

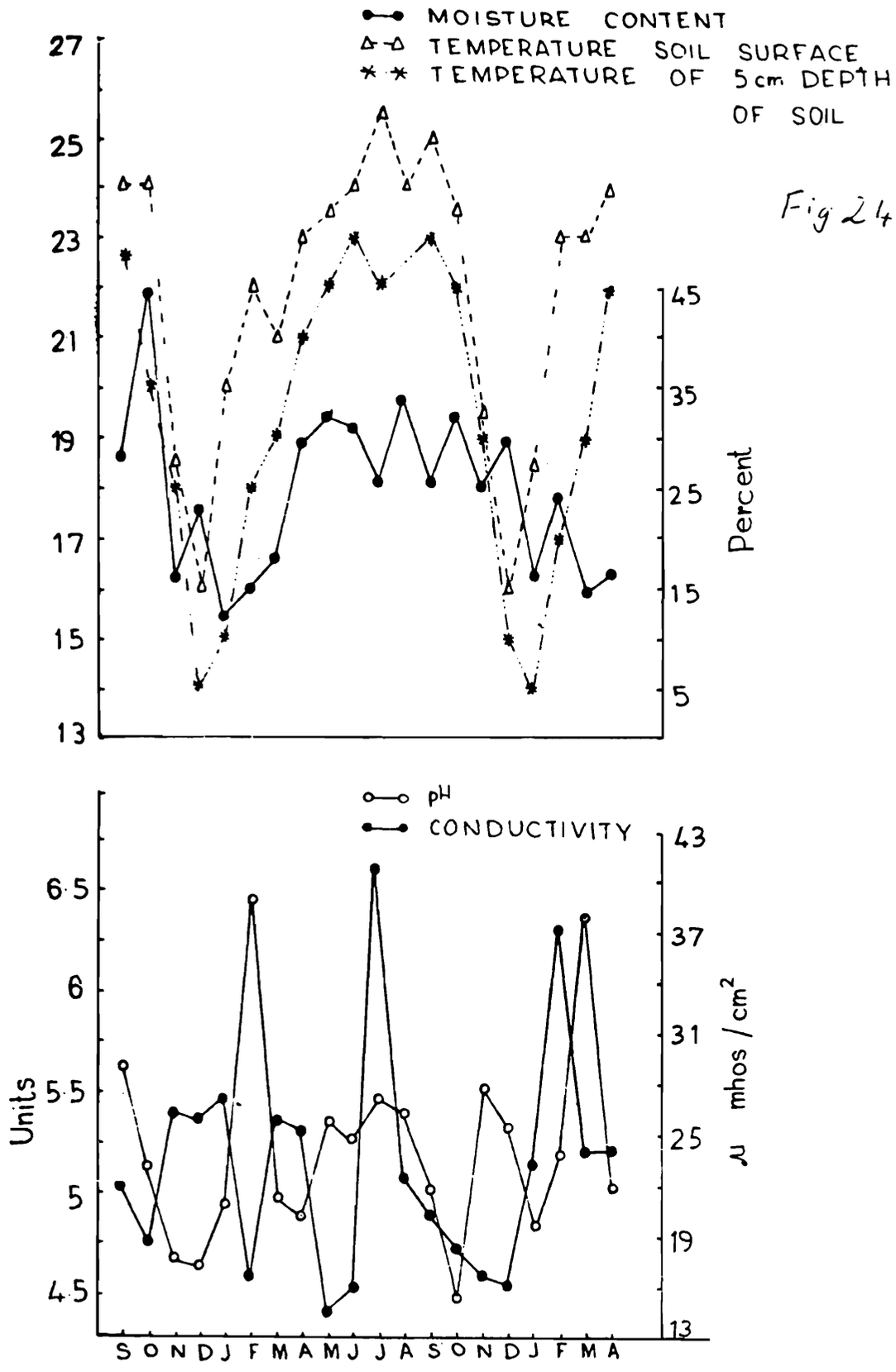


Figure 24 showing the seasonal fluctuation in the various physical factrs of soil during the entire study period.

a. Temperature of the soil surface, temperature at 5 cm depth and moisturé.
b. Conductivity and pH.

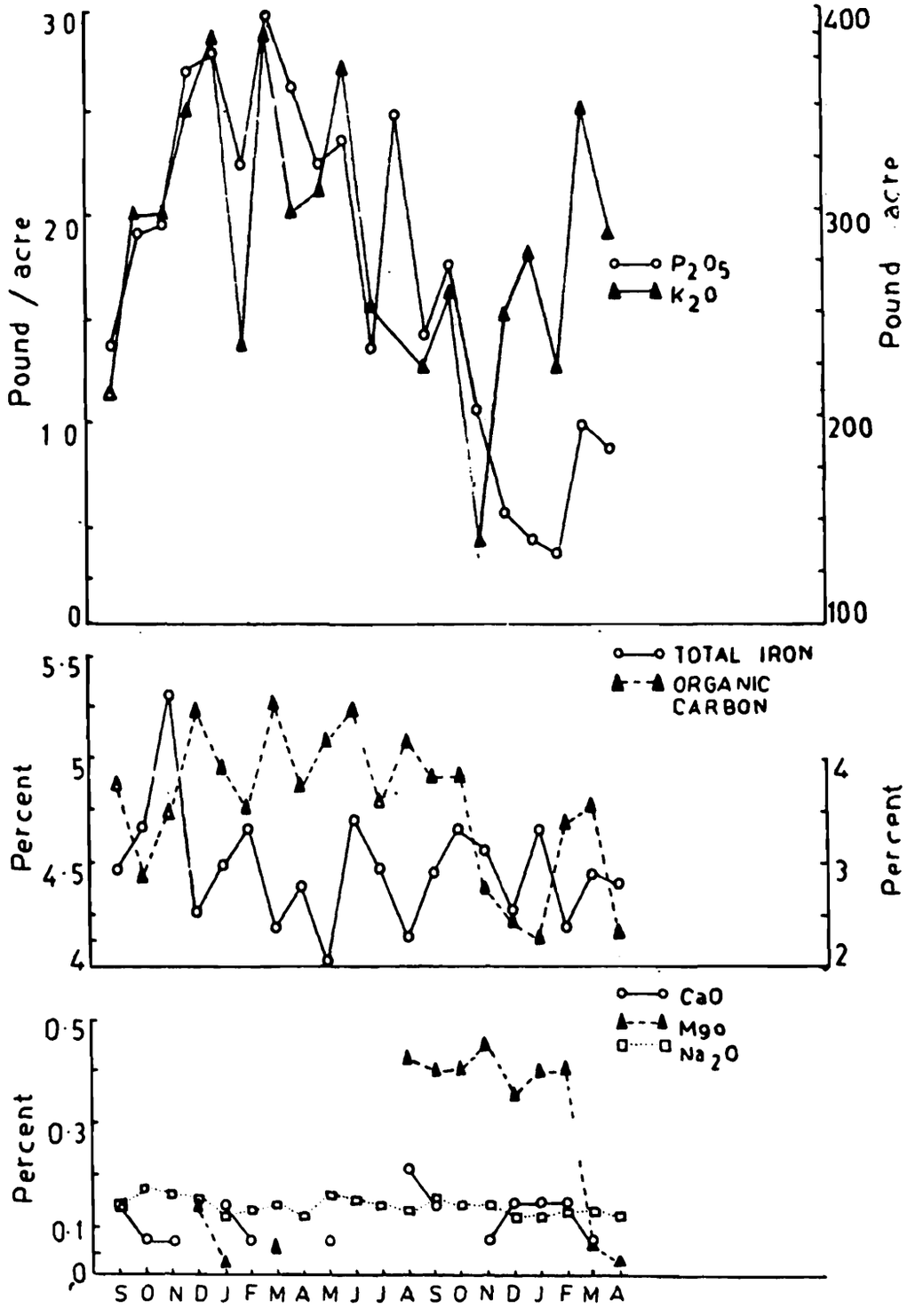


Figure 25 showing the seasonal fluctuation in the various chemical factors of soil during the entire study period.

a. P_2O, K_2O; b. Total iron, organic carbon; c. CaO, MgO, Na_2O

maximum being in the months of March, and minimum in the month of January. Besides that, the percentage of organic carbon also had a peak during June (Fig. 25b). There was very little monthly variation in percentage of total iron content. It ranged from 4.06% to 5.43%, the maximum being in the month of November and minimum in the month of May.

The percentage of Calcium (CaO), Magnesium (MgO) and Sodium (Na_2O) was very negligibly represented and the monthly variations could not be detected. Calcium (CaO) was recorded from trace to 0.21%. The maximum amount was recorded in August, and the trace was recorded during December of the first year March-June, October, and April of the second year. Magnesium (MgO) content ranged from trace to 0.45%. The maximum amount was recorded in November. The content of Sodium (Na_2O) ranged from 0.12% to 0.17%, the maximum being recorded in the month of October and minimum in the months of January, April and December of the first and January and April of the second year of study.

Decomposer Arthropods in Litter

All microarthropods recorded during the present investigation were exclusively from the litter bags. During the present investigation major emphasis was made to correlate the abundance of microarthropods with loss in weight of litter placed in the litter bags seasonally. Temperature and moisture content of litter in the bags were also taken to see any effect of these factors on the microarthropods. The mean number from replicate samples from each mesh sized bags, for different groups of litter microarthropods are presented in the Fig. 26a, b,c. The two most abundant microarthropod groups present in all three different mesh sized bags, were Collembola and Acarina, Collembola being more numerous than Acarina (Fig. 26a, b, c). The other groups encountered in much less numbers, were groups belonging to Apterygota such as Protura and Diplura; Myriapoda such as Chilopoda, Diplopoda, Symphyla and Pauropoda; Isopoda; Thysanoptera; Hemiptera; Coleoptera adults and larvae; Diptera larvae; Dictyoptera; juvenile earthworms; Araneidae and Molluscs. The group Collembola was represented by all the five families, Entomobryidae, Isotomidae, Sminthuridae, Onychiuridae and Hypogastruridae. Acarina was represented by three of the four sub-orders Prostigmata, Mesostigmata and Cryptostigmata, with the sub-order Astigmata completely absent. A mean total of $207x10^2$ litter microarthropods were collected during one annual cycle from all the litter bags irrespective of mesh size of the bags. However this total comprised of 35.36% from the maximum mesh sized bag, 31.57% from medium mesh size and 33.07% from the minimum mesh sized bag. Collembola was the dominant group representing 75.59%, while Acarina represented only 19.88%. Isotomidae was the most dominant group among Collembola and formed 66.16%, followed by Entomobryidae (5.31%), Sminthuridae (2.05%), Onychiuridae (1.84%) and Hypogastruridae (0.23%) of total microarthropods. Among Acarina, Prostigmata and Cryptostigmata were more or less same, the former being 7.28% and the latter 7.16%, while Mesostigmata represented 5.44%. Protura and Diplura together with Collembola forming the group Apterygota was 76.9% of which Protura was 1.28% and Diplura 0.03%. The group Myriapoda which constituted Chilopoda, Diplopoda, Symphyla and Pauropoda was 0.84% of which 0.57% was Pauropoda, 0.11% was Chilopoda, 0.12% Diplopoda and 0.04% Symphyla. The group Araneidae were poorly represented, encountering only 0.18%. All other groups such as Isopoda, Diptera and Coleoptera

larvae, Hemiptera, Coleoptera adults, Thysanoptera and Dictyoptera encountered were 0.56%, 0.4% and 0.38%, 0.26%, 0.22%, 0.11% and 0.04% respectively. Besides these earthworm juveniles and molluscs were also present, being 0.12% and 0.05% respectively.

A quantitative representation of litter microarthropods from the medium mesh sized litter bags are presented in Fig. 26b. As in the maximum mesh sized bags, Collembola and Acarina collectively represented 97.08%, of the total microarthropods in the medium mesh sized bags. Moreover Collembola was the most dominant group representing 78.95% of which Protura was 0.65% and Diplura was nil.

The group Myriapoda which comprised of Chilopoda, Diplopoda, Symphyla and Pauropoda formed 0.67%. Of this, Pauropoda was 0.29%, Chilopoda 0.24% and Diplopoda 0.13%. The group Symphyla was absent in these bags. The other groups such as Isopoda, Diptera larvae, Hemiptera, Coleoptera adults and larvae and Thysanopera represented 0.47%, 0.36%, 0.13%, 0.12% and 0.12% and 0.09% respectively. In addition to these, earthworm juveniles and mollusca represented 0.09% and 0.03%. Araneidae were present in very negligible numbers with 0.12%.

The quantitative composition of litter microarthropods from the minimum mesh sized litter bags are presented in Fig. 26c. As in the other two mesh sized bags, Collembola and Acarina were the dominant groups and formed 97.27% of the total litter fauna in the minimum mesh sized bags. Among these two major groups, Collembola was dominant representing 73.35%, while Acarina represented 23.92%. Among the different families of the group Collembola, Isotomidae was the dominant group representing 66.02% followed by Enomobryidae representing 4.08%, Sminthuridae representing 1.81%, Onychiuridae representing 1.11%, while Hypogastruridae represented only 0.29%. the group Aperygota represented 73.94% of which Protura formed 0.54% and Diplura 0.03%. Among the different suborders of Acarina, Prostigmata the dominant group represented 9.39% followed by Cryptosigmata with 7.86% and Mesostigmata with 6.66%. The group Myriapoda represented 0.28%, of which Pauropoda the dominant group was 0.54% followed by Diplopoda with 0.18%. Chilopoda with 0.12% and Symphyla with 0.04% were poorly represented. Araneidae constituted a very small quantity with only 0.12%.

The other groups were Diptera larvae, Coleoptera adults and larvae, Hemiptera, Hymenoptera, Isopoda and Thysanoptera which represented 0.37%, 0.19% and 0.09%, 0.12%, 0.07%, 0.04% and 0.03% respectively. Earthworm juveniles were also recorded which represented only 0.01%. No mollusca were recorded.

The maximum number of 7319 litter microarthropods was recorded in maximum mesh sized bags and a minimum of 6544 was recorded in the medium mesh sized bags. Collembola and Acarina the major groups of litter microarthropod fauna, collectively represented a maximum number of 6987 in maximum mesh sized bags and a minimum of 6353 in medium mesh sized bags.

On a general comparison between the three mesh sized bags (Table VIII) it was seen that the groups which were maximum according to their relative abundance were Isotomidae, Entomobryidae, Sminthuridae, Ornychiuridae, Araneidae, Protura, Paurpoda, Isopoda, Thysanoptera, Hemiptera, Coleoptera adults and larvae and Earthworm juveniles, recorded from the maximum mesh sized bags. Those maximum in the medium mesh sized bags were Hypogastruridae,

TABLE VIII

Microarthropod Groups	Maximum Mesh 3.0 mm^2	Medium Mesh 1.0 mm^2	Minimum Mesh 0.3 mm^2
Entomobryidae	388**	314	279*
Isotomidae	4842**	4654	4522*
Sminthuridae	150**	98*	124
Onychiuridae	135**	42*	76
Hypogastruridae	17	15*	20**
Prostigmata	508	436*	573**
Cryptostigmata	494	397*	521**
Mesostigmata	353	327*	448**
Araneidae	13*	8*	8*
Protura	94**	43	37*
Diplura	2**	—	2**
Chilopoda	8*	17**	8*
Diplopoda	9*	9*	12**
Pauropoda	42**	9*	37
Symphyla	3**	—	3**
Isopoda	41**	31	3*
Thysanoptera	8**	6	2*
Hemiptera	19**	9	8*
Coleoptera Adult	16**	8*	13
Coleoptera Larvae	28**	8	6*
Diptera Larvae	30**	24	23*
Hymenoptera (Formicidae)	3	1*	5**
Juvenile Earthworms	9**	6	1*

* = Minimum;

** = Maximum.

Table VIII Abundance of litter microarthropods, showing maximum and minimum density in the different mesh sized litter bags.

TABLE IXa

	Maximum mesh sized litter bags (3.0 mm^2)			
Microarthropod Groups	Temperature	Moisture	Weight loss	Multiple Correlation
Isotomidae	0.2320^{NS}	0.5138^{NS}	-0.6081^{*}	0.3549^{NS}
Entomobryidae	-0.5654^{*}	0.5277^{NS}	-0.1165^{NS}	0.7117^{*}
Total Collembola	0.0492^{NS}	0.6477^{*}	-0.5877^{*}	0.4890^{NS}
Prostigmata	-0.4036^{NS}	-0.2477^{NS}	0.5068^{NS}	0.1809^{NS}
Mesostigmata	-0.7074^{**}	0.9340^{**}	0.3345^{NS}	0.6009^{*}
Cryptostigmata	-0.5676^{*}	0.1989^{NS}	0.3215^{NS}	0.5465^{NS}
Total Acarina	-0.6556^{*}	-0.1097^{NS}	0.4822^{NS}	0.5338^{NS}
Total Arthropods	-0.2032^{NS}	0.6210^{*}	-0.4116^{NS}	0.4519^{NS}

NS = Not significant

* = $P < 0.05$

** = $P < 0.01$

Table IXa Coefficient correlation and multiple correlation between monthly abundance of litter microarthropods and various physical factors in the maximum mesh sized bags.

TABLE IXb

Microarthropod Groups	Medium mesh sized litter bags (1.0 mm^2) Temperature	Moisture	Weight loss	Multiple Correlation
Isotomidae	0.3180^{NS}	0.6257^{*}	-0.7433^{**}	0.6583^{*}
Entomobryidae	-0.6218^{*}	0.5850^{*}	-0.2815^{NS}	0.3465^{NS}
Total Collembola	0.2667^{NS}	0.7314^{**}	-0.7485^{**}	0.7407^{**}
Prostigmata	-0.5517^{NS}	0.1274^{NS}	0.3602^{NS}	0.4680^{NS}
Mesostigmata	-0.7467^{**}	0.1846^{NS}	0.4119^{NS}	0.7823^{**}
Cryptostigmata	-0.1379^{NS}	0.4017^{NS}	0.3055^{NS}	0.8434^{**}
Total Acarina	-0.5433^{NS}	0.2362^{NS}	0.4711^{NS}	0.7948^{**}
Total Arthropods	0.0677^{NS}	0.8429^{**}	-0.6144^{**}	0.7841^{**}

NS = Not significant

* = $P < 0.05$

** = $P < 0.01$

Table LXb Coefficient correlation and multiple correlation between monthly abundance of litter microarthropods and various physical factors in the medium mesh sized bags.

