ECOSYSTEM STRUCTURE OF A PINE FOREST IN NORTH-EAST INDIA WITH PARTICULAR REFERENCE TO CONSUMER AND DECOMPOSER ARTHROPODS

by

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Submitted in fulfilment
of the requirement of
the Degree of Doctor of Philosophy.

to

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I certify that the thesis entitled "Ecosystem structure of a pine forest in Northeast India with particular reference to consumer and decomposer arthropods", submitted by Mr. M. Vikram Reddy for the Degree of Doctor of Philosophy of the North-Eastern Hill University, Shillong embodies the record of original investigation carried out by him under my supervision. He has been duly registered and the thesis presented is worthy of being considered for the Award of the Ph.D. Degree. This work has not been submitted for any Degree of any other University.

Date : 31st March 1980

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Mr. M. Vikram Reddy had worked as a Research Fellow at this Department from 12th December, 1975 to 11th June, 1979 under a NEHU Fellowship. He carried out these studies under the guidance of my colleague, Dr. J.R.B. Alfred. The results of his investigations are compiled and supplicated in the form of a doctoral thesis entitled "ECOSYSTEM STRUCTURE OF A PINE FOREST IN NORTHEAST INDIA WITH PARTICULAR REFERENCE TO CONSUMER AND DECOMPOSER ARTHROPODS".

To my knowledge, this work is the first of its kind, particularly on faunal aspects of pine forests of India. I had the personal experience of going through the manuscript and find that the results achieved are significant. This functional study will be of value in furthering our knowledge of underlying mechanisms in forest ecosystems. In my opinion the data gathered, the presentation of results and discussions offered are adequate for consideration of the award of the Doctoral Degree.

(R. GEORGE MICHAEL)

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Finally, to my wife, a feeling that cannot be expressed in words, for she understood that the present work was not a mere trifle nor a pastime of fools.

M. VIKRAM REDDY

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GENERAL INTRODUCTION

GENERAL 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 man's history (Botkin and Miller, 1974). The need to study forest systems, stems from the need to understand, not only as a value for man's 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 man's 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 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 interelate 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.

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STUDY AREA

STUDY AREA

Location :

The study area named as "Riatkhwan Pine Plantation" (Plate-1) is about 15 kms. from the Montane temperate 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 an 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 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

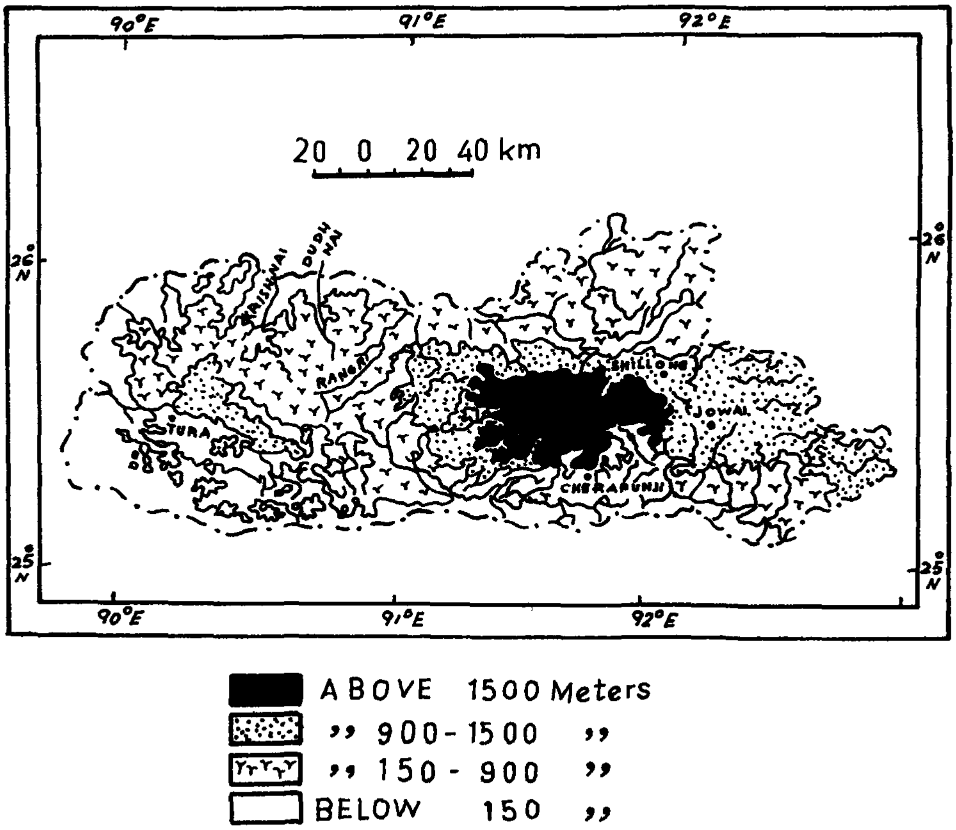
610-1544 m above M.S.L. and its tectonic history begins with the effusion of plateau basalts (Sylhet traps) through fractures and faults in the basement and uplift and subsidence of adjacent basement blocks. These were followed by upper Cretaceous/Tertiary sedimentation into the relatively down thrown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

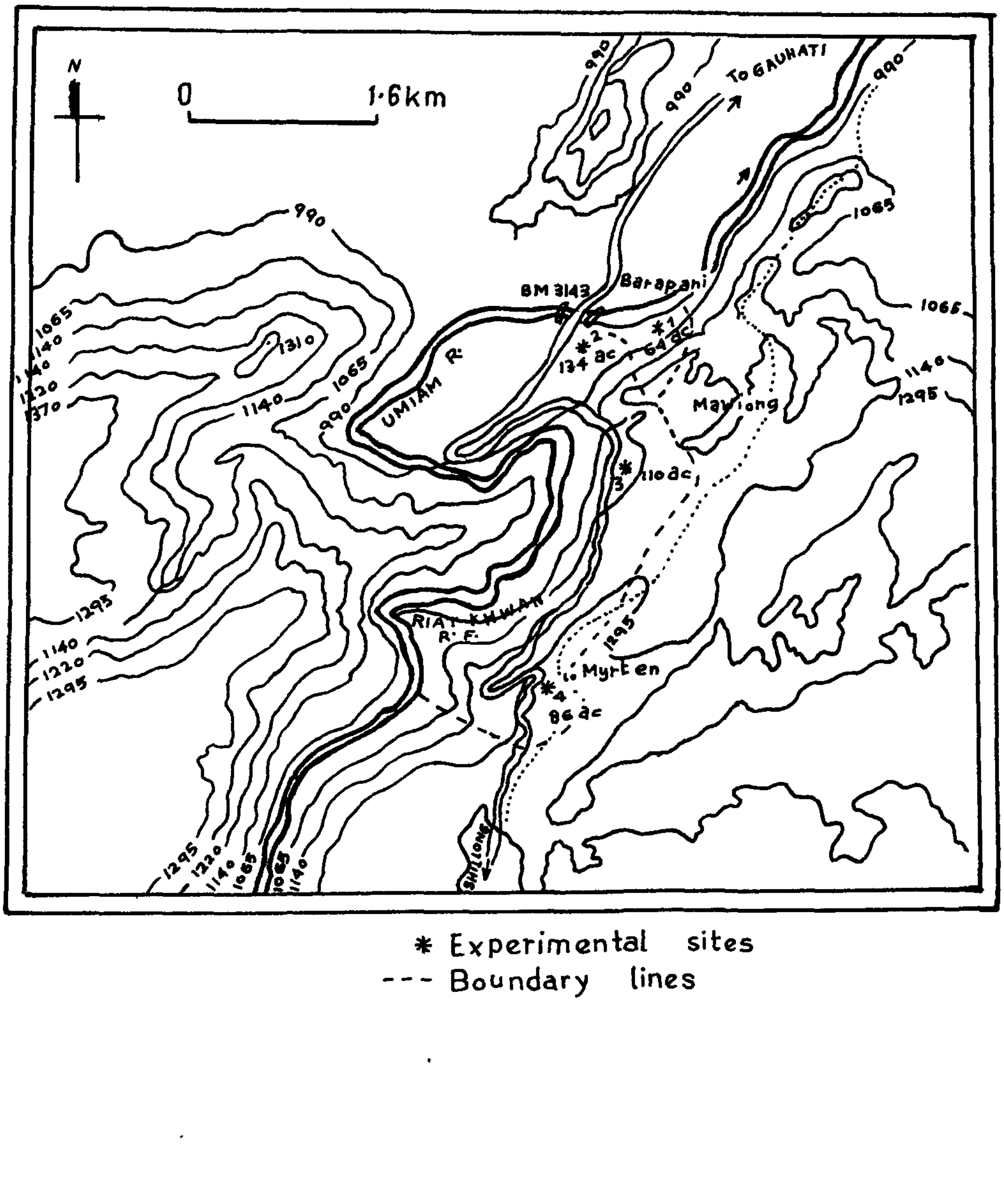
Climate :

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 250 cm, the maximum annual average of 1143 cm being recorded around nearby places at Cherrapunji and Mawsynram, the worlds rainiest spots.

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

b showing the physiographical map of the study area.





✱ Experimental sites
--- Boundary lines

Plate 1 showing the different plantations in the Riatkhwan pine forest study area.

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

Table I

List of plants present in the Riatkhwan Pine Plantation Area.

TREES :-

***Pinus kesiya*

Schima wallichii

HERBS :-

***Eupatorium adenophorum*
Urena lobata
Oxalis corymbosa
Rubos eupticus
Commelina bengalensis
Oldenlandia burmanniana
Scutelaria bicolor
Hypochaeris radicata
Artemisia vulgaris
Poa annula

Pouzolzia zeylanica
Oxalis corniculata
Frageria indica
Hedychium coronarium
Setaria glauca
Erigeron linifolius
**Anemone rivularis*
Anaphalis contorta
Trifolium repans

SHRUBS :-

Lantana camara
Capillipedium assimile

Desmodium triflorium
Osbecia crinata

GRASSES :-

**Setaria glauca*
**Imperata cyclindrica*
**Digitaria adscendens*
Erianthus sps.

**Capillipedium assimile*
**Paspalum dilatatum*
Saccharum officinalis

*Indicates dominant species.

SAP SUCKING CONSUMER ARTHROPODS

INTRODUCTION

Phytophagous insects are common ubiquitous elements of most terrestrial ecosystems. Forest ecosystems, in particular support myriads of phytophagous insects (Mattson and Addy, 1975), aphids constituting one such group. They are known to have originated from Archescytinidae in the Carboniferous era (Heie, 1967), and are an extremely successful group of small and inconspicuous insects, worldwide in distribution. Aphids or phloem sucking bugs belong to the super-family Aphididae, under the order Hemiptera. These are mostly restricted to those parts of the plants that can be pierced by their stylets. These are highly defenceless yet destructive, showing a high degree of polymorphism (Raychaudhuri, 1975). Owen and Weigert (1970) suggested that aphids can be good agents for nitrogen fixation. The aphids may be beneficial or harmful (Raychaudhuri, 1975) and can multiply so rapidly that they can reach pest proportion (Dixon, 1973), the study of their population dynamics being therefore highly essential for better management in farm, forestry and agriculture.

Even though aphid ecology has been worked out by many, knowledge about the population dynamics of aphids of both agricultural and forest crops, all over the world is very scanty. The population dynamics of M. persicae has been studied in different potato growing regions of India (Saxena and Rizvi, 1974). Several workers have studied one or more factors concerned in the growth of M. persicae on a particular crop. Hafez (1961) studied the seasonal fluctuations of population density of cabbage aphids Brevicoryne brassicae (L) in the Netherlands. Mitchell et al (1961) and Amman

(1962) described the seasonal history of the balsam woolly aphid, Adelges piceae (Ratzeburg) in Western and Eastern United States.

The rapid rate at which the aphid number changes necessitates frequent observations of the effects of all factors. Continuous observations of marked clusters of B. brassica have proved a useful way of integrating certain population events and processes (Van Emden, 1963). Such data are noteworthy in indicating a very significant aphid mortality from predation as well as intraspecific regulation by emigration. DeBoo et al (1964) noted that population fluctuation in the number of pine leaf adelgid Pinus pinifoliae (Fitch) has beem epidemic in portions of the North Eastern United States since 1955. Balch and Underwood (1950) recorded population abundance in Eastern Canada. Damage to white pine, produced by the pine leaf aphid first became noticeably severe about 1966 in Maine although signs of population build up were seen earlier.