TABLE IXc

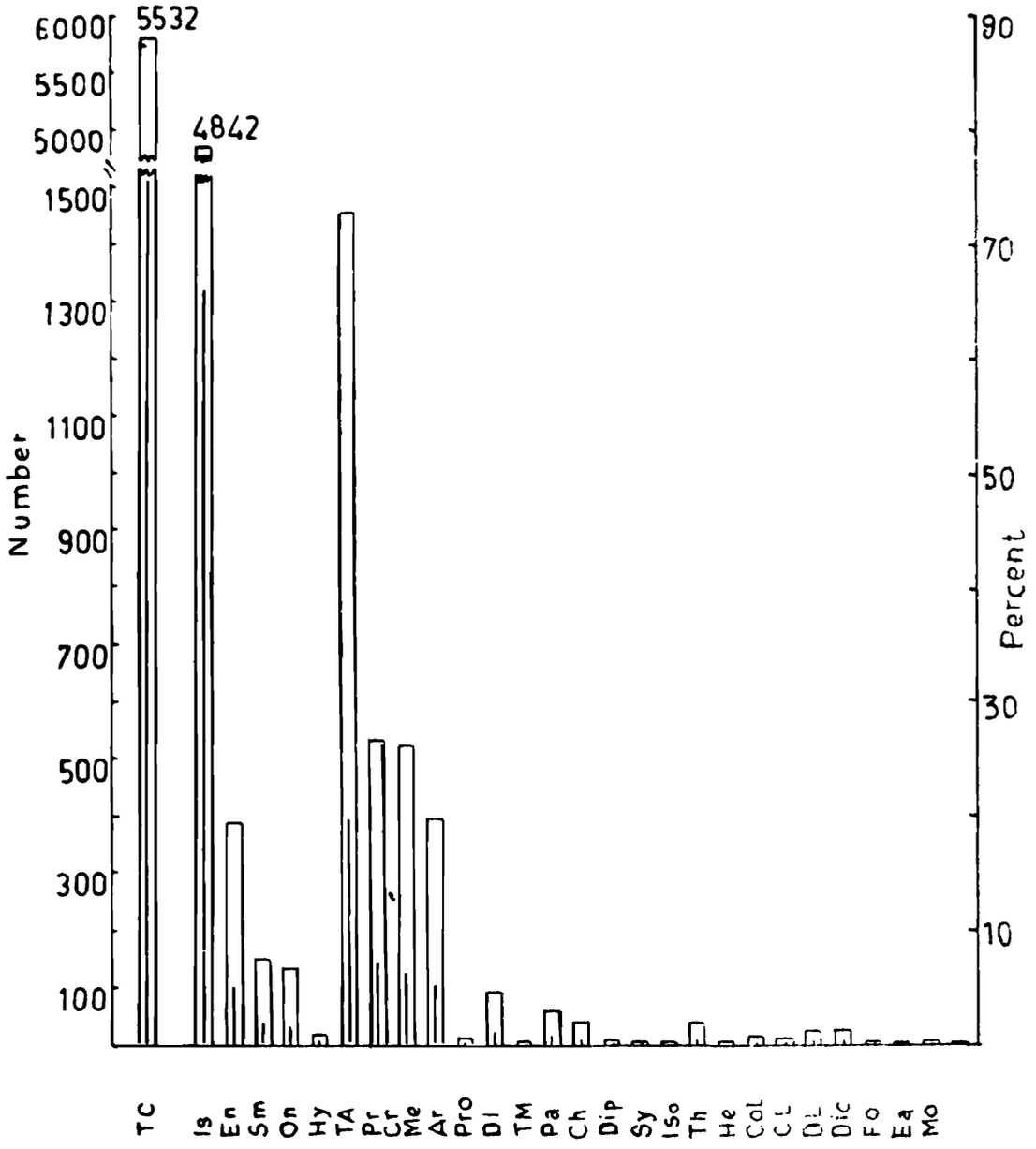
Minimum mesh sized litter bags (0.3 mm^2)				
Microarthropod Groups	Temperature	Moisture	Weight loss	Multiple Correlation
Isotomidae	0.1685^{NS}	0.7735^{**}	-0.4802^{NS}	0.6929^{*}
Entomobryidae	-0.1497^{NS}	0.4563^{NS}	0.1234^{NS}	0.3756^{NS}
Total Collembola	0.0841^{NS}	0.8419^{**}	-0.4325^{NS}	0.7730^{*}
Prostigmata	-0.1147^{NS}	-0.3850^{NS}	0.5779^{*}	0.3468^{NS}
Mesostigmata	-0.6342^{*}	0.3358^{NS}	0.3738^{NS}	0.7373^{*}
Cryptostigmata	-0.0339^{NS}	0.3458^{NS}	0.3870^{NS}	0.6936^{*}
Total Acarina	-0.2080^{NS}	0.0971^{NS}	0.5617^{NS}	0.5892^{*}
Total Arthropods	0.0120^{NS}	0.7889^{**}	0.1656^{NS}	0.7387^{*}

NS = Not significant

* = $P < 0.05$

** = $P < 0.01$

Table IXc Coefficient correlation and multiple correlation between monthly abundance of litter microarthropods and various physical factors in the minimum mesh sized bags.



Figuure 26a showing the qualitative and quantitative composition of the various microarthropods found in the maximum mesh sized (3.0 mm²) litter bags during the entire study period.

TC = Total Collembola; He = Hemiptera; Is = Isotomidae; Th = Thysanoptera;
En = Entomobryidae; Iso = Isopoda; Sm = Sminthuridae; Di = Diplopoda.
On = Onychiurridae; Pa = Pauropoda; Hy = Hypogastruridae; Sy = Symphyla;
TA = Total Acarina; Ch = Chilopoda; Pr = Prostigmata; TM = Total Myriapoda;
Cr = Cryptostigmata; CA = Coleoptera Adults; Me = Mesostigmata;
DL = Diptera Larvae; Ar = Araneidae; Hy = Hymnoptera; Pra = Protura;
Dic = Dictyoptera; Dip = Diplura; Ej = Earthworm juveniles. Mo = Molluscs

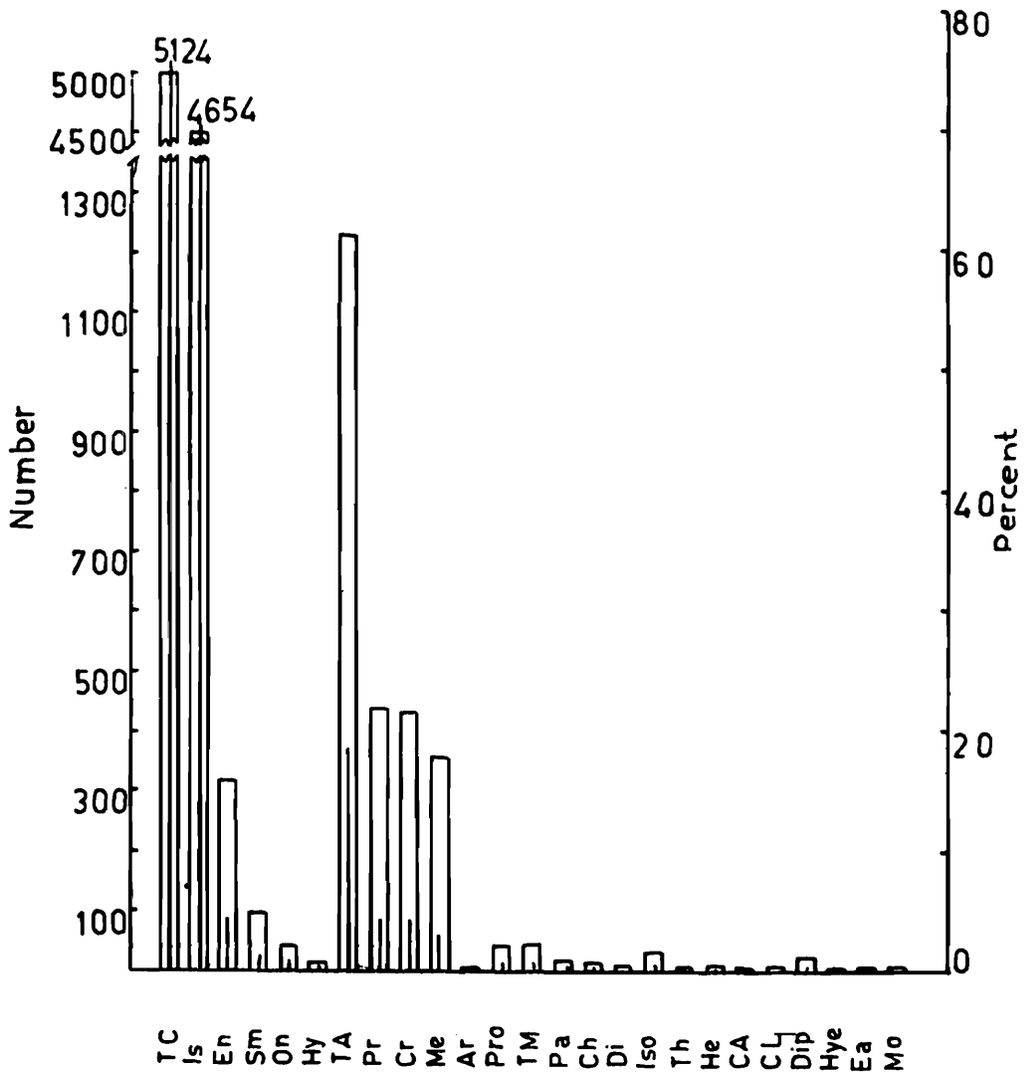


Figure 26b showing the qualitative and quantitative composition of the various microarthropods found in the medium mesh sized (1.0 mm^2) litter bags during the entire study period.

TC = Total Collembola; TM = Total Myriapoda; IS = Isotomidae; Ch = Chilopoda; En = Entomobryidae; Sy = Symphyla; Sm = Sminthuridae; Pa = Pauropoda; On = Onychiuridae; Di = Diplopoda; Hy = Hypogastruridae; Iso = Isopoda; TA = Total Acarina; Th = Thysanoptera; Pr = Prostigmata; He = Hemiptera; Cr = Cryptostigmata; CA = Coleoptera Adults; Me = Mesostigmata; DL = Diptera Larvae; Ar = Araneidae; Hy = Hymenoptera; Pro = Protura; Dic = Dictyoptera; Dip = Diplura; Ej = Earthworm juveniles; Mo = Molluscs

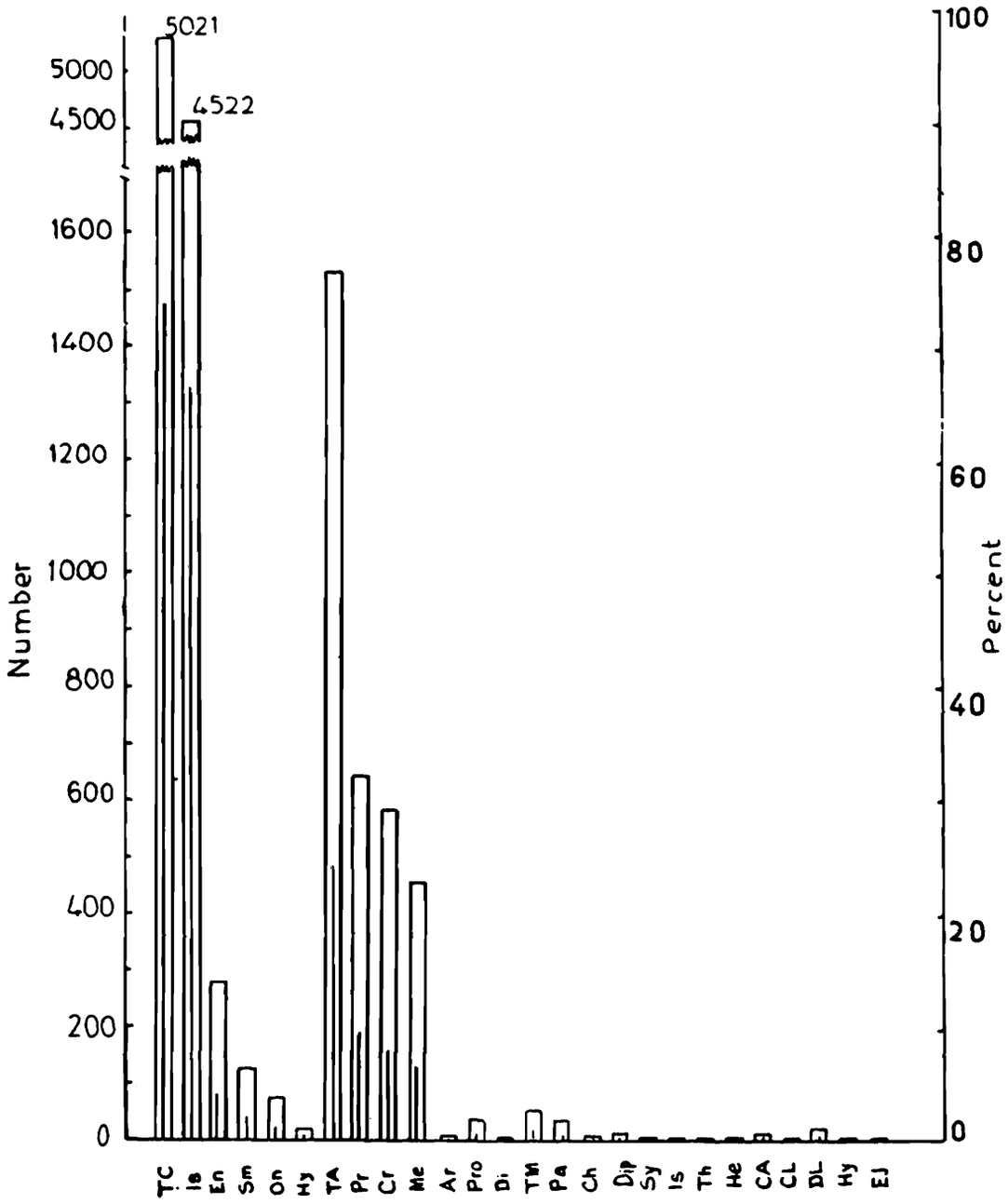


Figure 26c showing the qualitative and quantitative composition of the various microarthropods found in the minimum mesh sized (0.3 mm^2) litter bags during the entire study period.

TC = Total Collembola; TM = Total Myriapoda; IS = Isotomidae; Ch = Chilopoda;
En = Entomobryidae; Sy = Symphyla; Sm = Sminthuridae; Pa = Pauropoda;
On = Onychiuridae; Di = Diplopoda; Hy = Hypogastruridae; Iso = Isopoda;
TA = Total Acarina; Th = Thysanoptera; Pr = Prostigmata; He = Hemiptera;
Cr = Cryptostigmata; CA = Coleoptera Adults; Me = Mesostigmata;
DL = Diptera Larvae; Ar = Araneidae; Hy = Hymenoptera; Pro = Protura;
Dic = Dictyoptera; Dip = Diplura; Ej = Earthworm juveniles; Mo = Molluscs

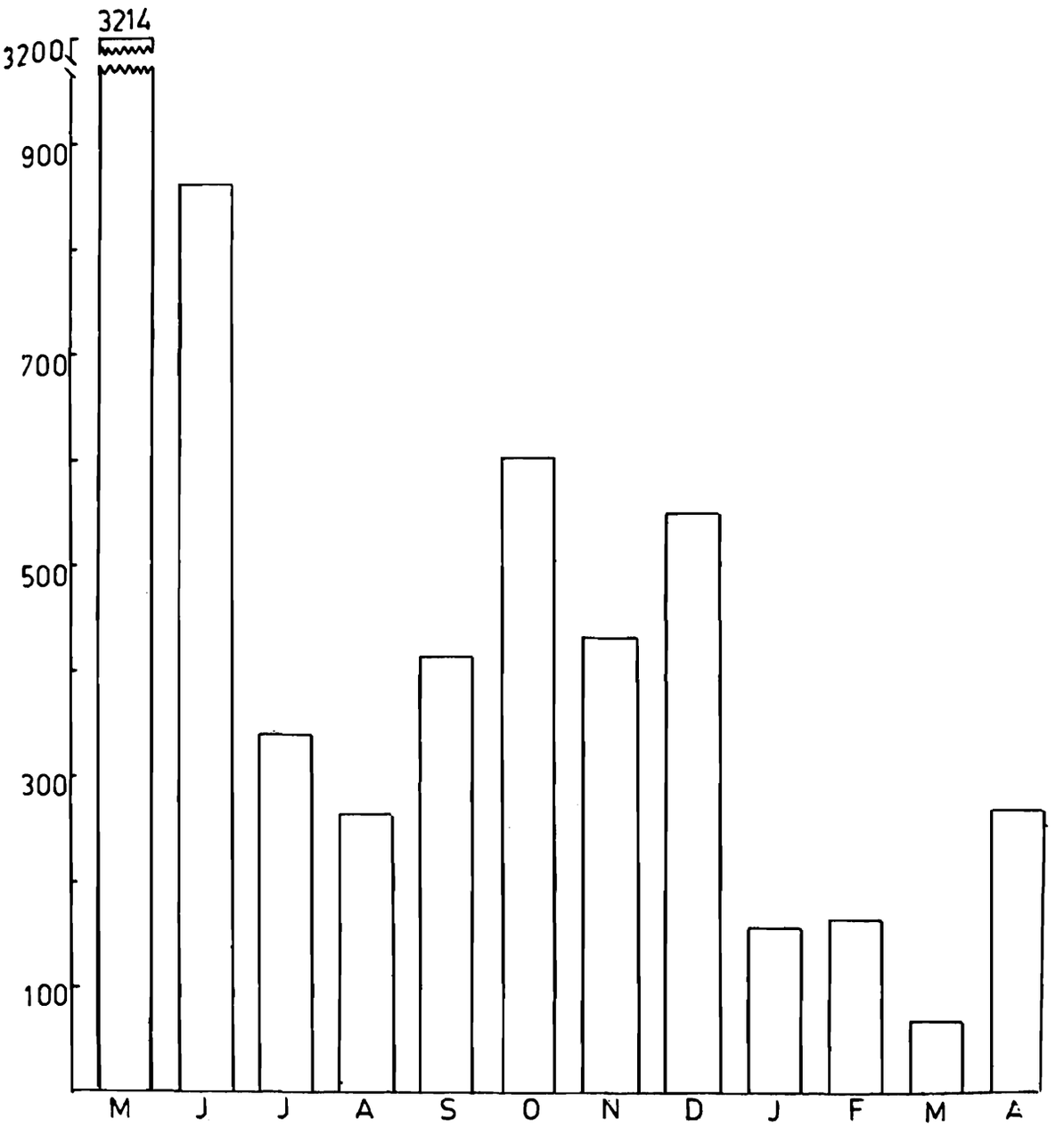


Figure 27a showing the seasonal fluctuation of total microarthropods found in the maximum mesh sized (3.0 mm^2) litter bags during the entire study period.

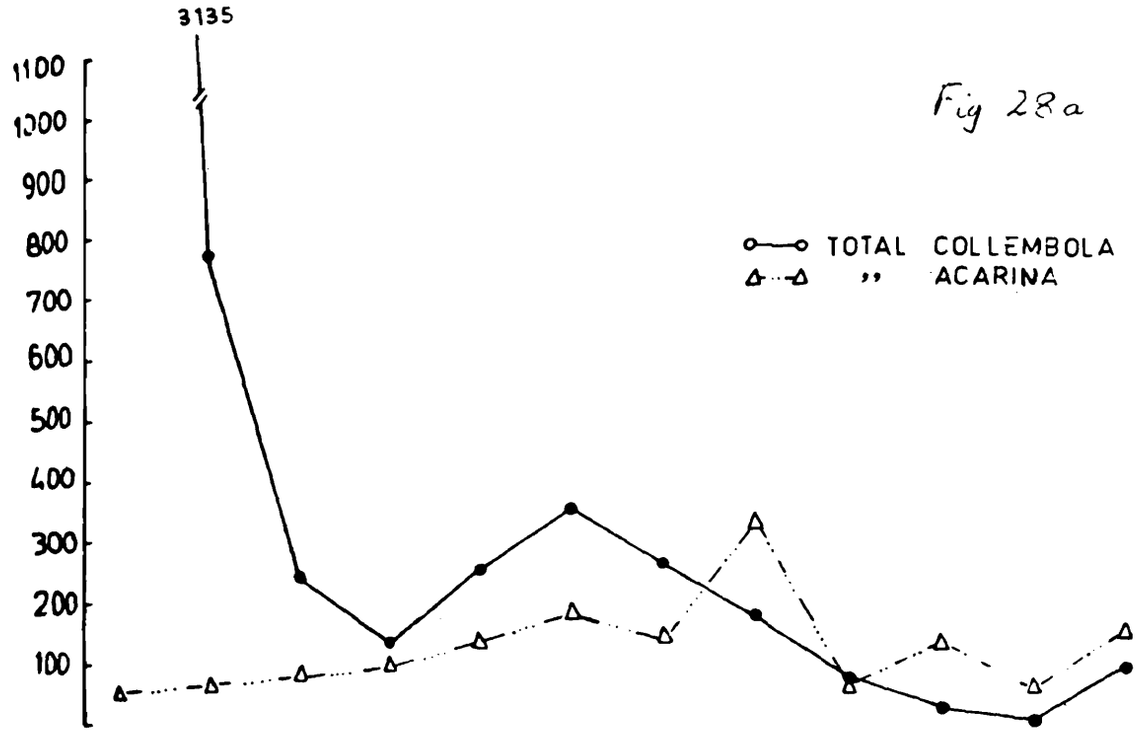


Figure 28a showing the seasonaal fluctuation of total Collembola and total Acarina found in the maximum mesh sized (3.0 mm^2) litter baags during the entie study period.