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. In 1976, he studied the abundance and survival of these aphids on balsam fir and concluded that to forecast outbreaks or assess the effect of stand treatments, it is necessary to measure aphid population levels. Van Rensburg (1973) reported the seasonal fluctuations in the numbers of field populations of the sorghum aphid, Melanaphis (Longiuguies) pyrarius (Passerina) forma Sacciari with special emphasis on the factors that cause these fluctuation. Mackauer (1973) studied the population growth of the pea aphid biotype R1 on broad bean and pea.

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). Kieckhefer (1975) reported the occurrence, abundance, composition and distribution of cereal aphids in small grains at several locations in South Dakota (U.S.A.) from 1963 to 1972.

In Britain, Hussey (1952) studied the population fluctuation of N. abietina, over a period of two years, when no infestations occurred. Studies on the populations dynamics of E. abietinum were begun at Forest of Deer (Aberdennshire) and Fetteresso Forest (Kincardineshire) early in 1967, due to a severe attack of the aphid (Parry, 1968). Sitka spruce (Picea sitchensis (Bong.) Carr.) when introduced in 1919 in

Ireland was attacked by the epidemic green spruce aphid, (*Neomyzaphis abietina* Walker) creating a havoc (Peterson,1962).. The attack was so severe that the trees were defoliated. Parry (1968, 1970) reported that spruce plantations densely populated with aphids showed upto 75% needle loss. Count of needles showed that the main loss of needles were just after the peak aphid population. 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 preceding 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 measures 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 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, on aphid taxonomy much has been done, 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. Behura (1977) stated that evaluation of aphid population on different crops in relation to different varieties and dates of seedlings is very much essential for the formation of effective insecticidal control measures against the pest.

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

MATERIALS AND METHODS

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 (Plate 2a,c). 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) of twenty each were selected growing at different experimental sites. Seedling shoot length ranging from 15 to 20 cm (Plate 2b) were selected at random for C. attrotibialis and E. thunbergii and 6 to 9 cm (Plate 2d) for N. circumflexus. Sufficient care was taken to prevent loss of any aphid either by cutting and plucking the seedlings. Eacn 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, a characteristic view of which is given in Plate 2a. 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.

Plate 2a showing the 1975 plantation of 1 year old pine nurseries, where *Cinara attrotibialis* and *Eulachnus thunbergii* occurred.

b showing individual 1 year old pine seedling planted in 1975.

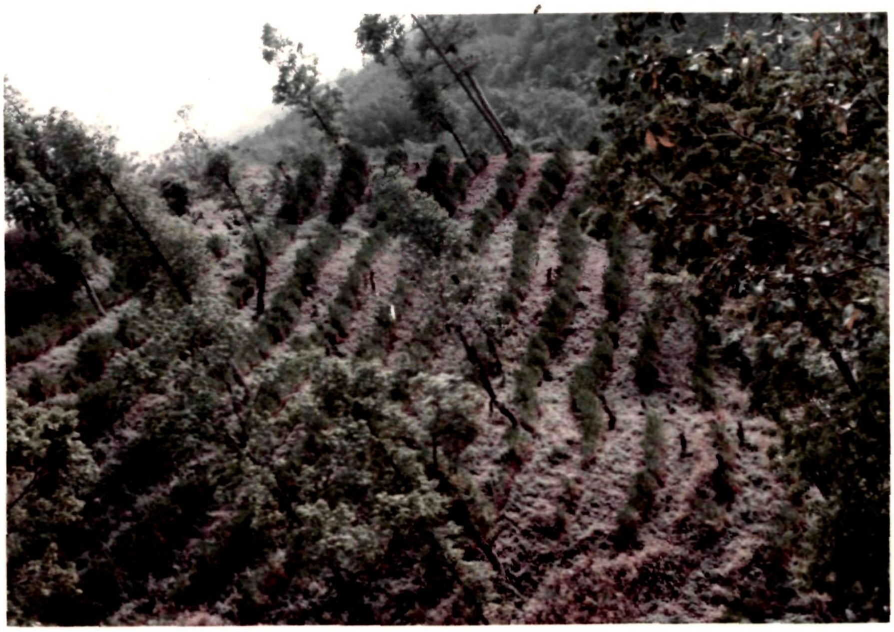
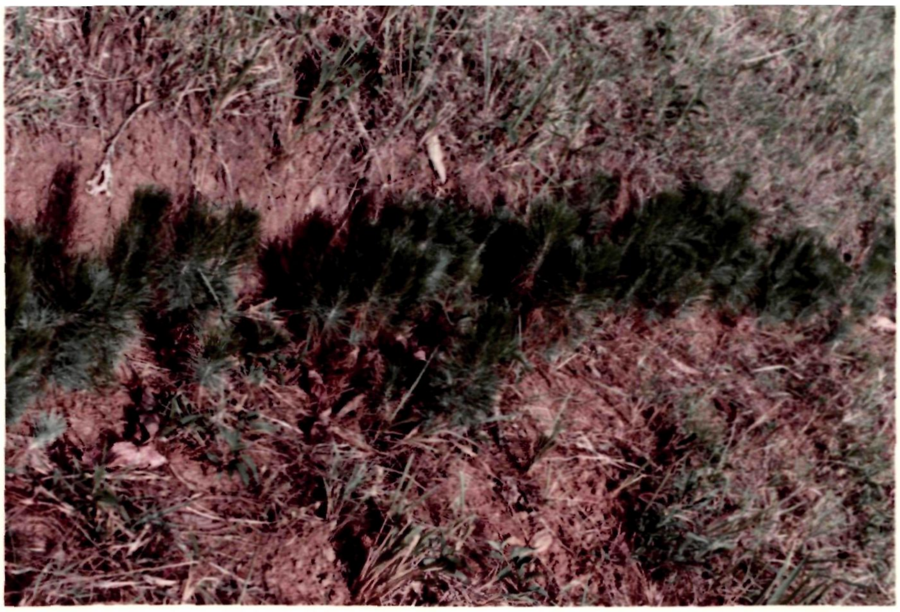


Plate 2c showing the 1976 plantation of 3 month old pine nurseries, where *Neomyzus circumflexus* occurred.

d showing individual 3 month old seedling planted in 1976



RESULTS

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 was first recorded in 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 1976-77 and 1977-78 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, 1976, after which a rapid decline was observed. Thus Cinara attrotibialis reached two peaks in one annual cycle (Fig. 2c). The first one in May, 1976 with the number of aphids 112 per 20 seedlings and the second during November, 1976, the number being 145 per twenty seedlings. Similarly, the lowest recorded 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 this annual cycle, the May 1977 peak recorded 94 aphids and the second peak was in November 1977, when the number reached 138. The lowest was observed one in March 1977 when the aphid number was 56 and the second one in September 1977 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, 1976 (2 per twenty seedlings) with complete absence in March and June, 1976. From July, 1976, onwards it started increasing gradually reaching a peak in January, 1977 of 58 aphids per twenty seedlings after which a sudden decline was recorded. The number then reached a minimum in April, 1977 (7 per twenty seedlings). From May 1977 onwards, it started increasing with considerable fluctuation and reached the peak in January, 1978 (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, 1976 and thereafter a gradual increase in the number occurred. The peak of 96 per twenty seedlings was recorded at the end of November, 1976 after which a rapid decline occurred reaching a minimum of 20 per twenty seedlings in the third week of April, 1977 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, 1977, the number being 2 to 3 per twenty seedlings and reached a peak during the third week of November, 1977 when the total population was 48 per twenty seedlings. Total absence was observed during July, last two weeks of September, first week of October, 1977 and first week of March,1978. However, the population was completely nil from the second week of April, 1978.

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$\pm$0.13°C to 24.38$\pm$0.68°C during 1976-77 the maximum being recorded in April, 1976 and minimum in January, 1977 and 13.21$\pm$0.68 to 24.46$\pm$0.52 during 1977-78. The maximum being recorded in August and minimum in January. During 1976-77, the maximum temperature in April was maintained upto September. It then gradually reached a minimum in January. From January, 1977 onwards it gradually increased till it reached the maximum in August and then decreased reaching the minimum in January, 1978. The minimum temperature range was 6.98$\pm$0.22 °C to 18.43$\pm$0.28°C during 1976-77, and 6.05$\pm$0.69 to 18.89 $\pm$0.09°C during 1977-78. The minimum temperature gradually increased and reached the peak in July, then decreased gradually to minimum in January, 1977. It started increasing gradually reaching the peak in July and gradually decreased to minimum in January, 1978 (Fig. 3b).

The monthly relative humidity (Fig. 3c) ranged from 53.25±2.57 to 87.42±1.55 percent during 1976-77, the minimum being in March, 1976 and the maximum in June and August, 1976 and 58.39±3.31 to 88.27±1.21 percent during 1977-78, the minimum being recorded in March, 1977 and maximum in July, 1977. The relative humidity from March, 1976 onwards gradually increased reaching the peak in June and August, 1977. It then gradually decreased to minimum in March, 1977. During 1977-78, it showed more or less a similar pattern of fluctuation.

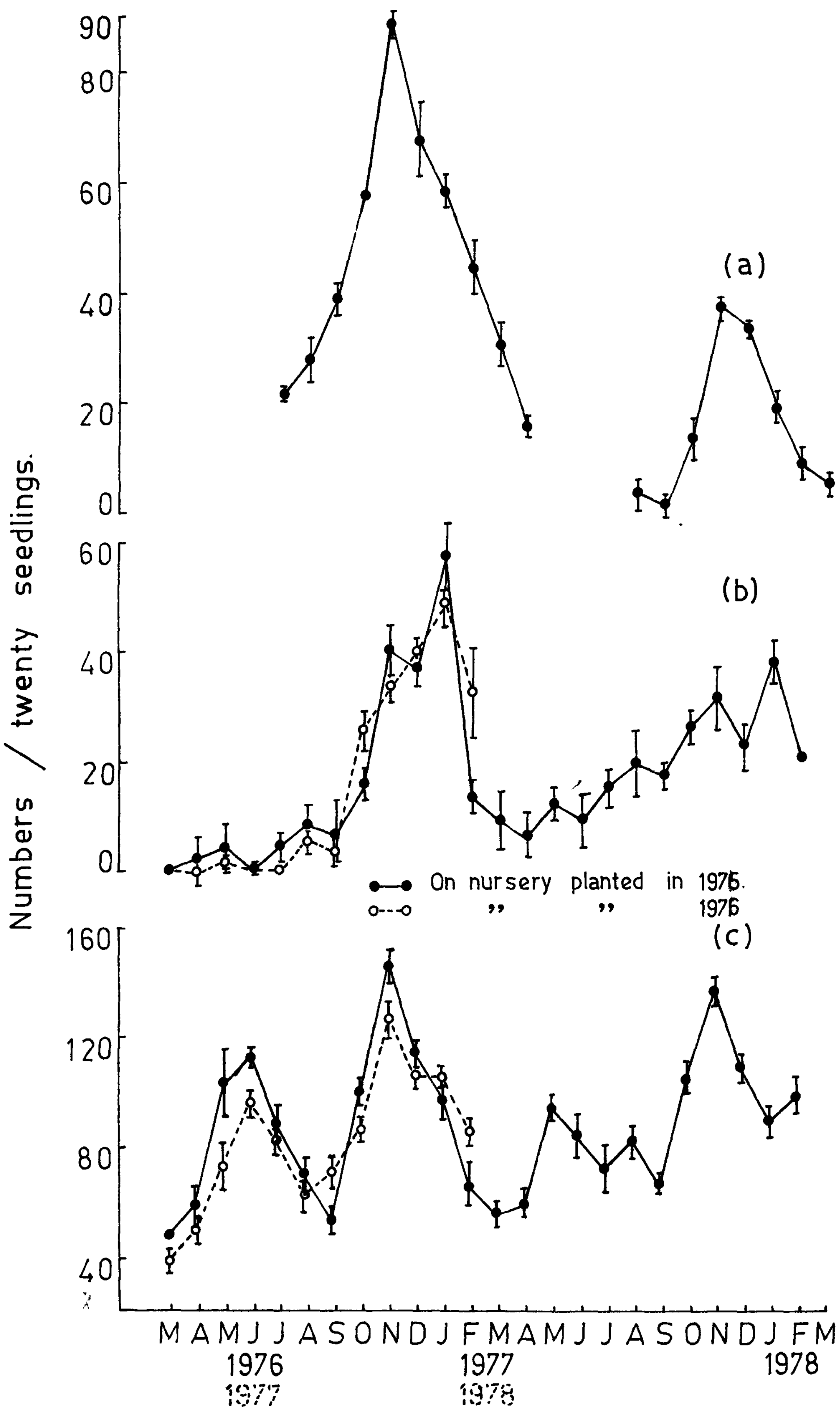
The rainfall ranged from 0 mm to 720.8 mm during 1976-77, the maximum being recorded in June, 1976 and nil being recorded in January, 1977 and 0 to 644.5 mm during 1976-77, the maximum being in May, 1977 and nil in January, 1978. During both the years, it showed more or less a similar type of fluctuation (Fig. 3a). From January it gradually increased with a sudden rise in May, 1976, reaching the maximum in June, 1976 after which it started gradually decreasing reaching nil in January. During 1977-78, 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, 1977 and was nil in January, 1978.