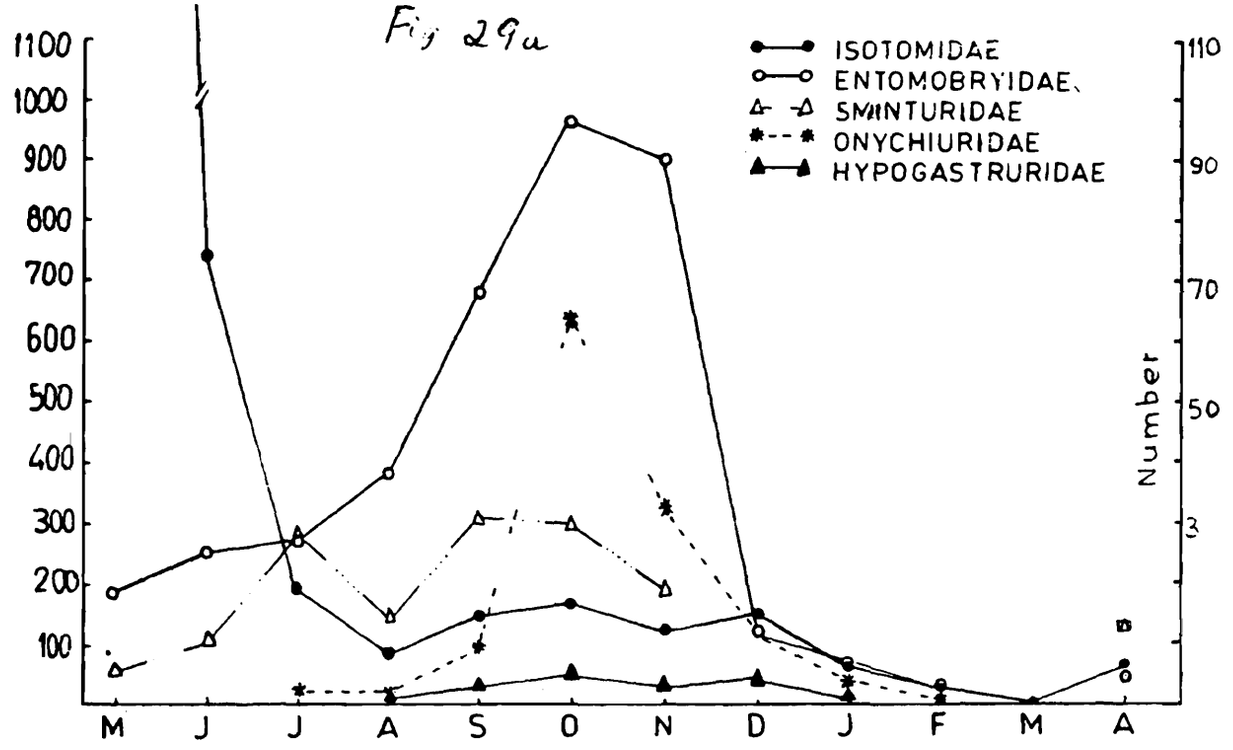


Figure 29a showing the seasonal fluctuation of Isotomidae, Entomobryidae, Sminthuridae, Onychiuridae and Hypogastruridae found in the maximum mesh sized (3.0 mm^2) litter baags during the entire study period.

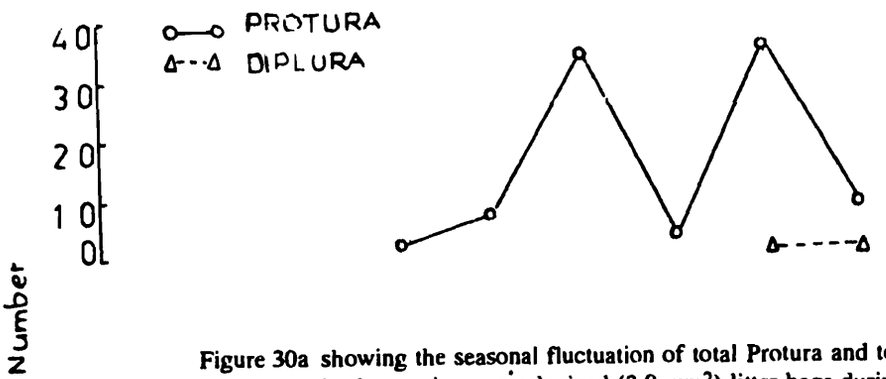


Figure 30a showing the seasonal fluctuation of total Protura and total Diplura found in the maximum mesh sized (3.0 mm^2) litter bags during the entire study period.

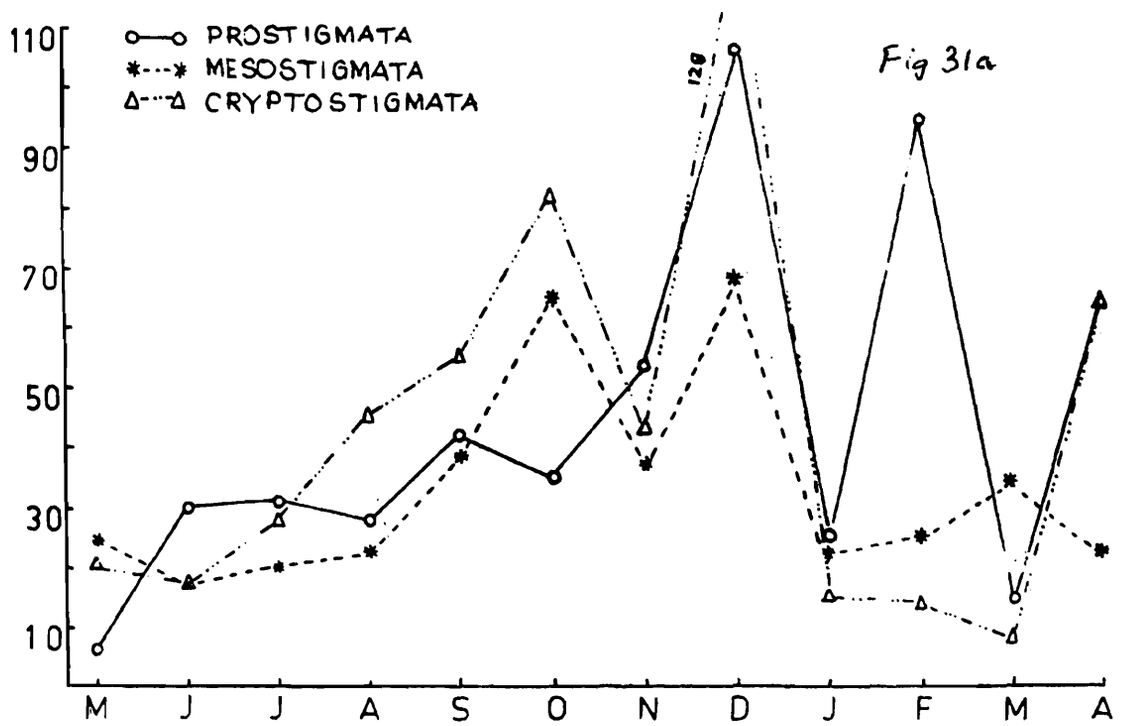


Figure 31a showing the seasonal fluctuation of Prostigmata, Mesostigmata and Cryptostigmata found in the maximum mesh sized (3.0 mm^2) litter bags during the entire study period.

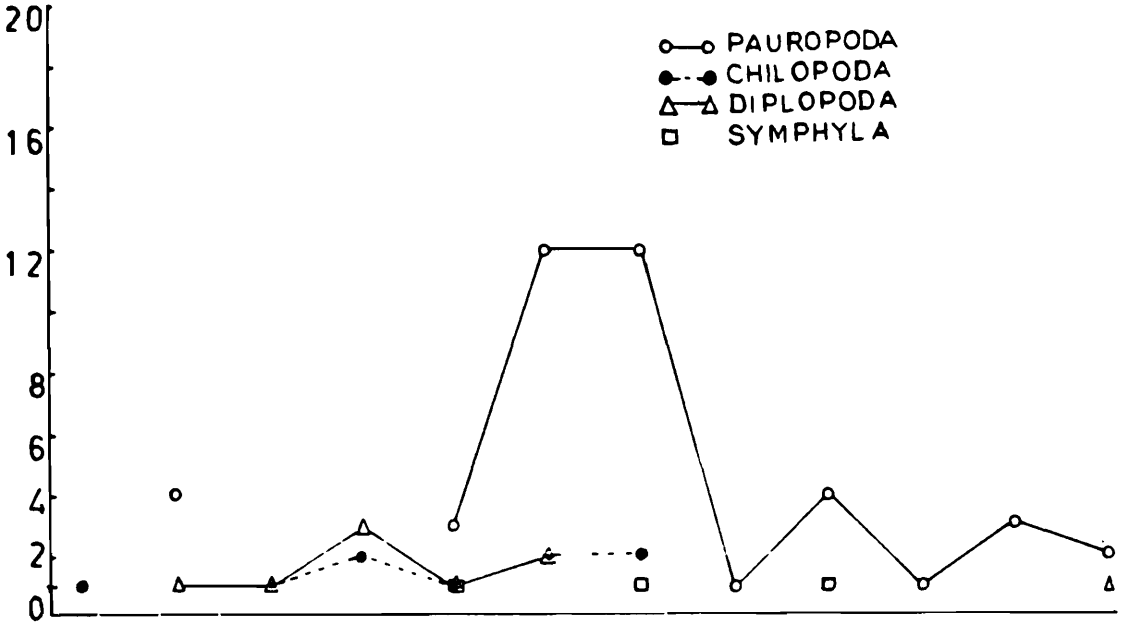


Figure 32a showing the seasonal fluctuation of Pauropoda, Diplopoda, Chilopoda and Symphyla found in the maximum mesh sized (3.0 mm^2) litter bags during the entire study period.

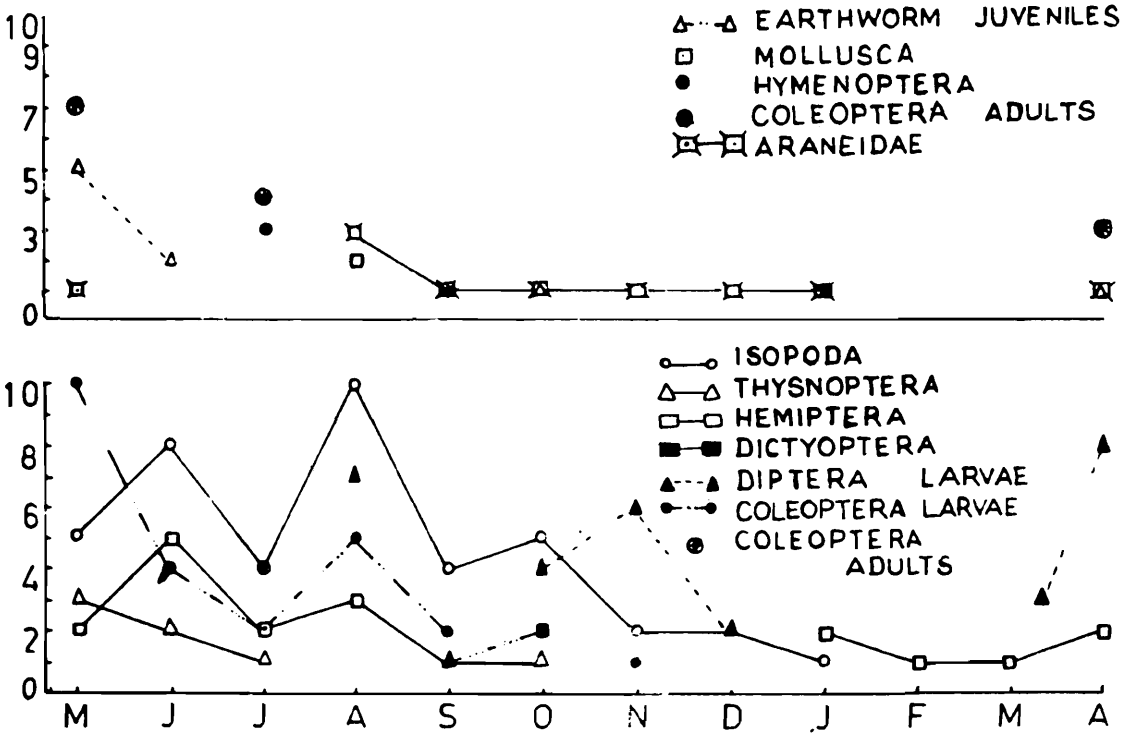


Figure 33a showing the seasonal fluctuation of Hymenoptera, Araneidae, Isopoda, Thysanoptera Hemiptera, Coleoptera adults and larvae, Diptera larvae, Dictyoptera, earthworm juveniles and mollusca found in the maximum mesh sized (3.0 mm^2) litter bags during the entire study period.

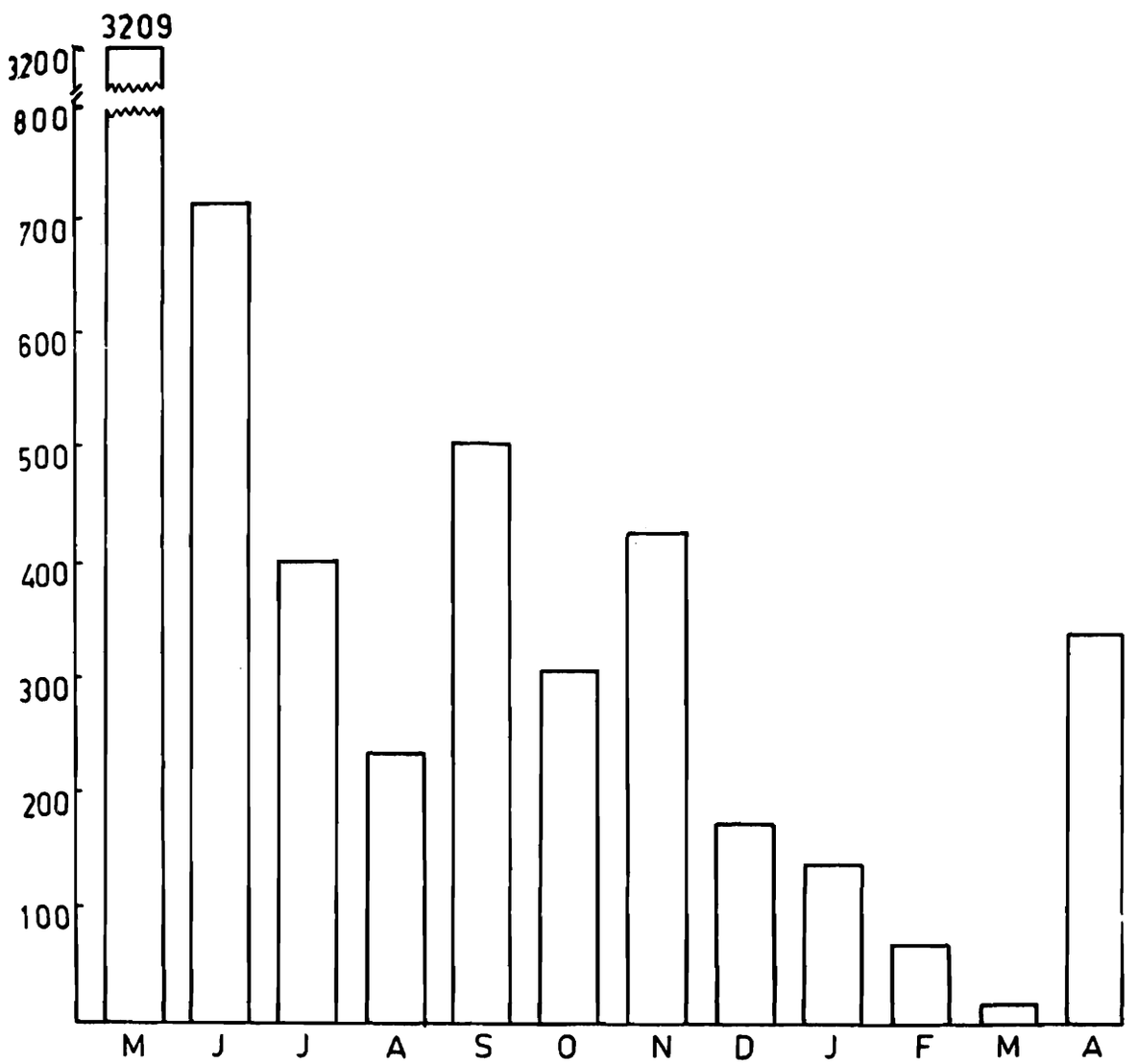


Figure 27b showing the seasonal fluctuation of total micro: arthropods found in the medium mesh sized bags (1.00 mm^2) during the entire study period.

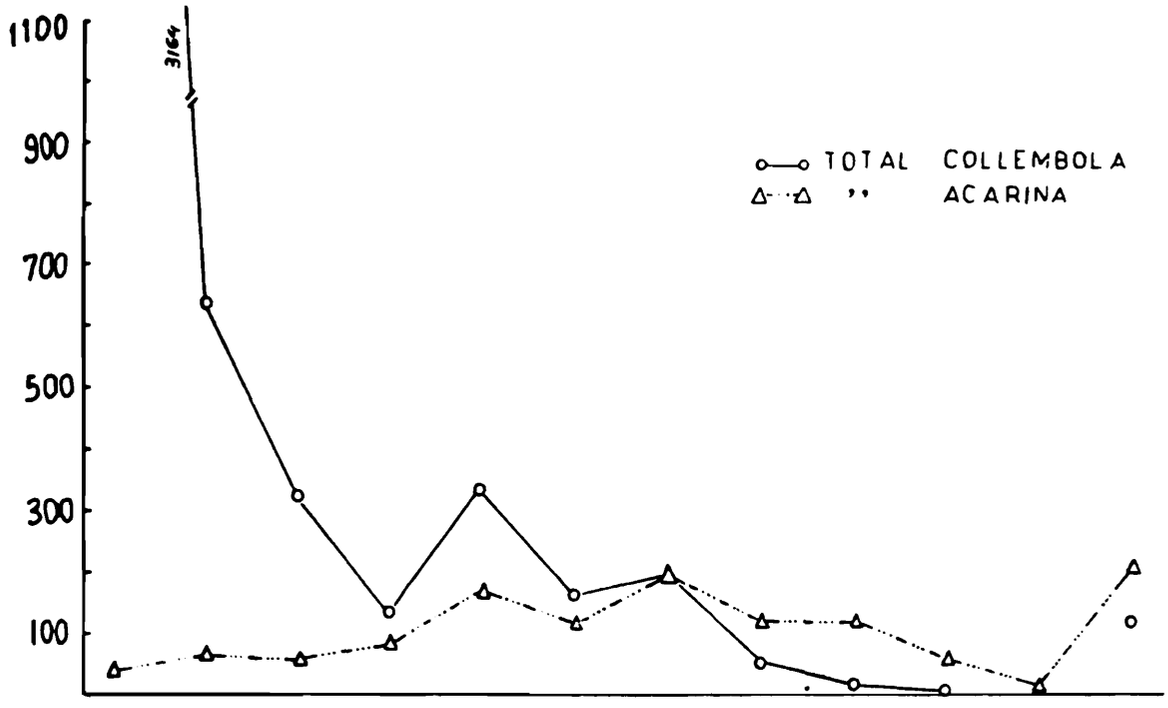


Figure 28b showing the seasonal fluctuation of total Collembola and total Acarina found in the medium mesh sized (1.0 mm^2) litter bags during the entire study period.

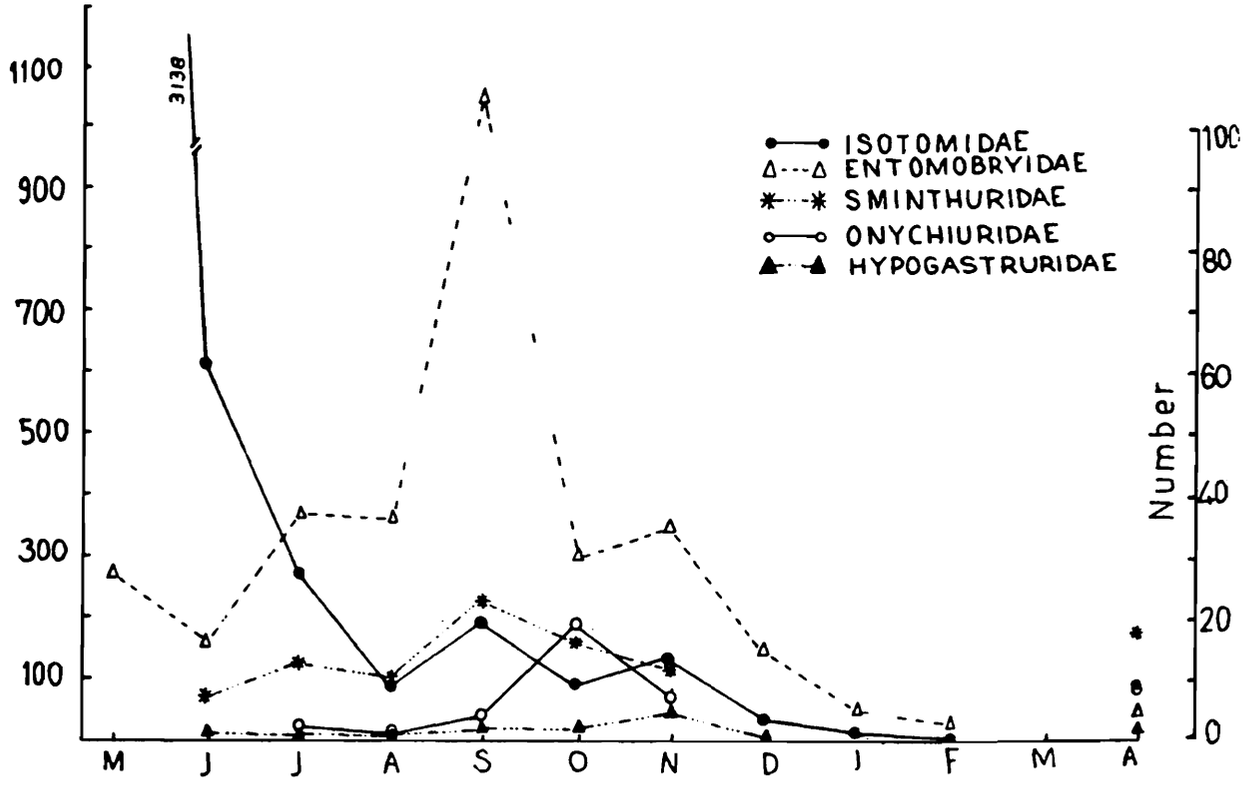


Figure 29b showing the seasonal fluctuation of Isotomidae, Entomobryidae, Sminthuridae, Onychiuridae and Hypogstruridae found in the medium mesh sized (1.0 mm^2) litter bags during the entire sttudy period.