Figure 2 showing the seasonal fluctuation of the three pine aphids during the entire study period.

a *Neomyzus circumflexus* (Buckton)

b *Eulachnus thunbergii* Wilson

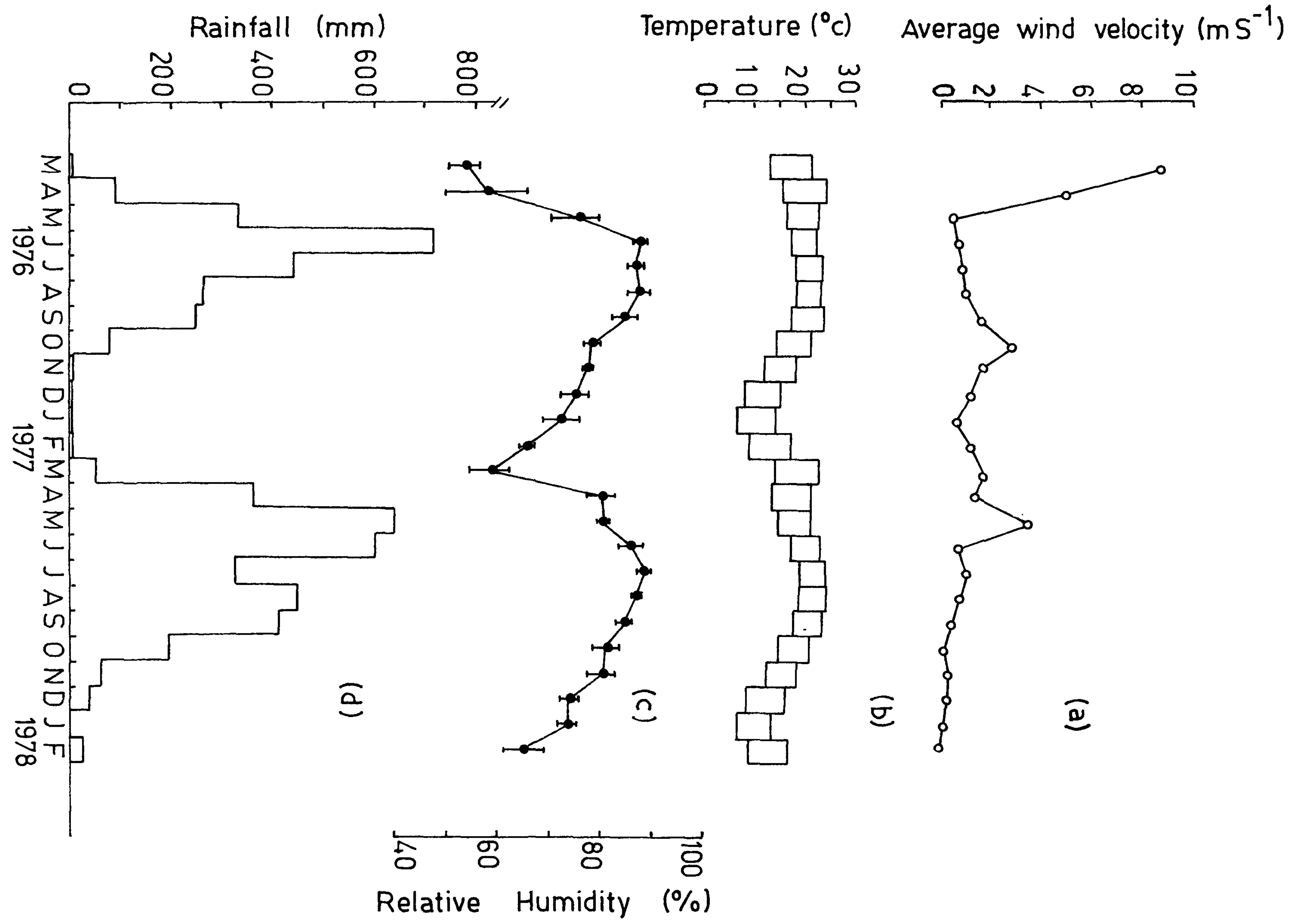
c *Cinara attrotibialis* David and Raja Singh



Numbers / twenty seedlings.
(a)
(b)
(c)
On nursery planted in 1975.
" " 1976
90
80
60
40
20
0
60
40
20
0
160
120
80
40
M A M J J A S O N D J F M A M J J A S O N D J F M
1976
1977
1977
1978
1978

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



Average wind velocity (m S[-1])
Temperature (°c)
Rainfall (mm)
Relative Humidity (%)
(a)
(b)
(c)
(d)
M A M J J A S O N D J F M A M J J A S O N D J F
1976
1977
1978

DISCUSSION

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 uld plantations during the two annual cycles (1976-77 and 1977-78). 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 (1977-78), *C. attrotibialis* and *E. thunbergii* showed a marked difference in their population abundance.

This may be due to the fact that during 1976-77, the seedlings had very soft tissue as they were then one year old, but during 1977-78, the plant tissue hardens as they grow, which might influence the migration of *C. attrotibialis* and *E. thunbergii* to plantations of softer plant tissues. Such plantations in the present study revealed populations being more or less constant yearafter year. The non-suitability of needles, could also have been influenced by a high population of aphids in the previous year (Parry, 1976).

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).

Both climate and weather play a significant role in the population dynamics of aphids (Behura, 1977; Mclean et al, 1977). Hughes (1972) stated that changes in environmental factors are associated with changes in aphid population number. In favourable weather, aphids multiply so rapidly that they soon reach the pest status (Dixon, 1973; Peterson, 1962). Climate influenced the distribution and abundance of woolly aphid populations, not only geographically but also within trees (Greenbank, 1970). Hodek et al (1972) went one step further and showed microclimatic influences affecting aphid abundance directly and indirectly. Rapid increase of aphid population could be possible under ideal temperature conditions (Parry, 1969; 1973). Dixon (1973) also reported that the rate of development of aphids and their fecundity were affected to a large extent by changes in temperatures.

The present study, clearly indicated that for the populations of E. thunbergii 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. thunbergii 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 the years 1977 and 1978 respectively. 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 effrcts of temperatures, as in the other species, but the former peak distinctly had a positive relationship.

A coefficient correlatiun 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 (Broadbent, 1953; Schreier, 1953; Fisken, 1959; Meier, 1959; Heie and Pertersen, 1961; Adams, 1962; Hughes, 1963; Daiber, 1964; Parry, 1969; Greenbank, 1970; Powell, 1974; Thambs-Lyche, 1975; Parry and Powell, 1977; Powell and Parry, 1976) in contrast, very few reports are available on low temperature being favourable for aphid multiplication (Dixon, 1973; Saxena and Rizvi, 1974;

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

TABLE II

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

NS = Not significant

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 per-cent 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. thunbergii* 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 (Markkula, 1953; Taylor, 1955; Kennedy *et al*, 1958; 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 corraborated 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 g 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 (Ullyett, 1947; Van Rensburg, 1973). Moreover, it is known that the effect of relative humidity on field population of aphids is highly controversial (Rivnary, 1938 and Hodek et al, 1972).

In the present study to further establish the effect of environmental factor under consideration on the population of three species of aphids a multiple correlation coefficient and 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 (Ohnesorge, 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 and enemies 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.

In conclusion, 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.

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CHEWING AND MINING CONSUMER ARTHROPODS

INTRODUCTION

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. Canteln 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. guyumi (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 fur 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 seems 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 phermone (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, sometimes 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 interrelationships 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 William's 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.

MATERIALS AND METHODS

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 moonday 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 (Plate 3b). 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 (Plate 3a). 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.

Plate 3a showing the 1955 plantation of 22 year old trees where light-trapping was conducted.

b Light-trap in use.

RESULTS

During the present investigation it was seen that insects of 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).

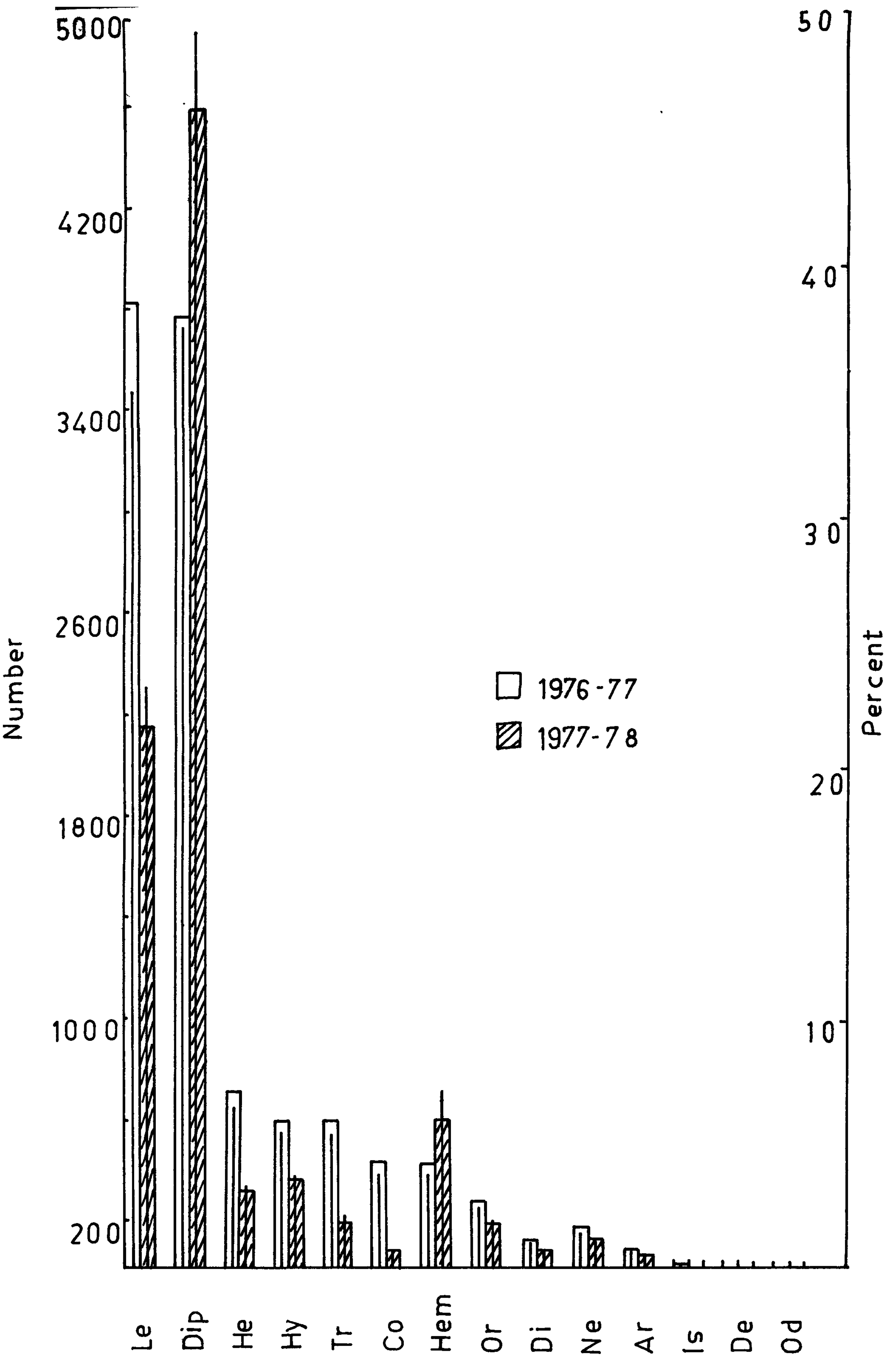
During 1976-77, the first year of study, Lepidoptera was the most abundant group representing 34.81 percent, followed by Diptera 34.39 percent, Heteroptera 6.36 percent, Hymenoptera 5.4 percent, Trichoptera 5.34 percent, Coleoptera and Hemiptera 3.8 percent each, Orthoptera 2.5 percent, Neuroptera 1.51 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 (1977-78) 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 1976-77 and 1977-78 data (Fig. 4)