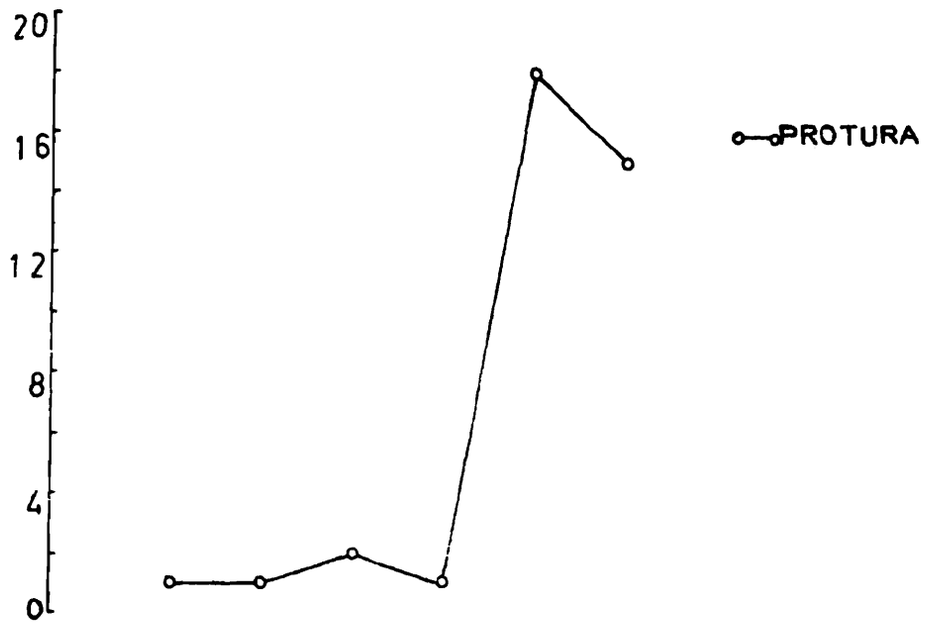


Figure 30b showing the seasonal fluctuation of total Protura found in the medium mesh sized (1.0 mm^2) litter bags during the entire study period.

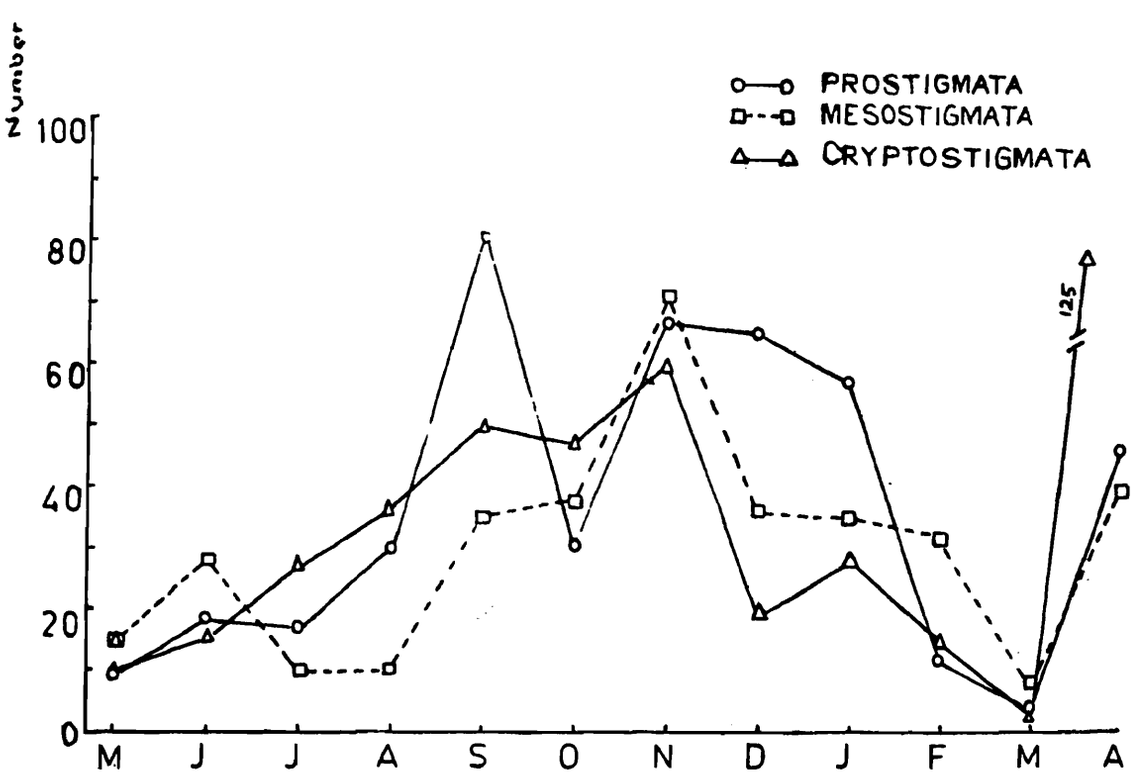


Figure 31b showing the seasonal fluctuation of Prostigmata, Mesostigmata and Cryptostigmata found in the medium mesh sized (1.0 mm^2) litter bags during the entire study period.

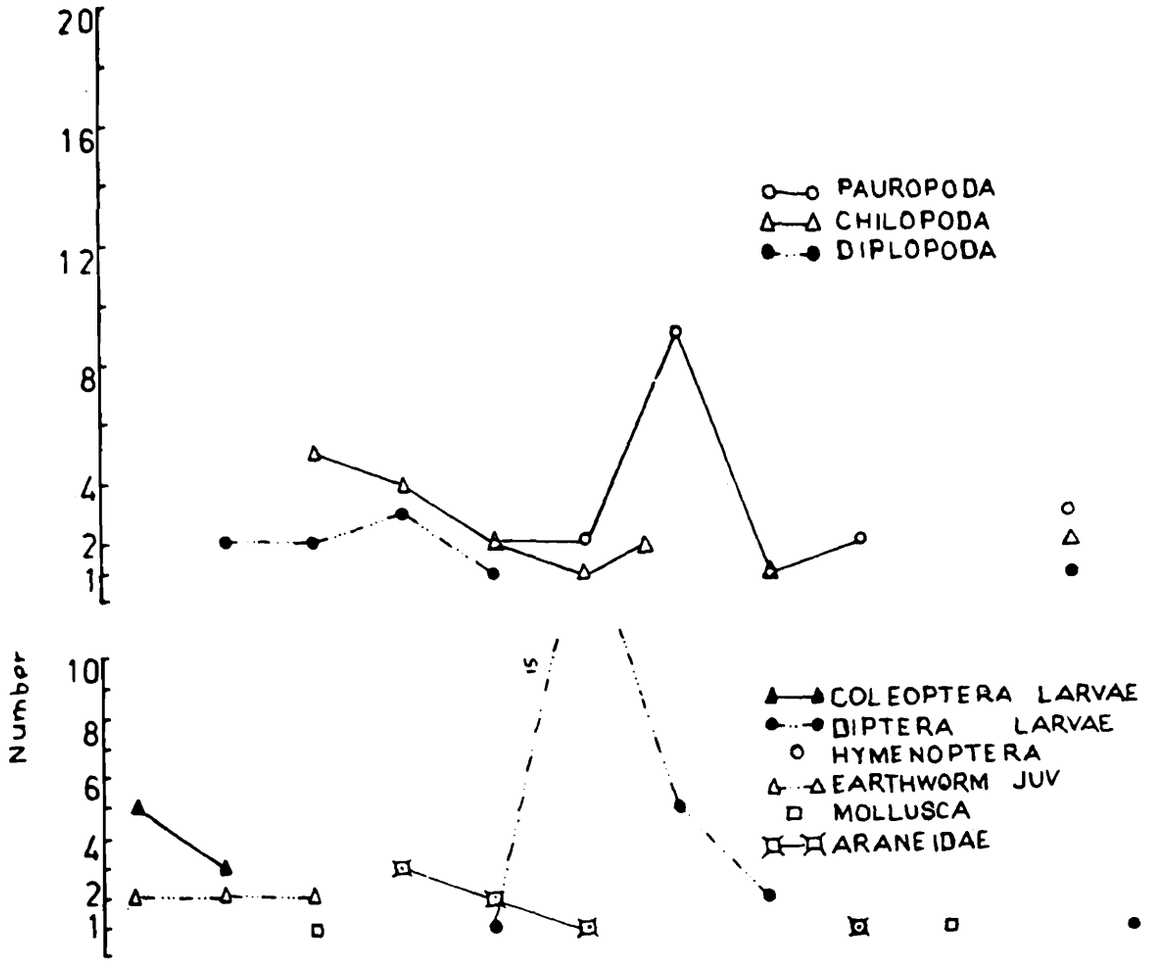


Figure 32b showing the seasonal fluctuation of Pauropoda, Diplopoda, Chilopoda and Symphyla found in the medium mesh sized (1.0 mm^2) litter bags during the entire study period.

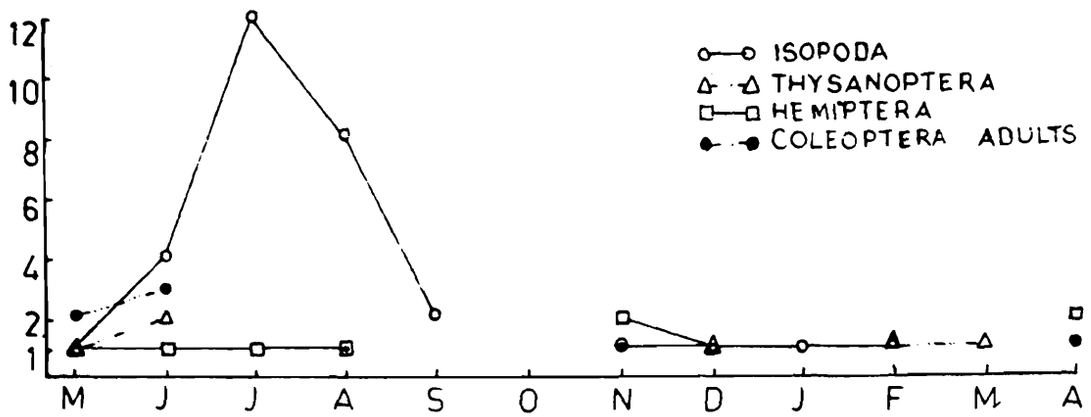


Figure 33b showing the seasonal fluctuation of Hymenoptera, Araneidae, Isopoda, Thysanoptera, Hemiptera, Coleoptera adults and larvae, Diptera larvae, Dictyoptera, earthworm juveniles and mollusca found in the medium mesh sized (1.0 mm^2) litter bags during the entire study period.

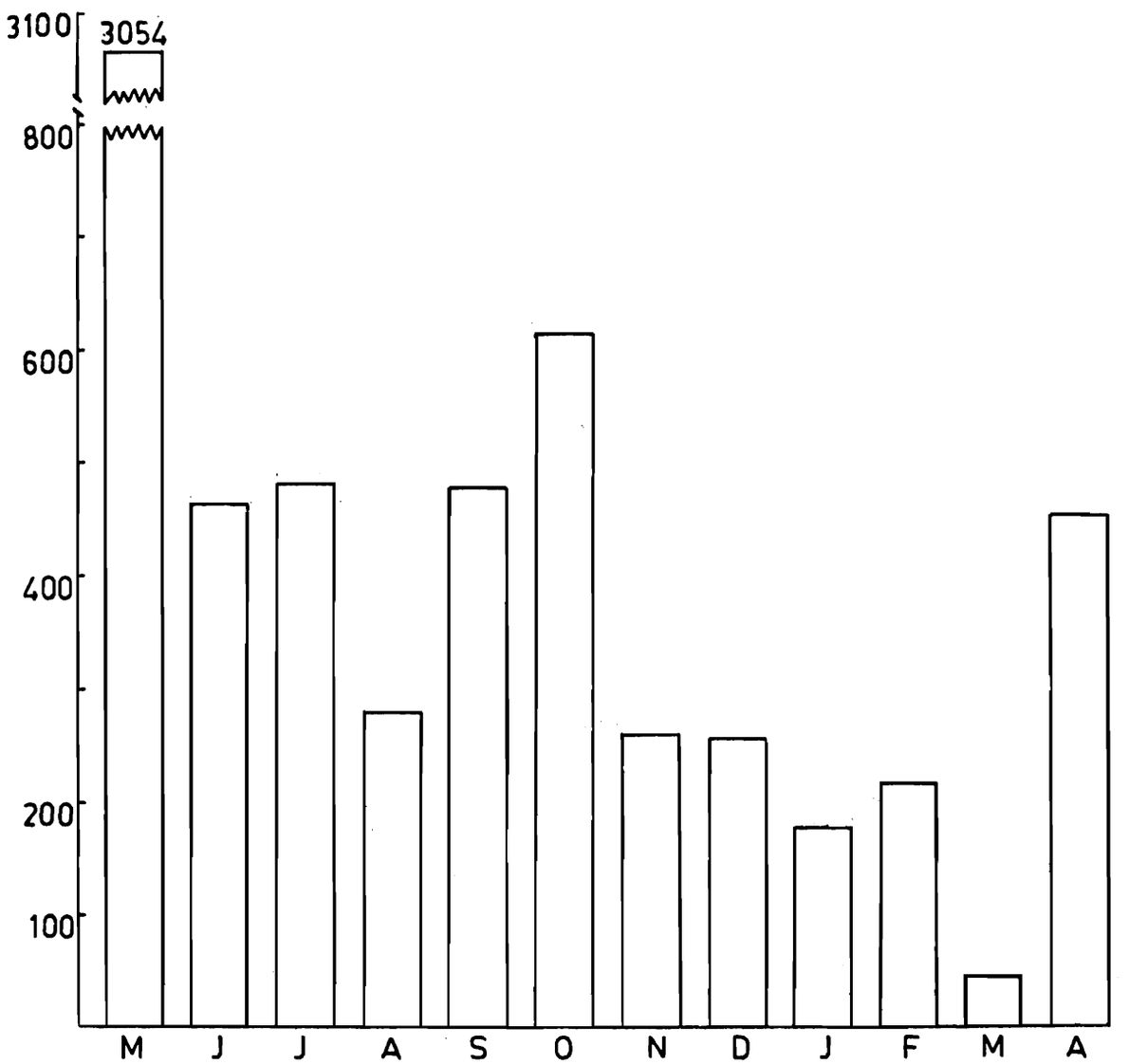


Figure 27c showing the seasonal fluctuation of total microarthropods found in the minimum mesh sized bags (0.3 mm^2) during the entire study period.

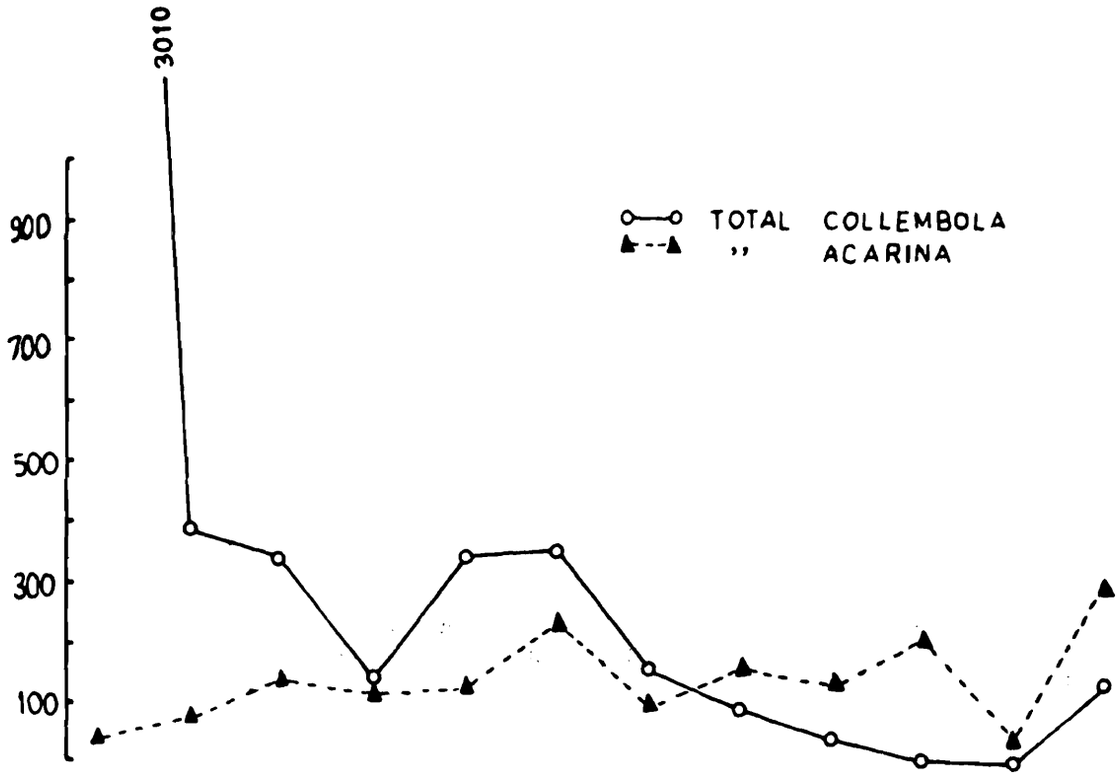


Figure 28c showing the seasonal fluctuation of total Collembola and total Acarina found in the minimum mesh sized (0.3 mm^2) litter bags during the entire study period.

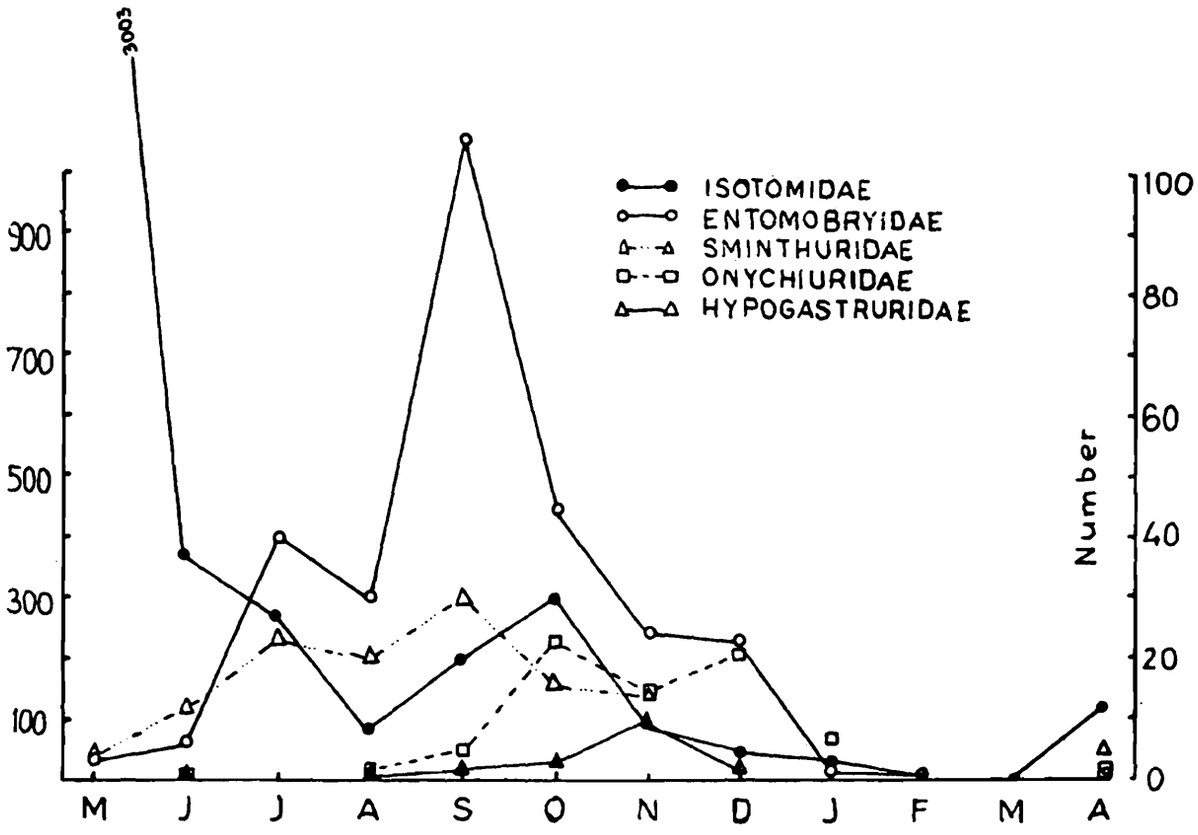


Figure 29c showing the seasonal fluctuation of Isotomidae, Entomobryidae, Sminthuridae, Onychiuridae and Hypogastruridae found in the minimum mesh sized (0.3 mm^2) litter bags during the entire study period.