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 = Odonata



Number
5000
4200
3400
2600
1800
1000
200
Percent
50
40
30
20
10
1976-77
1977-78
Le
Dip
He
Hy
Tr
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Or
Di
Ne
Ar
Is
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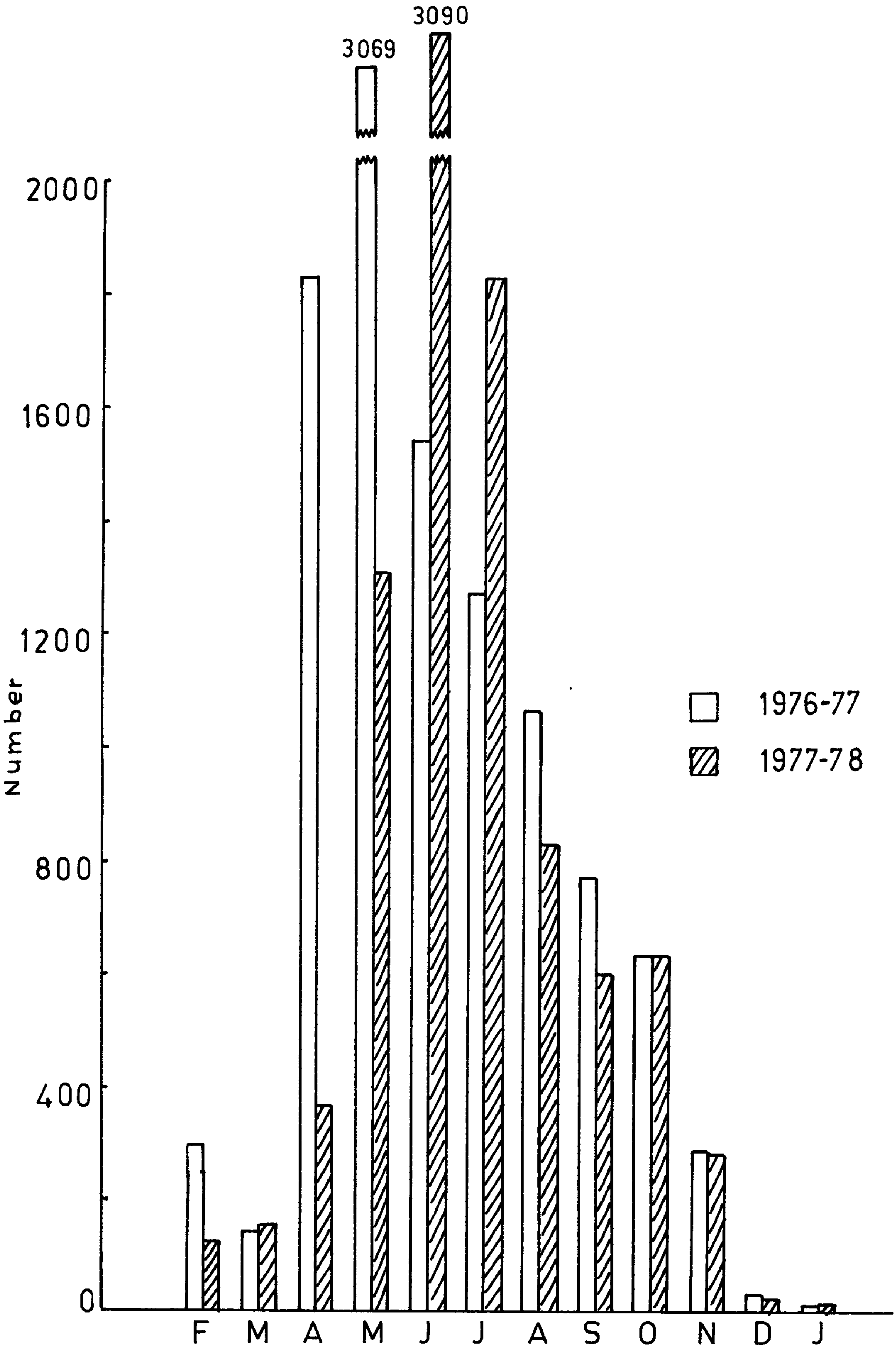
Od

revealed that the overall catch of 1976-77 was larger than that of 1977-78. Diptera and Hemiptera caught were more during 1977-78 than that of 1976-77 in the seasonal abundance of total insect consumers (Fig. 5). The total maximum catch was in the month of May, 1976 representing 3069 individuals. It then started decreasing and reached a low ebb in January, 1977 when only 15 individuals were caught. From February it increased till the maximum number of insects caught was in June, 1977 representing 3090 individuals, after which it decreased reaching a minimum in January, 1978 following the same trend as in the previous years.

The relationship between the monthly abundance of different orders of insects for both the years (1976-77 and 1977-78) is presented in Table-III. A positively significant relationship ($P < 0.01$) for the orders Diptera, Hymenoptera, Heteroptera, Orthoptera, Dictyoptera and Neuroptera exist and 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 during 1976-77 whereas no significance existed during 1977-78. 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

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



3090
3069
2000
1600
1200
800
400
0
Number
1976-77
1977-78
F
M
A
M
J
J
A
S
O
N
D
J

Table III Coefficient correlation between the monthly abundance of various insect orders for 1976-77 and 1977-78

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 IVa Coefficient correlation between the monthly abundance of total insects, various insect orders and monthly variation in the various abiotic factors for the year 1976-77.

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

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 IVb Coefficient correlation between the monthly abundance of total insects, various insect orders and monthly variation in the various abiotic factors for 1977-78

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

* = $P < 0.05$

** = $P < 0.01$

years, the correlation was greater during the year 1977-78 ($P < 0.01$) than the year 1976-77 ($P < 0.05$). Relative humidity also had a positive relationship with the total insect catch during 1977-78 ($P < 0.05$), whereas no relationship was seen during 1976-77. 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-V a,b which revealed that during the first year (1976-77) it was recorded maximum during 2000-2100 hrs. representing 15.07 percent of the total night's insect catch, while the minimum was during the early morning hours (0500-0600 hrs.) representing 0.22 percent. During 1977-78, 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 the maximum catch of 33.71% and 30.24% respectively, showing the first half of the night for the maximum number of insects caught.