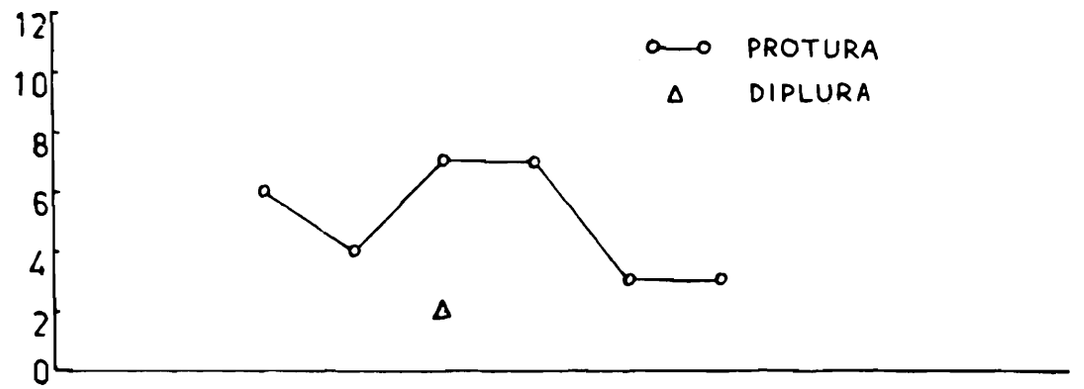


Figure 30c showing the seasonal fluctuation of toal Protura and total Diplura found in the minimum mesh sized (0.1 mm^2) litter bags during the entire study period.

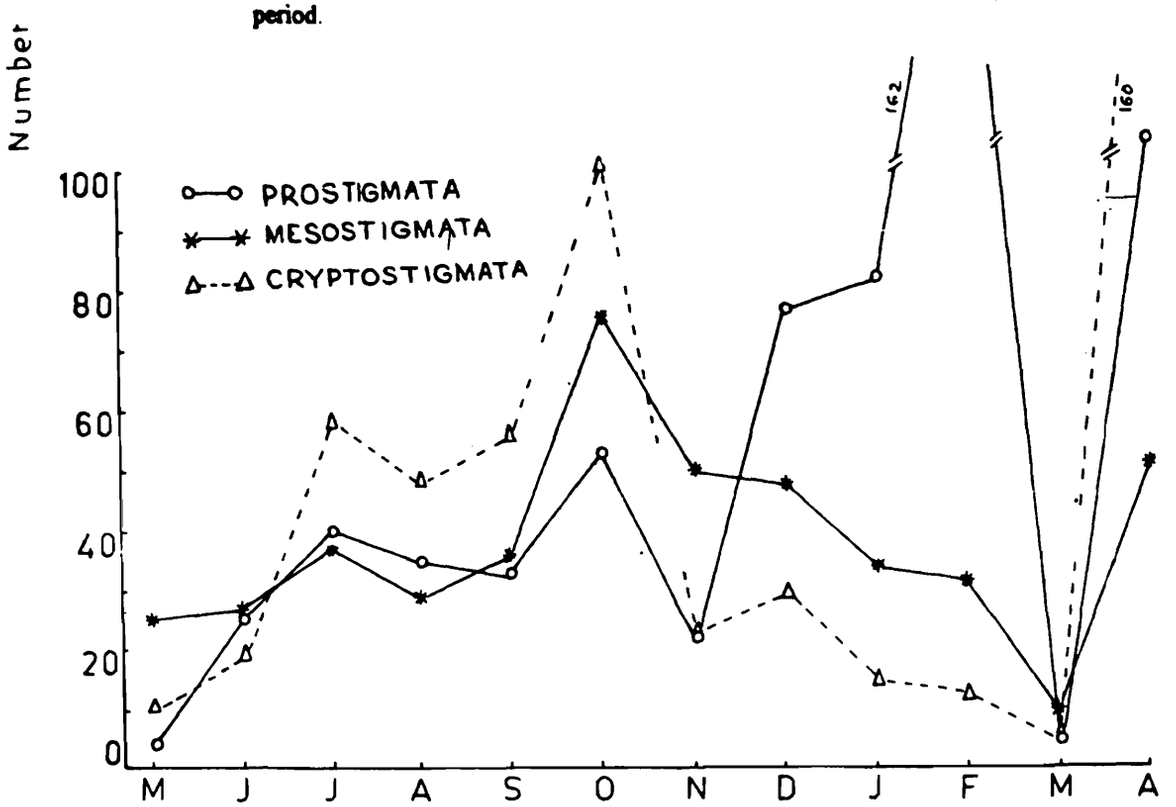


Figure 31c showing the seasonal fluctuation of Prostigmata, Mesostigmata and Cryptostigmata found in the minimum mesh sized (0.1 mm^2) litter bags during the entire study period.

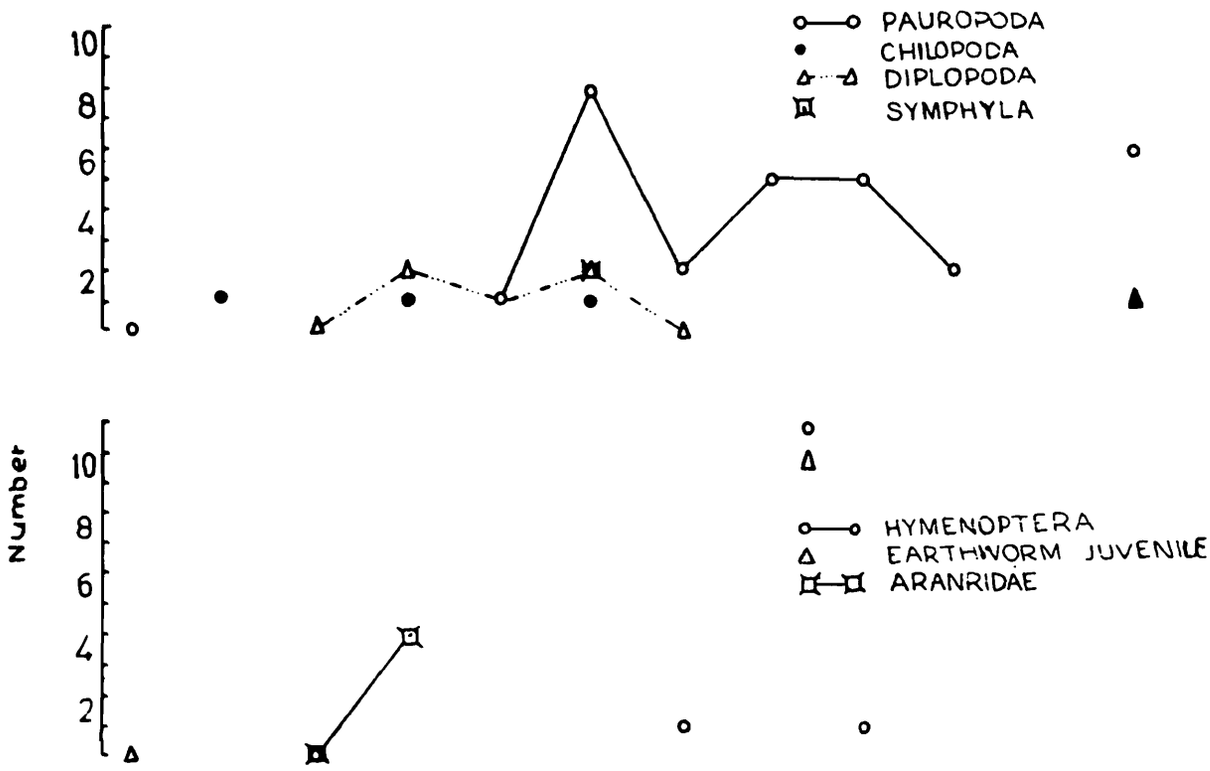


Figure 32c showing the seasonal fluctuation of Pauropda, Diplopoda, Chilopoda and Symphyla found in the minimum mesh sized (0.3 mm²) litter bags during the entire study period.

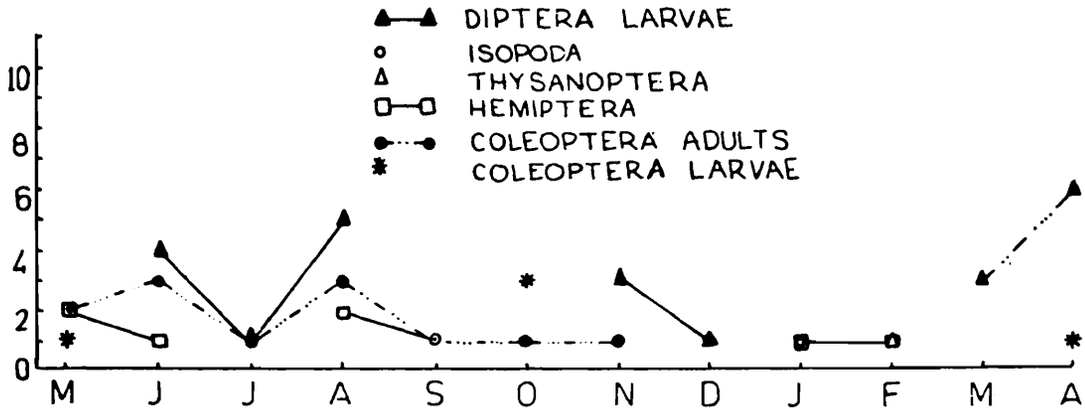


Figure 33c showing the seasonal fluctuation of Hymenoptera, Araneidae, Isopoda, Thysanoptera, Hemiptera, Coleoptera adults and larvae, Dipera larvae, Dictyoptera, earthworm juveniles and mollusca found in the minimum mesh sized (0.3 mm²) litter bags during the entire study period.

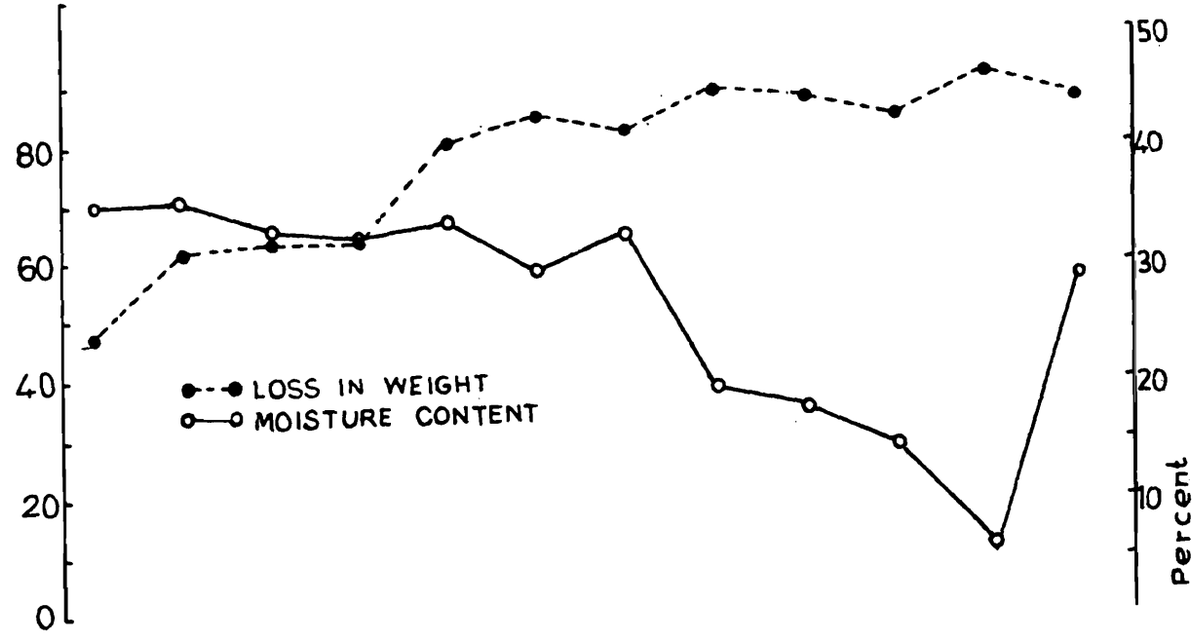


Figure 34a showing the seasonal fluctuation of various physical factors of litter moisture content and weight loss in percent in the maximum mesh sized (3.0 mm^2) litter bags during the entire study period.

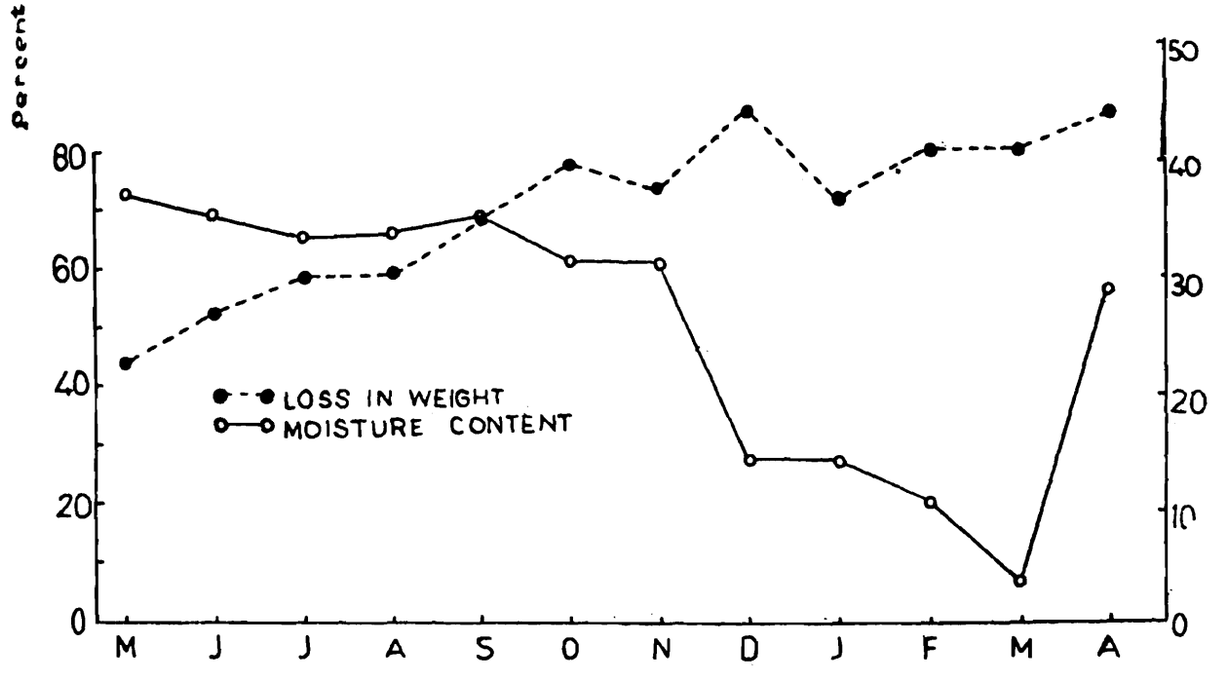
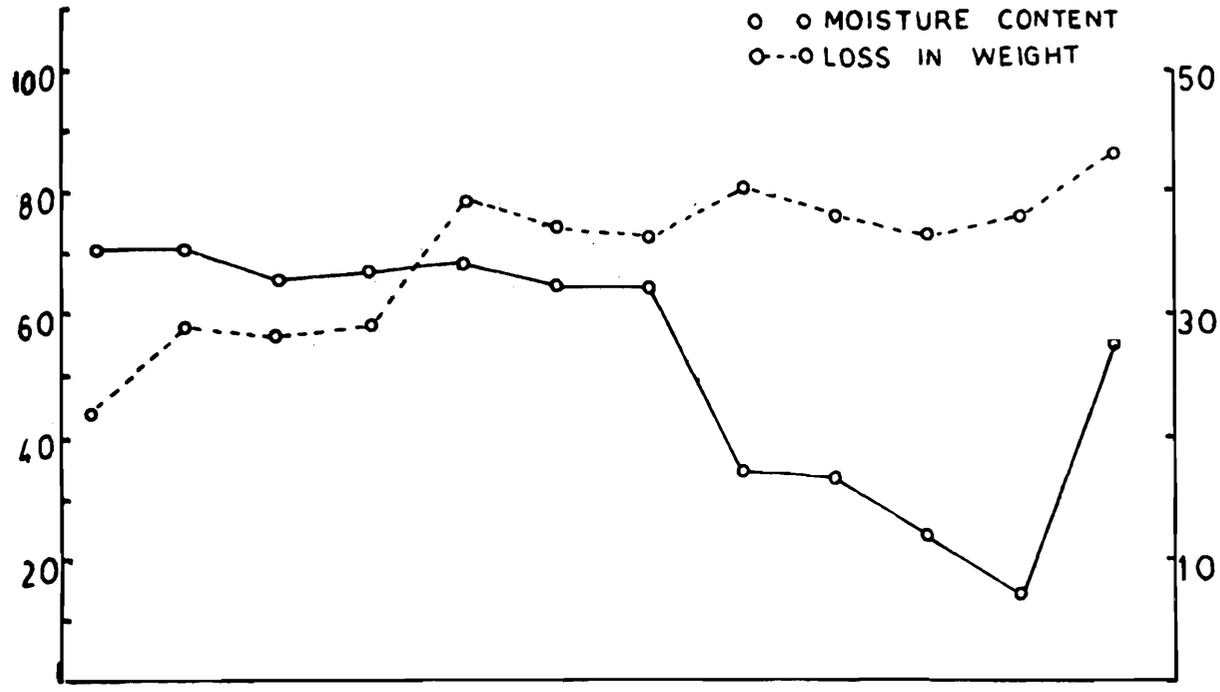


Figure 34b showing the seasonal fluctuation of various physical factors of litter moisture content and weight loss in percent in the medium mesh sized (1.0 mm^2) litter bags during the entire study period.



Fugvre 34c showing the seasonal fluctuation of various physical factors of litter - moisture content and weight loss in percent in the minimum mesh sized (0.3 mm^2) litter bags during the entire study period.

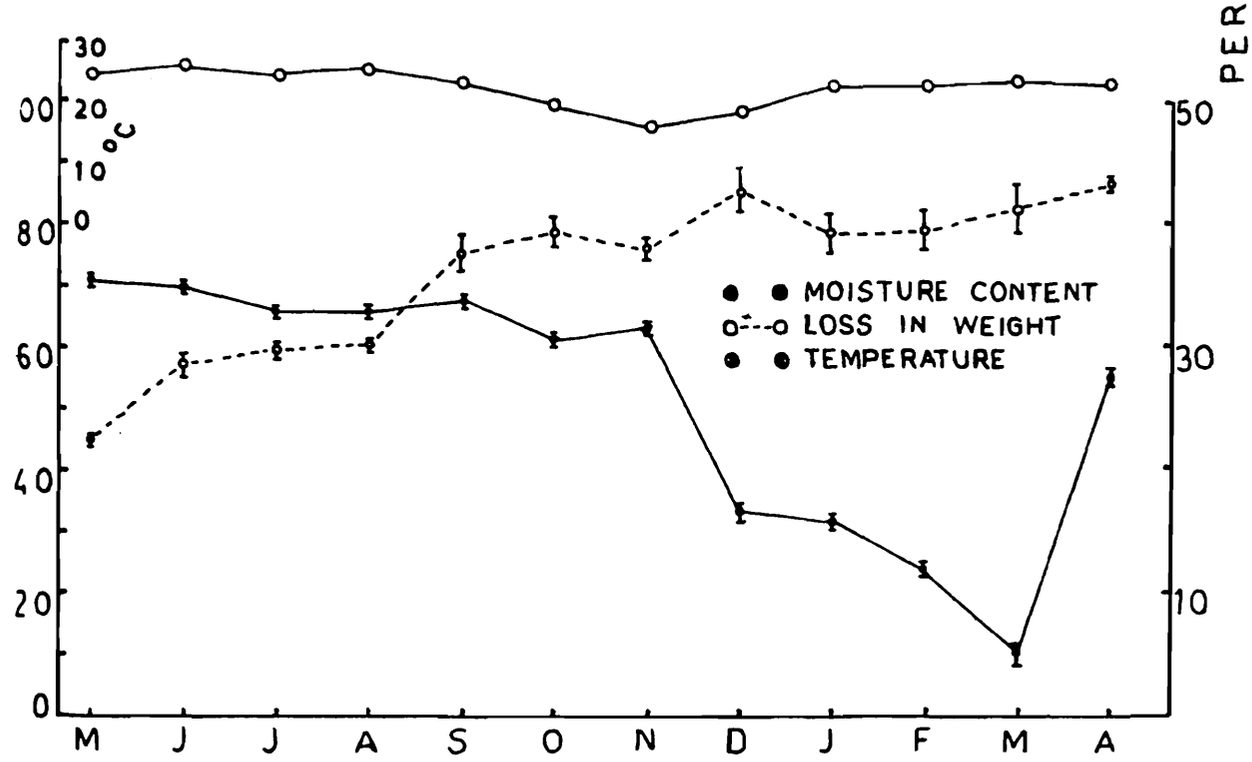


Figure 34d showing the seasonal fluctuation of various physical factors of litter moisture content and weight loss in percent as mean in all the three mesh sized bags.

Prostigmata, Cryptogastigmata, Mesostigmata, Diplopoda and Hymenoptera. The groups Diplura and Symphyla were maximum in both the maximum and minimum mesh sized bags, as they were exactly the same number in both the bags. Similarly Araneidae was minimum in medium and maximum mesh sized bags and Diplopoda minimum in maximum and medium mesh sized bags, while the group which was recorded minimum in maximum mesh sized bags were Chilopoda only. Those which were minimum in medium mesh size bags were Sminthuridae, Hypogastruridae, Prostigmata, Cryptostigmata, Mesostigmata, Pauropoda, Symphyla, Coleoptera adults and Hymenoptera. Those which represented minimum number in minimum mesh sized bags, were Entomobryidae, Isotomidae, Protura, Chilopoda, Isopoda, Thysanoptera, Hemiptera, Coleoptera larvae, Diptera larvae and earthworm juveniles (Table VIII).

Maximum mesh sized bags

The seasonal abundance of the total litter microarthropods in the maximum mesh sized bags is presented in Fig. 27a. They ranged from 69 to 3214 in numbers in the different seasons. The maximum number was recorded in the month of May and gradually decreased till August and thereafter rose again till it reached a small peak in October. It immediately fell in November to again rise in December after which it declined till it reached the minimum in the month of March in the following year. Collembola and Acarina were the major dominant groups and collectively ranged from 60 to 3185 in numbers and followed the same trend in fluctuation as that of the total microarthropods (Fig. 28a).

The total Collembola varied between 2 and 3135 numbers during the different months and were recorded maximum in May, 1977 and minimum in March of the second year with a small peak in October. Isotomidae the most dominant group of Collembola ranged from 2 to 3113 numbers and were maximum in May and minimum in March. They showed two small peaks of increase during the months of October and December. The family Entomobryidae ranged from 0 to 96 individuals and represented a gradual increase from May reaching a peak in October and then gradually decreased to nil in March of the second year of study. Sminthuridae ranged from 0 to 31 individuals, the maximum encountered were in the months of July, September and October and were completely absent from December to March. The family Onychiuridae ranged from 0 to 64 numbers, the maximum occurring in October and recorded nil during May and June and March. The family Hypogastruridae ranged from 0 to 5 in numbers, being maximum in October and December and were completely absent during May to July and from February to April of the second cycle (Fig. 29a).

The group Protura ranged from 0 to 35 individuals the maximum being recorded in October and December and were nil during May to July of the first year and during February and March of the second year. Diplura were completely absent throughout the annual cycle except during December and January (Fig. 30a).

The second dominant group Acarina ranged from 50 to 331 in numbers over the seasons, the maximum being recorded in December and minimum in May. It had small peaks of increase during October and February and April, (Fig. 28a). Prostigmata the dominant group among Acarina, ranged between 6 and 106 individuals, the maximum being recorded in December and minimum in May. There was another large peak of increased abundance during February. The group Cryptostigmata

ranged from 8 to 127 numbers, the maximum being recorded in December and minimum in March. There was a second peak of abundance during October. Mesostigmata ranged between 17 to 68 numbers, being maximum in December and minimum in June (Fig. 31a). The monthly variation in the Araneidae number was negligible, the range being 1 to 3 in numbers. The maximum was recorded in August (Fig. 33a).

The group Myriapoda ranged from 1 to 16 individuals, the maximum being recorded was in October and November and minimum in May and December and February of the next year. Pauropoda was the dominant among Myriapoda and ranged from 0 to 12 in numbers, the maximum being recorded in October and November. They were completely absent during May, July and August. The groups Symphyla, Chilopoda and Diplopoda were recorded in very negligible numbers, the range being 0 to 1, 0 to 2 and 0 to 3 respectively. Maximum numbers of Diplopoda were recorded in August, being absent during May, November, December of the first year and January, February and March of the second. Chilopoda were maximum during August, October and November, and absent during June and December of the first year and January and April of the second year. The Symphyla were completely absent throughout the annual cycle except in September and November and January (Fig. 32a).

The group Isopoda ranged from 0 to 10 in numbers and were maximum in August and were completely absent from February to April of the second year. Thysanoptera and Hemiptera had a range of 0-3 and 0-5 individuals respectively. Thysanoptera were recorded maximum in May and were completely absent in August, November and December of the first year and from January to April of the second. Hemiptera were recorded maximum during June and were nil from October to December and January of the next year. The Coleoptera adults and larvae ranged between 0 to 7 and 0 to 10 respectively. They were both maximum during May and the adults were absent from June and August and October to December of the first year and February and March of the second. The larvae were absent during October and December, January and March. The Dipteran larvae number ranged from 0 to 8, the maximum during August of the first year and April of the second and were completely absent from May to July, September and January and February of the following year. Dictyoptera were absent during the entire annual cycle except during September and October. The juvenile earthworms ranged from 0 to 5 in numbers, the maximum recorded in May and were completely absent from July to September, November and December and in the next year from January to March. The molluscans were recorded in very negligible numbers only in May and August (Fig. 33a).

Medium mesh sized bags

The seasonal abundance of total litter microarthropods from medium mesh sized bags is presented in Fig. 27b which revealed that the microarthropod groups reflected more or less a similar type of fluctuation as that in the maximum mesh sized bags. The total microarthropods ranged from 19 to 3209 numbers, the maximum recorded in the month of May and minimum in March. They further showed two smaller peaks of abundance in the months of September and November. Collembola and Acarina together ranged between 15 and 3198 and followed the trend in fluctuation of total litter microarthropods for these mesh sized bags (Fig. 28b).

The total Collembolan numbers ranged from 0 to 3165 and were recorded maximum in May with a gradual decrease to nil in March of the following year. In between it had two small peaks of increase in September and November. The family Isotomidae ranged from 0 to 3138 numbers and was maximum in May and absent in March of the next year. They had similar peaks of abundance like that of total microarthropods and Collembola. The family Entomobryidae ranged from 0 to 105 individuals. From June, the number gradually increased reaching a peak in September and gradually decreased to nil in March with a small peak during November. The family Sminthuridae ranged from 0 to 23 in numbers, the maximum being recorded in September and completely absent in May and from December to March. The family Onychiuridae ranged from 0 to 19 in numbers, maximum being in October and completely absent during May and June and from December to March. The family Hypogastruridae ranged from 0 to 5 in numbers, the maximum recorded being in November and completely absent in May and from January to March (Fig. 29b).

The group Protura ranged from 0 to 18 numbers, maximum being in the month of October and absent in May and from December to March. The Diplura were completely absent throughout the annual cycle (Fig. 30b).

The total Acarina ranged from 15 to 211 numbers and from May onwards it gradually increased till September and then decreased in October. It reached the peak again in November. Then it gradually decreased to minimum in March and increased to maximum in April (Fig. 28b). The number of Prostigmata ranged from 4 to 81, the maximum being in the month of September and minimum in March. The number of Cryptostigmata ranged from 3 to 125. They gradually increased from May and with a small peak in November, decreased to minimum in March with a sudden range of increase to maximum in April. The number of Mesostigmatid mites ranged from 8 to 71, the maximum was during November and minimum in March with a small peak in the following month (Fig. 31b). The range in the number of Araneidae was 0 to 3, the maximum being recorded in August and were absent during May to July and November and December of the first year and February and March of the second (Fig. 33b).

The total Myriapoda ranged from 0 to 11 individuals. They were maximum in numbers during November and absent during May and February. In the group Chilopoda, the numbers ranged from 0 to 5, the maximum being recorded in July. They were entirely absent during May, June and December of the first year and February and March of the second. The Diplopoda number ranged from 0 to 3, the maximum in August and recorded nil during May and from October to March. The group Symphyla were completely absent. Pauropoda ranged from 0 to 9 in numbers. The maximum was recorded in November and were recorded nil from May to August and February and thereafter in the next year in February and April (Fig. 32b).

The number of Isopoda ranged from 0 to 11 in numbers, the maximum encountered were in July. This group was nil in October and during March and April. Both the groups Thysanoptera and Hemiptera ranged from 0 to 2 in numbers, the former being maximum in June and absent during July to November and January and April of the second year and absent during September, October and January to March of both the years. The Coleoptera adults and larvae ranged from 0 to 3 and 0 to 5 respectively. The adults were maximum in June and absent during July, September and December

and from January to March of the next year. The larvae were maximum in May and recorded nil from July to April. The Diptera larvae numbers ranged from 0 to 15, the maximum being recorded in October and absent completely during May to August and from January to March of the second year. The Juvenile earthworms were only two in numbers every month from May to July and absent throughout the remaining annual cycle. Mollusca were nil for most of the period, except in July and February when they represented only one individual each time (Fig. 33b).

Minimum mesh sized bags

The seasonal abundance of total litter microarthropods from minimum mesh sized bags is presented in Fig. 27c, which depicted that they had more or less a similar pattern in seasonal fluctuation to those seen in the maximum and medium mesh sized bags. The total microarthropods ranged from 48 to 3054 in numbers, the maximum being in May and minimum in March of the following year with a small peak of abundance in October of the first year. The groups Collembola and Acarina collectively represented 42 to 3049 in numbers (Fig. 28c). They also showed the same type of seasonal variation as recorded in that of the medium mesh sized bags.

The range in total Collembola numbers was 2 to 3010, the maximum being in May and minimum in March of the second year with a small peak of increase in October of the first year. The family Isotomidae numbers ranged from 2 to 3003. It was encountered maximum in May and minimum in March with a small peak of abundance during October. The family Entomobryidae ranged from 0 to 105. It gradually increased from May till it reached a small peak in July, fell and then reached the maximum in September and thereafter decreased gradually to nil in March. The range for the family Sminthuridae was 0 to 30, the maximum being in September. They were completely absent from December to March of the second cycle. The family Onychiuridae and Hypogastruridae ranged from 0 to 23 and 0 to 10 respectively. The maximum number of Onychiuridae was recorded in October while the maximum number of Hypogastruridae was recorded in November. They were both recorded nil during May and July and February and March of the following cycle (Fig. 29c).

The number of Protura ranged from 0 to 7, the maximum recorded being in September and October of the first and April of the second cycle. They were completely absent during May and June in the first and from January to March in the second cycle. The Diplura were recorded only in September, when they were two in number (Fig. 30c).

The group Acarina ranged from 39 to 299 in numbers, the minimum being in May and maximum in April of the next year. Besides it showed two smaller peaks of abundance during October and February of the following year (Fig. 28c). The sub-order Prostigmata ranged from 4 to 162 in numbers, the minimum being recorded in May and maximum in February. besides, they showed small peaks of abundance in July, October and April. Cryptostigmata ranged from 5 to 160 in numbers, the maximum being recorded in April, and the minimum in March, with a small peak of increase in October. Mesostigmata ranged from 10 to 76 numbers, being maximum in October, and minimum in March with a sudden increase forming a small peak in April (Fig. 31c). The group Araneidae ranged from 0 to 5 numbers. The maximum was encountered during August and were absent from May, June and September to December and from January, February and April of the next

year (Fig. 33c)

The total Myriapoda ranged from 0 to 17 individuals, maximum being recorded in October with a small peak in April and recorded nil in March. The number of Pauropoda ranged from 0 to 9, maximum being recorded in October and recorded nil during June to August and March. The Diplopoda numbers ranged from 0 to 3, the maximum being recorded in August and October and nil during May and June and from December to March. The number of Chilopoda recorded each time was only two in number during June, August and October and April. Symphyla were recorded 3 in number only in October and absent throughout (Fig. 32c).

The group Isopoda was recorded only one each time in July and September and January. Thysanoptera was recorded only in December and February as one individual each time. The group Hemiptera ranged from 0 to 2 in numbers, maximum in May and August and were nil in July and from October to January and April. Both Coleoptera adults and larvae ranged from 0 to 3 in numbers, the maximum recorded being in June and August for adults and in October for larvae. Adults were absent during December to March and larvae were absent from June to September and November and from January to March of the next year. The range of Diptera larvae was from 0 to 6 numbers, the maximum being recorded in April. A second peak of increase was recorded in August and were absent during May, September and October and January and February. Hymenoptera was recorded two each time in November and January. A juvenile earthworm was recorded only once in May as one individual (Fig. 33c).

Physical Factors

The physical factors recorded during the present investigation were temperature, moisture and weight loss in the litter bags. The seasonal variation in temperature is presented in Fig. 34d. It ranged from 16°C to 25.5°C. The maximum temperature was recorded in June and minimum in November. The total mean moisture content and mean weight loss for all bags is presented in Fig. 34d. The mean moisture content ranged from 10.80% ± 1.55 to 70.6% ± 1.01, the maximum recorded being in May and minimum in March of the next year. The mean percentage loss in weight of litter ranged from 22.45% ± 0.19 to 43.56% ± 0.66, the former being in May and the latter in April of the recent year. The annual average rate of decomposition was 36.09%.

The percentage of moisture content and weight loss of litter in the maximum mesh sized litter bags are presented in Fig. 34a. Moisture content ranged from 10.27 to 69.63%, the highest being recorded in June while lowest in March. The percentage loss in weight of litter ranged from 23.3% to 43.75%, the lowest being in the month of May and the highest in the month of April. The annual average rate of decomposition was 38.25%.

Moisture content and loss in litter weight for the medium mesh sized litter bags are presented in Fig. 34b. The range of the moisture content was between 7.56% and 73.00%. The highest recorded was in May and minimum in March of the next year. The weight loss in the litter bags ranged from 22.16% to 43.75%, the minimum recorded during May and the maximum in April. The annual average rate of decomposition in these bags was 35.34%.

The percentage moisture content and loss in litter weight for the minimum mesh sized bags are

presented in Fig. 34c. The range of moisture content was between 14.58% and 70.20%, the maximum being recorded in June and minimum in March. The loss in litter weight ranged from 21.88% to 43.18%, the minimum being in May and the maximum in April of the next year. In these bags the average rate of decomposition was 34.68%.

DISCUSSION

Sap Sucking Consumer Arthropods

The study of population dynamics during the present investigation revealed nearly the same abundance in the numbers of the species, *C. attrotibialis* and *E. thunbergii* when analysed in different 1- year old plantations during the two annual cycles. It was also similar in the case of *N. circumflexus* in the 3 month old plantations. Moreover they disappeared when the plantation was nearly 10 months old. However, when the population was continuously sampled on the same plantation for the next year, *C. attrotibialis* and *E. thunbergii* showed a marked difference in their population abundance.

Though the above phenomenon of abundance in the three aphids, *C. attrotibialis, N. circumflexus* and *E. thunbergii* was marked, yet they exhibited the same trend of fluctuation during the two annual cycles under study. A coefficient correlation analysis for these two years for the different populations of aphids revealed a significant positive-relationship (Table-II). This significance is one criteria which indicated the prediction of population for succeeding years. Such trends of predictive fluctuation has also been shown by Van Rensburg (1973).

The present study, clearly indicated that for the populations of *E. thunberqii* and *N. circumflexus* which had only one peak of abundance, they were inversely related to temperature. Whenever the temperature fell in both the years of study, the populations of *E. thunberqii* and *N. circumflexus* which started building up in September and August respectively reached its maximum in January the temperature being 14.61°C and 13.21°C, the lowest recorded for both the years. However, in the case of *C. attrotibialis* there were two distinct peaks of population abundance, one in June and the other in November. The latter peak could be attributed to similar effects of temperature as in the other species, but the former peak distinctly had a positive relationship.

A coefficient correlation analysis between temperature and the total number of aphids for the three species is presented in Table-II. The population of *E. thunbergii* and *N. circumflexus* has a statistically significant negative relationship ($P < 0.01$) with temperature. However, the population of *C. attrotibialis* though had an inverse relationship with temperature was not statistically significant. This was due to the fact that two peaks occurred, one in summer and the other in winter.

The above is a clear indication that different aphids have different temperature regimes for their favourable multiplication and growth. This finds support from Hughes (1962), that different aphid species reach the reproductive age at different times and the rate of increase varies continuously with temperature.

Though many reports exist on low temperatures being detrimental to aphid population (Heie and

Pertersen, 1961; Adam, 1962; Hughes, 1963; Daiber, 1964; Parry, 1969; Greenbank, 1970; Powell, 1974; Thambs-Lyche, 197; Parry and Powell, 1977; Powell and Parry, 1976) in contract, very few reports are available on low temperature being favourable for aphid multiplication (Dixon, 1973; Saxena and Rizvi, 1974; Raychaudhuri, 1975; and Behura, 1977). Two ideas worth mentioning are those of Dixon (1975) who reported that low temperature and high nutritive quality reduces the restlessness of aphids and hence allows accumulation of large number percent area and Raychaudhuri (1975) that low temperature, short day length and the physiological condition of the plant are factors responsible for production of sexual forms.

Rainfall as an environmental factor had the same effect as temperature. The correlation coefficient analysis not only revealed the same picture but confirmed it. For the species *E. thunberqii* and *N. circumflexus*, it was inversely related, whereas for *C. attrotibialis* it had no significant effect. Similar reports where low rainfall and cold climate along with altitude reducing the water content of the plant and thereby increasing the population number exist (Legge, 1966; Wearing, and Van Emden, 1967 and Wearing, 1967). The detrimental effect is also mentioned where heavy rainfall reduces the population (Hughes, 1963; Bryant, 1971; Hodek *et al,* 1972; Dixon, 1973 and Parry, 1974). Hughes (1963) feels that rainfall dislodges the aphids. But in the present study such a phenomenon is ruled out as conifers have needle leaves enabling the rain drops to slide off. Moreover, coniferous aphids adapt themselves to rain, it being a common feature for a major part of the year. Hence it could be the rate rather than the amount of rainfall affecting the population (Dunn and Wright, 1975; Lewis and Siddorn, 1972). This is further corroborated by the fact that the first peak of *C. attrotibialis* occurs in June, the period of peak monsoon.

Throughout the period of investigation the relative humidity was high, never below 50%. The effect of relative humidity on the populations of the different aphids is seen in Table-II, where a correlation coefficient analysis is given. Except in the case of *N. circumflexus,* it did not have any effect on the other two species. Moreover, in *N. circumflexus,* the negative significance was very low ($P < 0.05$). Reports exist where relative humidity was not an important factor for though there may be marked changes in atmospheric humidity, yet very little was influenced at the surface of the leaf which was at or near the saturation point always (Van Rensburg, 1973). Moreover, it is known that the effect of relative humidity on field population of aphids is highly controversial (Hodek *et al.,* 1972).

In the present study to further establish the effect of environmental factors on the population of three species of aphids a multiple correlation coefficient analysis was performed. This enabled an assessment of the cumulative or total effect of all the environmental factors acting simultaneously on the population. From Table-II it is seen that it is highly significant. It is understandable in the case of *E. thunbergii* and *N. circumflexus* as most of the factors acting individually were also highly significant. Surprisingly enough in the case of *C. attrotibialis* though the individual environmental factors showed no significant relationship, their cumulative effect, however, had a significance though not as high as the other two species.

From the present study it was very clear than in all the three species there was the maintenance of a fairly large over wintering population (Ohnessorge, 1959; Peterson, 1960; 1962) but highly

dependent on the mildness of the winter. Moreover, there was no evidence of winter mortality. It seemed likely therefore the establishment of density independent population were favoured by low temperature and negligible rainfall. Such overwintering populations did not have any effect during the succeeding summer, except in the case of *C. attrotibialis*. The summer peak which was marked in June in the case of *C. attrotibialis* may have had several operative factors like food, lack of disease, predators and the building up of the nitrogen level in the plants by washing down of honey dew where in turn the nitrogen being fixed by soil bacteria transported back to the plant through the roots. This became more evident as seen in the present study when the population abundance decreased on the same plantation during the second year of the study. Hence, a possible migration from these hardened growing plants to the younger ones revealed the same pattern. Another reason for the summer build up in *C. attrotibialis* could be attributed to its ecological niche. In the present study *C. attrotibialis* occupied the stem portions while *E. thunbergii* occupied the needles of the same plant. This was further confirmed by the fact that when the plants started growing and even before the first flush of needles, *N. circumflexus* made their appearance and continued till for about 10 months after which they disappeared and *E. thunbergii* appeared on the needles of the same plant. More or less around the same time *C. attrotibialis* were also found occupying the stem of the same plants. Thus, a clear pattern of succession was seen among these three species of aphids which was either due to physiological changes in the plant and/or environmental factors occurring either independently or together.

From the present study it was seen that the abiotic factors did play a significant role in controlling the population of the three species of pine aphids. The pattern of population followed the same trend and fluctuation year after year on the younger plants while the abundance fell in the older plantations. In both cases, however, the trend of fluctuation remained constant. This further enabled to predict the population of succeeding years and therefore would help to a large extent in the prediction of any of these species reaching pest status.

Chewing and Mining Consumer Arthropods

Fourteen orders of insect consumers were caught during the present investigation. This was probably the first time that maximum number of insect orders had been caught from a single light source. The nearest to such a variety being caught was that of Yates (1973) who used Black-light and blacklight blue sources unlike the present study where the yellow light source was used. His catches comprised of thirteen orders of which ten orders were common to the present study. This, therefore proved that a simple light trap as used in the present study was as efficient if not more, than any sophisticated ones known so far.

From the results it was seen that the total insect catch was much more in the first year than during the second (Fig. 5). This was due to the fact that most of the insect orders caught were nearly half in density during the second year of investigation and the complete disappearance of the two orders of Isoptera and Odonata. The only two orders which had an abundance during the second year of investigation were that of Diptera and Hemiptera though they did not have any effect on the total catch. Such annual variation in insect consumers have been reported by Deay *et al.* (1964) and Bakke

(1974). Yates and Ebel (1975a) reported similar results where in certain years, some groups were totally absent followed by 80% of their catches in succeeding years. Raychaudhuri (1975) stated that natality was one of the main causes of insect multiplication in any ecosystem. The catch fall, in the second year of investigation may therefore be due to the mortality of gravid females being trapped during the preceding annual cycle. This was further, elaborated from the present study, when the correlation coefficient between the abundance of the insect orders during the two years was highly positively significant for most of the orders (Table-III). This enabled to predict the population fluctuation for succeeding years. However, this prediction value was not possible for about five orders (Table-III), either at high or low populations (Hagen, 1976).

The total insects caught during both the annual cycles followed a similar trend with the peak during May-June and the lowest recorded during January. An interesting observation made in the present study was that when the peak occurred in May of the first year the total number caught was 3069 and in June, of the next year it was 3090. Similarly, during January of both the years the number trapped was only 15. Such a constancy in trend year after year may be attributed to the regularity of environmental factors like rainfall and temperature for insect increase and decrease respectively, (Cantello *et al.* 1973; Frith, 1975). This was supported when a strong positive significant correlation existed between rainfall, minimum temperature and total insects for both the years in the present study (Table-IVa, b).

A quantitative analysis of the hourly activity of insects during the present study revealed that most of them were caught during the first half of the night as shown in Table-VI. The general activity of the insects during the winter months was high during the first quarter of the night and decreased steadily as dawn approached. However, the flight activity seemed to continue for all the first three quarters before there was a drastic fall in the fourth or last quarter during summer. Similar flight activities of insects have been reported by Hanna (1969, 1973) when the number declined towards 0200 hrs. Hamilton and Steiner (1939) and Day and Reid (1969) recorded highest catches of moths and wireworms respectively during the first quarter of the night (1800-2100 hrs.). Graham *et al.* (1964), and Gentry and Davis (1973) recorded peak activity near or slightly before midnight. In contrast to these, Glick and Hollingsworth, 1954; Haddow, 1961; Standfast, 1965 and Gladney and Turner, 1970 had light trap collections which were greater after midnight. However, Tashiro (1961) reported two peaks of activity in the European chafer, one before midnight and one after 0300 hrs. with a lull in activity around midnight. During the present study, though the maximum catch, was recorded before midnight there was a small peak around 0200-0300 hrs., thereby confirming Tashiro (1961). Whatever the case may be, it was very clear that midnight was a turning point for all major insect groups in their response to light traps, acted upon, however, by over all climatic conditions and seasonality.

The monthly fluctuation of Lepidoptera had a trend of fluctuation similar over the two annual cycles. The maximum caught were during the rainy months of May and June. This clearly showed the presence of only one generation for most of the Lepidoptera. However, none of the environmental factors had any effect on the fluctuation of first annual cycle, whereas minimum temperature and rainfall had a significant relationship over Lepidoptera fluctuation for the second annual cycle. No immediate reason could be attributed except that the relative abundance of second year of

Lepidoptera being much lower than the previous year, could have been affected by either one or both of the abiotic factors. Cantelo *et al.* (1972a); Cantelo *et al.* (1973) and Frith (1975) have all reported a positive correlation between total rainfall and total moth catch. However, Cook (1961), Yates and Ebel (1975a,b) contradicted that rainfall had any effect and felt that the rainy weather appeared to capture as many moths as on rainless nights. The effect of minimum temperature on the Lepidoptera caught as revealed in the present study found support from the works of that of Tashiro (1961), Cook (1961), Ahmed *et al.* (1973), Chalfant *et al.* (1974) and Broersma *et al.* (1976).

Of the nine families represented by Lepidoptera in the current study some families had two generations as clearly indicated by their two periods of flight activity, one during the monsoon and the other during the post-monsoon or pre-winter months. Interestingly enough, not all the families which showed the two peaks of activity during the first annual cycle, showed a similar trend during the succeeding year (Fig. 8). This discrepancy the fluctuation pattern of the different families of Lepidoptera did not allow any conclusions to be drawn. Such controversies exist earlier as by Abul-Nasir *et al.* (1973), who reported three distinct fluctuations of moths of cotton leaf worm during 1964, and a very low and irregular pattern in following two years. The support for the existence of two generations of moths in a year came from Bakke (1974), who also showed that the two peaks occurred in May and October. Frith (1975) was of the opinion that rainfall or a marked increase in precipitation had a direct positive effect on the amount of Lepidoptera catch. Families Geometridae, Pyralidae and Arctiidae represented 77% of the total moth catch. The relative peaks of Lepidoptera abundance, therefore reflect the relative abundance of these three predominant families. Moreover, since the family Geometridae which formed more than 40 percent, the two generations observed in the families Pyralidae and Arctiidae got evened out and presented a single total Lepidoptera generation (Fig. 6). The least catch for all the families were during the winter months of December, January and February and some families even disappeared during these months. This clearly indicated that rainfall and temperature were the only abiotic factors which had, if any, a marginal effect on the abundance of the different families of Lepidoptera. The hourly catches of Lepidoptera followed a similar trend as that of the total insect catch. Maximum were caught before midnight and with a slight peak around 0200-0300 hrs. (Tashiro, 1961) completely disappeared as dawn approached.

The order Diptera presented the same trend in the seasonal fluctuation of relative abundance for the two annual cycles. The maximum catch was during the rainy months of May and June similar to that Lepidoptera. However, unlike Lepidoptera, Diptera exhibited an extra smaller peak which occurred during the post- monsoon or pre-winter months of October during both the years (Fig. 6) and hence depicted the presence of two generations per annum. Such bimodal patterns occurring in Diptera has been shown by Jamnback and Matthews (1963) and Kline and Axtell (1976).

The effect of different environmental factors on the population trend of total Diptera caught had no significant correlation except with rainfall ($r = +0.7663$ and $r = +0.7369$ during the first and second years respectively) and minimum temperature ($r = +0.7119$ and $+0.6396$ during the first and second years respectively). The other factors were either not significant for one year or both the years. The significance of rainfall on Diptera had been shown by Bertram and McGregor (1956) and Williams (1961) who reported large collections during heavy rains or rainy nights respectively.

Minimum temperature being more effective than maximum temperature as in the present study, is supported from the works of Bradley and McNeal (1935), Porter and Gojmerac (1970) and Kline and Axtell (1976). Among the Diptera caught during the present study all the three sub-orders were represented. Of these Brachycera and Nematocera formed more than 80 percent thus reflecting the relative abundance of total Diptera. All the sub-orders had at least two peaks representing two generations. A similar trend as was seen in Lepidoptera and its families was also observed here, when the peaks occurred in the monsoon and post-monsoon months. Lewis (1959) reported similar peaks of abundance, the larger ones in May and June while the smaller during August and September. The hourly analysis catch for Diptera and its sub-orders revealed the same trend as discussed for Lepidoptera.

The remaining orders comprising of Coleoptera, Hymenoptera, Hemiptera, Heteroptera, Orthoptera, Dictyoptera, Trichoptera, Neuroptera and Arachnida followed more or less the same trend of fluctuation as for Diptera. Most of them and their families showed similar peaks of abundance, one during the rainy season and the other after the rains, just before the onset of winter. Except for Trichoptera and Arachnida rainfall had no effect on all the orders (Table-IVa,b). Maximum and minimum temperature had an effect only on Hemiptera, Orthoptera and Neuroptera for both the years of study. The orders Dermaptera, Isoptera and Odonata though represented in both the annual cycles were in such low numbers that they had no effect on the total insect catch. Hence no definite conclusions could be drawn from either the absence or presence of these three orders in the present study. The results of the hourly analysis of the twelve orders followed a similar pattern as was seen for Lepidoptera and Diptera (Table-Va,b).

Many a work exist on light-trap catches, most of them confined, however, to agricultural pests. One can count on one's fingers the light trap work in forest ecosystems. Two major aspects emerged from the present study. One was, that, whatever may be the diversity of the insect orders and their families trapped, they followed a similar trend in their relative abundance of population fluctuation. The other was that of all the environmental factors, only rainfall and minimum temperature seemed to have any effect on the insect consumer population.

In general, however, catches were dominated in all the orders by some families or sub-orders present throughout the trapping period even though there was considerable variation in their monthly totals. The results suggest that insect diversity was relatively high for most part of the year except during winter months. This was due to the constancy of the families in all the catches and also during the months when the total insect abundance was high. Such a phenomenon was in contract to tropical regions in general where the insect abundance and diversity were negatively related (Frith, 1975) and in temperate regions where diversity increased with seasonal abundance (Williams, 1964). The present work was done in a place which could be attributed as sub-tropical where temperature fluctuations were not very high.

The light trap catches in the present study indicated that most of the insect Orders were capable of overwintering, and had a surge in population after the onset of first monsoon, as when average temperature exceeds 16°C, development of larval and adult activity accelerate rapidly (Chalfant *et al*, 1974). In tropics, rainfall was the most important factor which regulated the size of insect

population, where abundance of species occurred following period of heavy rainfall (Owen, 1969). In the present study too, the peak activities of most of the orders caught occurred immediately after rains and therefore rainfall could be attributed as an operationally significant factor in the regulation of insect abundance.

During the second annual cycle, though the trend of fluctuation remained constant as for the first annual cycle and the diversity being constant, yet there was a drastic fall in their total abundance. This may be due to the diminishing effect of the insect populations by light-trapping, which act as food reservior for the insectivorous predators and parasites increasing the pressure on the remaining host populations. A chain reaction gets built which limit reproduction of predators and parasites thereby decreasing the pressure on the remaining insect hosts. Therefore resurgence of many populations will still occur but far less than initial levels indicating that the rates of increase approached the net biotic potential (Cantello *et al*, 1974).

The present study further revealed that considerable differences in the influence of climatic factors on catch sizes were evident. This meant that other environmental and sampling factors influenced the relative abundance of these catches. They could be, the determination of activities of relevant population (Southwood, 1960; Strickland, 1961; Manley and Farrier, 1969; Murdoch *et al*, 1972) and the threshold values of climatic factors for insect activity (Taylor and Carter, 1961; Lewis, 1963, 1964; Johnson, 1969; Rahn and Berger, 1973).

Variation of climatic factors during a catch period (night) occurred and influences of such variation as well as periodicity of activities was investigated by hourly catches. As temperatures rise, the relationship between ambient temperature and insect activity resembled a sigmoid curve (Taylor, 1963). The insects response to warming temperature would be most rapid in the central portion of the curve with progressively slower rates towards extremities. Therefore, temperatures at dawn being invariably lower than the evenings probably accounted for the nil catches during the early morning hours (Table-Va,b).

The statistical analysis performed for the present study does not enable us to pin down the effect of any single environmental factor on insect population. Johnson (1969) mentioned that the use of regression to determine the relationship between the activities and climatic factors was very complex and regressions may be only an empirical convenience or they may indicate functional relations. However, the study, helped in the prediction of populations so that insect pest outbreaks could be easily reflected if such studies were done and records maintained continuously over several years for proper forestry management.

Decomposer Arthropods in the soil

Drift (1951) reported $3365 \times 10^2/m^2$ of arthropods in a beach forest soil, while Harding (1969) and Price (1973) found $2150 \times 10^2/m^2$ in an oak woodland and more than $2207 \times 10^2/m^2$ in pine forest soil respectively. In the present study where a maximum of $1600 \times 10^2/m^2$ have been reported was much lower than these and the nearest comparison could only be made with the temperate pine forest soil where Crossley and Bohnsack (1960) reported $1020 \times 10^2/m^2$. Drift (1963) and Greenslade and Greenslade (1968) reported $514 \times 10^2/m^2$ and $920 \times 10^2/m^2$ respectively from tropics and compared

their estimates with those of earlier tropical workers and reported that there was no significant difference. The present study site located at an altitude of 1175 m approached to near temperate climatic regimes, but still the total microarthropod densities reported fell between those of reported temperate and tropical estimates.

The seasonal fluctuation in the total microarthropod population did not show any regularity in their peaks of abundance for entire period of study. A comparison made between the first eight months of both the years studied showed a maximum of $1356x10^2/m^2$ during April of the first year while it was a minimum for the same month in the following year. Since the study was not extended to complete the second annual cycle no concrete conclusion in the total microarthropod population and their pattern of trend could be drawn. In any case, however, the trend during the first eight months of both the annual cycles being not similar, the effect of season seemed to be minimal on the relative abundance of total microarthropods. This was confirmed by a perusal of Table-VIIa, where none of the abiotic factors except rainfall had any significant correlation with the total microarthropods. However, it was known that edaphic and climatic factors influenced the development and maintenance of any soil community (Drift, 1963). This was supported by Usher (1971) who reported that populations of soil arthropods were affected by the two factors of temperature and precipitation. The physical factors like pH and conductivity and all the chemical factors under study seemed to have no significant effect on total microarthropods when they were either positively related or negatively related.

Of the total microarthropods, Collembola and Acarina constituted a major portion comprising nearly 89.54%. Among these two, Collembola dominated Acarina and was 58.42% during the total study period and ranged between $24x10^2$ and $1312x10^2/m^2$. Such an abundance of Collembola has also been reported earlier by other workers like Tragardh (1929) - $1200x10^2/m^2$; Kaczmarek (1973) - $170x10^2$ to $220x10^2/m^2$; Price (1973) - $1461x10^2/m^2$. The trend in seasonal fluctuation of total Collembola showed one large and two small peaks of abundance during an annual cycle. The two smaller peaks occurred during the post-monsoon months of October and November and the post-winter month of February. The larger peak occurred during April - July which is the monsoon season for the present study undertaken. A comparison of these peaks of abundance could be done with other forest soils and in particular coniferous soils of the temperate region, if our monsoon was summer season and the post-monsoon and post-winter be attributed as autumn and spring respectively. If so, Poole (1961) reported summer maximum with smaller winter peaks and Bellinger (1954) recorded a spring peak while Joosse (1969) showed maximum for some species during spring and autumn and others during summer. A better comparison would however be with that of tropical forest soils, where most of the work was confined to South East Asia and Japan. Here, Ogino *et al* (1965) reported an increase in Collembola from August to March with an abrupt rise in May while Takeda (1973) recorded two peaks one in December and the other in March. Niijima (1975) reported three peaks in a year for the dominant species of Collembola studied. Though all comparisons made were between forest soils, yet no definite trend of fluctuation in population density was seen to be similar in any two studies. Such lack of definite fluctuations could be attributed to differential preferences of individual species, their migration, natality and mortality dissimilar to one another, having a disadvantage in the total presentation of seasonal population fluctuation as Collembola in general

(Joosse, 1969). Different climatic conditions prevailing in different regions could also have an effect on the pattern of fluctuation allowing no true comparisons between any two regions (Niijima, 1975).

All the five families represented in Collembola have been recorded during the current study. Of these, the family Isotomidae was the most dominant in abundance while Hypogastruridae was the least. A perusal of Fig. 19 revealed that the population trend of fluctuation for the family Isotomidae followed the same pattern as that of total Collembola. This was not surprising since they formed 84.14% of the total Collembola. Other than the attributes given for total Collembola, in relation to the peaks of abundance, nothing thought provoking could be added for Isotomidae. Regarding the other families, the pattern of fluctuation was so irregular that no conclusions regarding their seasonality could be drawn. The only possible reason for rise and fall in populations successively was that the families Entomobryidae, Sminthuridae and Onychiuridae had several generations of overlapping populations.

The maximum Collembola occurring during rainy months showed a significant positive relationship ($r = +0.5950$ and $P<0.01$) with rainfall. The other abiotic factors which had a similar relationship though only at $P<0.05$ level was also understandable as the population started building up during the onset of summer. These results find support of Kevan (1965); Butcher *et al*, (1971 and Gupta and Mukherjee (1978) where they reported a marked effect on soil arthropods by the influence of temperature. Niijima (1971) had attributed that temperature was one of the main causes for the low density of Collembola during winter. Temperature was one factor responsible for oviposition and growth rate of Collembola (Kevan, 1955, 1965 and Hale, 1966, 1967) could be the probable reason for their increase in abundance during the summer. Among the physico-chemical factors only pH and CaO were significantly related to total Collembola, the former being positive at $P<0.01$ level and the latter negatively at $P<0.05$ level. The pH during the present study was always on the acidic side and therefore the Collembola species encountered were related to acidity (Hale, 1966; Nosek, 1967) and seem to have a distinct preference for that range. On the other hand there exists more reports on PH having very little or no effect on Collembola populations (Agrell, 1941; Bellinger, 1954; Paclt, 1956; Cassagnau, 1961, 1964 and Christiensen, 1964).

Among the different families of Collembola, Isotomidae the dominant group also had the same correlations significant as for total Collembola. The other two families Entomobryidae and Sminthuridae were not effected by any abiotic (either physical or chemical) factor except MgO which did show some relation to Entomobryidae.

The group dominant next to Collembola during the present investigation was Acarina. However, it represented only half of the total Collembola in relative abundance. Acarina followed a more or less similar pattern in their fluctuation to that of Collembola. Their peaks of abundance occurred during pre-winter (late autumn), post-winter (early spring) and monsoon (mid- summer). The first eight months of the two annual cycles were similar in their trend of fluctuation for Acarina except for their peaks of abundance being reversed. The maximum numbers recorded were during the months of September and October for both the annual cycles. For most temperate soils, a July peak for Acarina was common (Bellinger, 1954; Madge, 1965). Peaks of abundance in November was also not unusual (Curry, 1971), except that in the present study, the range being much more in November

than in July, which has not been reported earlier. The possibility of an over-wintering population making its impact in summer as in temperate soils was not as significant as the population building up after the monsoon as seen from the present study. Altitude and the climatic regime of the present study site should probably be one factor having a similarity near to temperate conditions.

Among Acarina all the three sub-orders had been recorded during the present study. The sub-order Prostigmata was the most abundant comprising of 53.02% of the total Acarina. The peaks of abundance in their seasonality followed more or less a similar pattern as that for the whole order except than an extra peak was observed in the month of April during first annual cycle. A dominance of the sub-order Prostigmata had been earlier reported by Loots and Ryke (1967) and Price (1973) though reports exist of the group having very low density (Madge, 1965 and Block, 1965, 1966). Their dominance could be attributed to their adaptation as a group tolerant of external environmental conditions of the region under study (Loots and Ryke, 1967).

Cryptostigmata followed Prostigmata in order of abundance during the present study. Though Price (1973) is in agreement, yet Madge (1965) and Wallwork (1967) had different views to that of the present study, for the latter two had reported more than 75% of the sub-order Cryptostigmata in their respective works. The trend in the population fluctuation of this sub-order did not follow any significant seasonal variation. The only period when they were in an increased state was during March of both the years attributed to the probability of an overwintering population making its effect felt during early spring. The low population abundance was seen during the summer. Reports of such trends were seen in Wallwork (1959); Evans *et al* (1961) and Madge (1965). As species were not identified during the present study, no conclusions could be drawn from the seasonal fluctuations of the whole group as has been clearly pointed by Usher (1975) that different species had not only different peaks of abundance but also the number of peaks varied between species. This was further confirmed by Harlov (1960); Evans *et al* (1961); Block (1966) and Mitchell (1977) who had reported well defined bimodal peaks for most oribatid groups.

The sub-order Mesostigmata during the present study was not only too few in number (Price, 1973 and Madge, 1965) but also showed no seasonal trend in their fluctuation (Usher, 1971). Hence no significant conclusion could be drawn for them.

Though the trend of fluctuation was more or less similar as for Collembola, the effect of the various abiotic factors had a significant relationship on the total Acarina population. A very interesting observation revealed from the present study is that, temperature (air, soil surface and at 5 cm depth), rainfall and moisture were negatively correlated and were highly significant, at $P<0.05$ level for the former two and at $P<0.01$ for the latter with total Acarina. The other physical factors like pH and conductivity and for all the chemical factors, no significant relationship was found and hence probably had very little role to play in regulating the Acarina population. Some investigators did show no relationship between soil moisture and Acarina (Macfadyen, 1952, 1954; Huther, 1961; Marcuzzi, 1967, 1968, 1973) yet others reported definite negative correlation (Hammer, 1934, 1937, 1953 and Stebayev, 1962). It was known that the effect of moisture was complex, indirect and to a large extent interwoven with that of temperature (Glasgow, 1939; Gisin, 1943, 1952). Such a relationship existing between temperature and moisture was also found in the present study, as both

the factors were negatively correlated. With the above two factors rainfall may also be included. Belfield (1964) and Gupta and Mukherji (1978) had reported excess moisture or water logged conditions to adversely affect microarthropod populations. pH not having any effect on Acarina unlike Collembola was understandable as it's correlation with the density of Acarina would be misleading when effects of temperature, humidity and animal respiration combined, acidify the substrate (Lebrun, 1965; Frank, 1965 and Loots and Ryke, 1967).

Among the various groups of Acarina it was intriguing to find that not all the abiotic factors effected their population densities, than when they are treated together. This was more so, especially when even the dominant group Prostigmata did not follow the total Acarina for they were significantly negatively correlated only with air temperature and soil moisture and positively correlated with total iron. Cryptostigmata was negatively correlated for the abiotic factors like moisture, pH and CaO while positively correlated for total iron. The last group Mesostigmata was negatively correlated with air temperature, temperature at 5 cm depth and organic carbon ($P<0.05$) while positively correlated with pH (Table-VIIb). This was a clear indication, as mentioned earlier while dealing with total Acarina, that temperature, rainfall or moisture either singly or together with one of the other factors or all three combined together did play a significant role in controlling the different sub-orders of Acarina. As regards the organic matter with Mesostigmata, this was probably the first time that a negative correlation had been found. Most of the authors were of the opinion that highest densities of arthropods were recorded by many workers where the organic matter was more and organic substance being rich, depending on the humus of the environment (Poole, 1961; Lutz and Traitteur, 1965, Choudhuri and Roy, 1967; Loots and Ryke, 1967; Butcher *et al*, 1971; Niijima, 1971 and Castri, 1973).

Other than the groups discussed earlier, Protura, Diplura, Pauropoda, Symphyla, Chilopoda, Diplopoda, Isopoda, Thysanoptera, Hemiptera, Hymenoptera, Coleoptera adult and larvae and Diptera larvae, Calanoids and Arachnida, were also present. Except for Protura, Chilopoda and Hymenoptera which were a little more than 1% of the total microarthropods, all the others recorded less than 1%. Moreover, all these were very few in number and not being present throughout the year no seasonal pattern in their trend of fluctuation was found. An interesting observation made during the present study was the occurrence of Formicidae (Hymenoptera) in the month of December, in such large numbers having a predatory effect on the population of most other groups as was obvious in their low numbers being revealed during that month.

While considering the remaining groups together it was seen that none of the physical factors had any effect and among the chemical factors only organic carbon ($P<0.05$) had a significant negative correlation. It further proved that as in Mesostigmata, the organic carbon and its abundance drastically effected the population of most microarthropods.

Decomposer Arthropods in Litter

The rate of decomposition of forest litter has been used as an indication of soil fertility and decomposition activity (Lahde, 1974). For such a breakdown of organic matter in the soil, the role of soil organisms in relation to the size in terms of biomass and numbers has often been discussed and

frequently cited as evidence that these populations were important (Bornesbusch, 1930; Murphy, 1955). To improve the reliability of such results in field experiments, litter has been enclosed in glass fibre (Mikola, 1954, 1960) or nylon mesh (Bocock and Gilbert, 1957; Bocock *et al*, 1960; Shanks and Olson, 1961; Bocock, 1964; Anderson, 1973a,b, 1975) bags. Change in weight of litter sample over time had also been a measure of the activity of soil animals causing litter breakdown (Heath and King, 1964; Heath and Arnold, 1966; Heath *et al*, 1966; King and Heath, 1967).

The present work incorporated the study of enclosed pine needle litter in nylon mesh bags and an attempt to relate the activity of soil organisms over a season to the loss of litter weight. The most abundant organisms in dry funnel extracts of plant litter have been Collembola and Acarina, and in most studies they are referred to as litter microarthropods (Harding and Stuttard, 1974). However, most other groups as included in the present study in addition to these two, came under the broad definition of this. The present investigation incorporated a detailed study of these microarthropods in relation to litter decomposition as the mesh size of the nylon bags used, prevented the activity of macroarthropods.

Published estimates of Collembola and Acarina density exist for habitats ranging from deserts to Arctic and tropical systems (Edwards and Fletcher, 1971). Very little information however is available on the activity of other microarthropods in relation to litter weight loss to the extent where comparisons would be feasible. The reason was obvious as their densities in relation to either Collembola or Acarina or both was very negligible as to draw conclusions of their role in such an ecosystem. The present study also revealed that both Collembola and Acarina constituted more than 95% of the total microarthropods extracted. Hence, the role of these two major groups, where one has mandibulate mouth parts (Collembola) and the other chelate jaws (Acarina) seemed to effect the litter decomposition rather than the remaining microarthropods which totally constituted less that 5%. Such findings have been reported earlier (Weigert, 1974). When only the two dominant groups were considered it was seen that for the entire period of investigation, Collembola dominated Acarina in numbers and formed more than 70% in all the three mesh sized bags. This was in contradiction to Witkamp *et al* (1966) who reported that though the total arthropods comprised 98% of Acarina and Collembola yet 90% of these were Acarina. However, during the monthly analysis, it was revealed that the activity of Collembola was more during warmer months and the onset of winter has a dominance of Acarina population. This phenomena was consistent as seen in Figs. 28a,b,c, where Collembola from the month of May till November were in maximum numbers and fell from December to April. A very clear indication of interplay between these two groups of organisms existed and there could at least be two possible reasons for such rhythms. The dynamic activity of Collembola during the warmer periods and Acarina during winter and secondly, the feeding habits of these two groups. The litter gets primarily broken down by Collembola and this partially decomposed litter gets acted upon by Acarina.

As observed in the previous chapter on soil it was seen that Collembola comprised of all the five families with the family Isotomidae dominating over the other four families in terms of population numbers. However, they were found to be maximum only during the months of May and June. During the succeeding months of investigation, till the completion of one annual cycle though their number fell drastically they were found throughout the year when the other families were absent,

which could account for their total maximum abundance. This family Isotomidae could be designated as an indicator species for habitats as in the present study. The next dominant family was Entomobryidae which together with Isotomidae was responsible for fluctuation of total Collembola. This family was seen to be maximum during the month of September which was the lag phase of the monsoon period. All the other families did not show any significant effect either in numbers or their activity over the seasons.

The maximum number of total microarthropods encountered in the nylon bags was above 3000 in all mesh sizes and this occurred during the month of May. Similarly the least was recorded in all the mesh sized bags during the month of March, when their number were below 100. No earlier reports exist to make a comparison, except to show from the present study that the activity of total microarthropods depended primarily on season rather than on anything else.

Table IX - a,b,c represents the coefficient correlation, where it was seen that though the maximum numbers of total microarthropods occurred during the summer months, yet temperature did not seem to play any role and the possible reason may be due to the narrow range of fluctuation in litter bag temperature over the different seasons. However, from the same table it was seen that the moisture content in all the litter bags of different mesh sizes were highly positively significant with the total microarthropods (Witkamp and Drift, 1961; Witkamp *et al,* 1966; Rosswall, 1973, 1974, 1975, Rosswall *et al,* 1975). Hence moisture, which was absorbed by the litter seemed to play a greater role in the regulation of these populations.

Collembola as a group when analysed for coefficient correlation analysis between the factors like temperature, moisture and weight loss revealed that moisture was one factor which was responsible for their activity as it was found to be positively significant for all the three mesh sized litter bags. As Collembola being the most dominant group in the present investigation, it further reflected the activity of microarthropods in general on pine litter. This was all the more obvious when the coefficient correlation (Table-IX) revealed that Collembola with weight loss was negatively correlated in all the mesh sized bags though significant for the maximum and medium mesh sizes only. Further, this was corroborated by the fact that this was an indication of the dominance of one family Isotomidae under Collembola (Table-IXa,b).

Though Acarina formed the second dominant group during the present investigation it never exceeded 25% of the total microarthropods. They further failed to show any significant correlation with the loss of weight in the litter and interestingly enough they were positively correlated in all the three mesh bags with percentage loss in weight of the litter. This phenomenon was quite intriguing since the Acarina population dominated after half the study period was over, when the litter weight loss was nearly 40% and at the end of the study period a further loss of only three to four percent more was recorded (Witkamp and Drift, 1961; Gill, 1969). Under the different suborders of Acarina, Prostigmata and Cryptostigmata population numbers were nearly the same, with Mesostigmata following close behind. Though all the three were negatively correlated with temperature, only Mesostigmata was significant for all the three mesh sizes and Cryptostigmata for the maximum mesh size only. None of them were significantly related with any of the other factors.

All the other groups of microarthropods represented in this study were so few in number that

relationships from either their presence or absence could not be derived.

The population densities of microarthropods and also the weight loss of litter was negligibly affected by the mesh size of the litter bags. This may be due to the fact that the largest mesh sized bags used during the present study allowed colonization of microarthropods which could also enter the smallest mesh size, excluding only macroarthropods. However, it was felt that this study being done in acidic areas where very little macroarthropods existed in comparison to microarthropods (Reddy and Alfred, 1978a,b), the use of larger mesh sized bags could not have had any significant effect on weight loss.

The present study revealed that though there was a succession of population in microarthropods, their role differed either individually or totally in litter decomposition, which was significant. However, Harding and Stuttard (1974) were of the view that moisture, metabolism, chemical decomposition of litter and microarthropods were less important compared with microflora. However, Howard and Howard (1974) stated that burst of activity of microarthropods, particularly Collembola and Acarina was due to the preceeding fungal population rise. Subsequently the activities of these microarthropods were responsible for the reduction of not only plant debris but also the fungal hyphae forming the organic matter of the soil. Decomposition will slow down and totally stop if this animal activity was removed (Burges, 1967; Kendrick and Burges, 1962; Howard and Howard, 1974; Millar, 1974; Das, 1980) confirming that though Acarina and Collembola were inefficient feeders, decomposition was accelerated by comminution of the litter (Mitchell, 1978) and also helped in fungal spore transport to new sites (Pandey and Berthet, 1975). In any case there was general agreement that the overall rate of decomposition may increase when the material was converted into faeces (Drift, 1961; Drift and Witkamp, 1960; Macfadyen, 1955, 1963). This was further confirmed by Drift (1975) who reported that the primary effect of soil fauna was indirect rather than direct.

Witkamp (1971) further corroborated that comminution of litter by animals could lead to increased leaching of the substances by rain. In confirmation of these and from the present study the initial rapid loss of weight of litter during the first two months could be attributed to physical leaching of readily soluble materials (Crossley and Hoghland, 1962; Madge, 1966; Macklin and Witkamp, 1973; Anderson, 1975; Reddy and Alfred, 1978a,b), while the slower rate of weight loss thereafter, approximated an exponential relationship with time (Olson and Crossley, 1961) probably due to a combination of biological and physical factors. Our study revealed that litter, its decomposition and its breakdown into elements, was only possible when both the fauna and flora acted synergestically.

General Discussion

Total ecosystem analyses were based on the concepts of landscape being organised into logical patterns of self sustaining internally regulated and dynamic components. Relationships between pools and fluxes, seasonality and variability of these parameters need to be explored for comparison from different ecosystems (Reichle *et al,* 1973). As mentioned earlier to the ecologists, the landscape was organised by nature into a mosaic of systems called ecosystems. In spite of gross and obvious differences all ecosystems possess the same inherent structure and more importantly the same basic

processes. However, the individual composition of these processes (primary producers, consumers and decomposers) differed considerably, depending on the climate of the region, its evolutionary history, its extent of modification by man, and the chemical and physical nature of the supporting substrate. Nevertheless, inspite of what appeared as differences, all materials moved in an organised, albeit cyclic pattern in any ecosystem (Auerbach *et al,* 1974).

The study of interactions had long been of interest to ecologists. Moreover, interaction had been included in the definition of ecology, the scientific study of interactions which determined the distribution and abundance of organisms. However, natural communities were nude in terms of the economics of consumption, production and mechanisms for bringing into balance, producer-consumer activities (Rapport and Turner 1975). Population dynamics are usually concerned with the increment and decrement of the populations, numerically based on the amount of natality and mortality, but functionally an integration of all interactions of factors contributing to a particular density (Cole, 1974). As the effects of population density were studied in an increasingly wide variety of arthropods it was apparent that there might be a common range of factors effecting them. Hence, the differences in response between population, served to illustrate, that, the precise direction and effect of environmental factors depended on a genetically controlled ability responding in the individual animal. From this it followed that the ecological results of the total pattern of response was peculiar to the particular group of arthropods (Long and Zaher, 1958). MacArthur (1972) had suggested that the four essential ingredients of all interesting biogeographic patterns, were the structure of the environment, the morphology of the species, the economics of the species behaviour and the dynamics of populations. The close relationships of the first and the last had been the main focus of the present work.

The numbers of population species, tend to increase to very high levels, unchecked by natural control factors and only becomes stabilised when biotic factors adapt to the new race or subspecies. Therefore, effective forest protection depended on reliability of identifying races or subspecies for appropriate control measures (Bryant, 1974). Although various environmental and physiological variables effect the rates of uptake and turnover of materials, ultimate concentration factors for chemical compounds or elements were intimately related to the stable element chemistry of the consumer organism and its food (Reichle and Van Hook, 1970). A unique advantage gained from the present study was, that we could predict unmeasured ecosystem parameters from a limited set of data. This was primarily because we had maintained traditions to increase scientific knowledge through the classic approach, familiar to population biologists. We were convinced, however, that the paradigm was promising even with our limited knowledge with it, and we do not hold any illusions that what we have offered, was singularly best in all situations or that there were no alternative strategies which may prove superior.

The significance, was not that the present conceptualisation was capable of drawing realistic bounds on the ecosystem response volume. The significance lay in the potential to refine this type of analysis as ecosystem theory becomes better developed (O'Neill, 1976). Although certain coefficient correlation analysis had failed to prove that there were significant differences between abiotic factor and the arthropods under different components, it must be pointed out that the differences would have to be very great to be pronounced statistically significant. However, even with the number of

samples used in the present study, many relationships stood significant (Coyne and Critchfield, 1974). Within India, the number of ecosystems for which comprehensive information was available were too few to allow regional comparison and interpretation of characteristics. However, within the faunal research, the population studies had provided information on population dynamics which was essential to the understanding of the regulation of production (Heel and Perkins, 1976).

Concluding Remarks

With the above mentioned background a general overview of the study undertaken prompted certain conclusions to be drawn. The portions dealing with fauna at the consumer level had many attributes of similar nature probably proving that the effect of environmental factors on the species of populations considered, was in a regular systematic pattern. The prediction of populations for succeeding years stood out as one very important feature enabling control of species, if and when they would reach pest status. Most populations further had distinctive bimodal patterns of fluctuation over an annual cycle. Temperature and rainfall were two factors which seemed to play a major role in regulation of both sap-sucking, chewing and mining consumers, proving either one of these abiotic factors as operationally significant. In those cases where statistical significance of any one factor on a population failed to express itself it was seen that a highly significant relationship existed when a multiple correlation was computed for all the factors with the groups of the populations considered. This did not prevent the conclusion, though general, it seemed that the extrinsic factors of the environment played a dominant role than microclimatic effects. A further phenomena worth the mention was the decrease in population abundance during the second year of investigation proving thereby that the rates of increase never reached beyond the net biotic potential known to be effected by factors like emigration, predators and parasites.

The remaining two portions dealt with the role of microarthropods on plant litter breakdown and their importance in the soil. In both cases, Collembola and Acarina formed the dominant groups, the former playing a major role. One common factor effecting their population levels had been the water content, as rainfall for soil and moisture of the litter while pH was another factor (which positively influenced the soil organisms which preferred the acidic range), generally known to have a significant effect on the soil microarthropods and understandably much more than a factor to be reckoned with in the pine litter as seen in the present study. There was a clear indication of an interplay between Collembola and Acarina with seasons, for summer, had a dominance of Collembola, while the winter months revealed a greater activity of Acarina. Not only was this phenomena observed at that level but it was seen to have similar effect while treating them at either sub-order or family levels. It was generally accepted that it is difficult to isolate the decomposition processes from faunal activity without disturbing the microbial processes (Mignolet, 1972). One of the effects of fauna populations on detrital processing was comminution which exposed greater surface area for microbial attraction (Drift and Witkamp, 1960; McBrayer *et al.* 1974; Mitchell, 1978). The present investigation not only confirmed these findings, but also is supported from the microbial aspect of the study done simultaneously (Das, 1980).

It was now felt to interpret a total analysis of the results of the different components of the ecosystem studies. The average turnover rate for the trophic levels studied, which changed during the

season as temperature and moisture changed when populations underwent shifts in abundance. The total ecosystem had an obvious application in the movement and eventual fates of the populations due to interplay of certain abiotic factors. The results of this study thus, had an unique advantage of these emerging general concepts of the ecosystem in that we could predict unmeasured ecosystem parameters.

The strength of this paradigm was derived from the fact that it seeked to extend analytical insights possible at the population level to the community, thereby forging a formal relationship between the two levels. On the one hand community dynamics were interpreted whenever possible as population biology was studied only within the community concept as seen in the present study. What had emerged from our own evaluation of ecosystem analysis, was to identify the kinds of research for the next phase and that great opportunities existed for building models and to solve the underlying mechanisms of integration between the community and population. This would require solutions based on life histories, ecotypic variation, genetic regulation, and species interactions (Odum and Pigeon, 1970). We had made the beginning and have a long and hard way to go to explicitly put down our understanding on total ecosystems. The study helped us to raise questions to be answered in the near future to further the insight into the pathways of this unique pine forest ecosystem such as What are the rates of the metabolic processes in principal pine forest component ? How fast do the leaves, trunks, soils and animals process carbon ? How much energy is stored and how much is utilized in the main classes of the forest community ? How do members of the Shillong pine forest compare with other forest systems in the topics and elsewhere ? What.do comparisons between successional and climax species show ?

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