However, for each month the maximas during different quarters of the night varied. During February, October and December, 1976, till March, 1977 and from November, 1977 to January, 1978, the maximum insect catch was confined to 1800 -2100 hrs. whereas in March, April, June, July and November, 1976, April, June, July and October, 1977, the maximum

Table Va An hourly analysis of the total insects and various insect orders caught in light trap during 1976-77

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 Va

Insect Orders	1	2	3	4	5	6	7	8	9	10	11	12
Lepidoptera	489 12.78	191 4.99	623 16.28	361 9.44	402 10.51	418 10.93	352 9.20	278 7.27	421 11.00	220 5.75	71 1.86	0 0
Diptera	288 7.65	296 7.84	380 10.06	259 6.86	522 13.82	377 9.98	427 11.31	378 10.01	449 11.89	311 8.23	72 1.91	18 0.48
Heteroptera	3 0.43	66 9.57	195 28.26	111 16.09	110 15.94	70 10.14	40 5.80	46 6.67	29 4.20	15 2.17	5 0.72	0 0
Hymenoptera	27 4.55	35 5.90	67 11.30	37 6.24	51 8.60	44 7.42	30 4.06	32 5.40	26 4.38	189 31.87	52 8.77	3 0.51
Trichoptera	16 2.65	33 5.46	97 16.06	61 10.10	67 11.09	61 10.10	67 11.09	54 8.94	81 13.41	61 10.10	4 0.66	2 0.33
Coleoptera	37 8.47	48 10.98	119 27.23	43 9.84	41 9.38	28 6.41	41 9.38	18 4.12	34 7.78	24 5.49	4 0.92	0 0
Hemiptera	21 5.26	49 11.21	47 11.78	33 8.27	40 10.03	48 12.03	42 10.53	40 10.03	14 3.51	57 14.29	7 1.75	1 0.25
Orthoptera	25 9.16	44 16.12	55 20.15	18 6.59	29 10.62	18 6.59	15 5.49	25 9.16	14 5.13	21 7.69	9 3.30	0 0
Neuroptera	20 11.83	11 6.51	35 20.71	7 4.14	15 8.88	17 10.06	16 9.47	14 8.28	17 10.06	12 7.10	5 2.96	0 0
Dictyoptera	4 3.45	11 9.48	24 20.69	11 6.51	18 10.65	20 17.24	16 13.79	8 6.90	3 2.59	1 0.86	0 0	0 0
Arachnida	3 8.33	6 16.67	3 8.33	6 16.67	1 2.78	2 5.56	0 0	3 8.33	6 16.67	4 11.11	2 5.56	0 0
Isoptera	6 54.55	0 0	3 27.27	1 9.09	0 0	0 0	0 0	0 0	1 9.09	0 0	0 0	0 0
Dermaptera	0 0	0 0	0 0	2 50.00	0 0	0 0	1 25.00	0 0	0 0	1 25.00	0 0	0 0
Odonata	0 0	0 0	0 0	1 50.00	0 0	0 0	0 0	0 0	1 50.00	0 0	0 0	0 0
Total Insects	939 8.59	790 7.22	1648 15.07	950 8. 69	1296 11.85	1103 10.09	1047 9.57	896 8.19	1096 10.02	916 8.38	230 2.10	24 0.22

Table Vb An hourly analysis of the total insects and various insect orders caught in light trap during 1977-78.

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 2.44	229 4.77	377 7.85	572 11.91	382 7.95	1308 27.23	617 12.84	207 4.31	521 10.85	232 4.83	143 2.98	99 2.06
Lepidoptera	274 12.76	107 4.98	288 13.41	228 10.61	265 12.34	252 11.73	188 8.75	191 8.89	185 8.61	110 5.12	60 2.79	0 0
Coleoptera	29 4.11	73 10.35	118 16.74	103 14.61	48 6.81	64 9.08	89 12.62	64 9.08	71 10.07	40 5.67	4 0.57	2 0.28
Homiptera	45 7.14	58 9.21	135 21.43	94 14.92	40 6.35	68 10.78	63 10.00	45 7.14	36 5.71	14 2.22	22 3.49	10 1.59
Hymenoptera	13 3.79	38 11.08	61 17.78	48 13.99	33 9.62	46 13.41	20 5.83	21 6.12	17 4.96	36 10.50	9 2.62	1 0.29
Heteroptera	4 1.30	36 11.69	36 11.69	68 22.08	23 7.47	42 13.64	25 8.12	9 2.92	21 6.82	38 12.34	6 1.95	0 0
Orthoptera	34 18.89	51 28.33	21 11.67	16 8.89	10 5.56	17 9.44	11 6.11	9 5.00	1 0.56	6 3.33	0 0	4 2.22
Trichoptera	7 3.87	21 11.60	13 7.18	11 6.11	22 12.15	46 25.41	19 10.50	5 2.76	14 7.73	10 5.52	12 6.63	1 0.55
Neuroptera	2 1.61	14 11.29	32 25.81	19 15.32	14 11.29	12 9.68	14 11.29	7 5.65	8 6.45	1 0.81	1 0.81	0 0
Dictyoptera	0 0	35 49.30	8 11.27	4 5.63	6 8.45	6 8.45	1 1.41	4 5.63	5 7.04	0 0	2 2.82	0 0
Arachnida	1 1.25	7 8.75	9 11.25	8 10.00	12 15.00	8 10.00	5 6.25	8 10.00	10 12.50	11 13.75	1 1.25	0 0
Dermaptera	0 0	0 0	0 0	0 0	0 0	0 0	1 50.00	0 0	0 0	1 50.00	0 0	0 0
To al Insects	526 5.55	567 5.98	1098 11.59	1171 12.36	855 9.02	1869 19.73	1053 11.11	570 6.02	889 9.38	499 5.27	260 2.74	117 1.23

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.

TABLE VI

Months	1st Quarter 1800-2100hrs.	2nd Quarter 2100-2400hrs.	3rd Quarter 2400-0300hrs.	4th Quarter 0300-0600hrs.	1st Half 1800-2400hrs.	2nd Half 2400-0600hrs.
February '76	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 '77	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 '78	60.00	20.00	13.34	6.66	80.00	20.00

catch was recorded during 2100-2400 hrs. and in May, August, September, 1976 and 1977, 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, 1976.

Diptera :-

Diptera were one of the most abundant groups of insects caught in the present light trap, representing a total of 8382 individuals. During the year 1976-77 this order was next only to Lepidoptera constituting 34.39 percent of the total insect catch (Fig. 4). However, during 1977-78 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 1976-77, diptera trapped were maximum comprising 926 individuals in May, 1976 and gradually decreased with a small peak of increase in October, 1976 and reached its low ebb in January, 1977 representing only four individuals. From May, 1977 onwards, the abundance gradually increased to reach its peak of abundance in June, 1977 representing 1658 individuals. Once again it decreased however, with a slight increase in October, 1977 and reached its lowest ebb in January, 1978 representing only 5 individuals (Fig. 6).

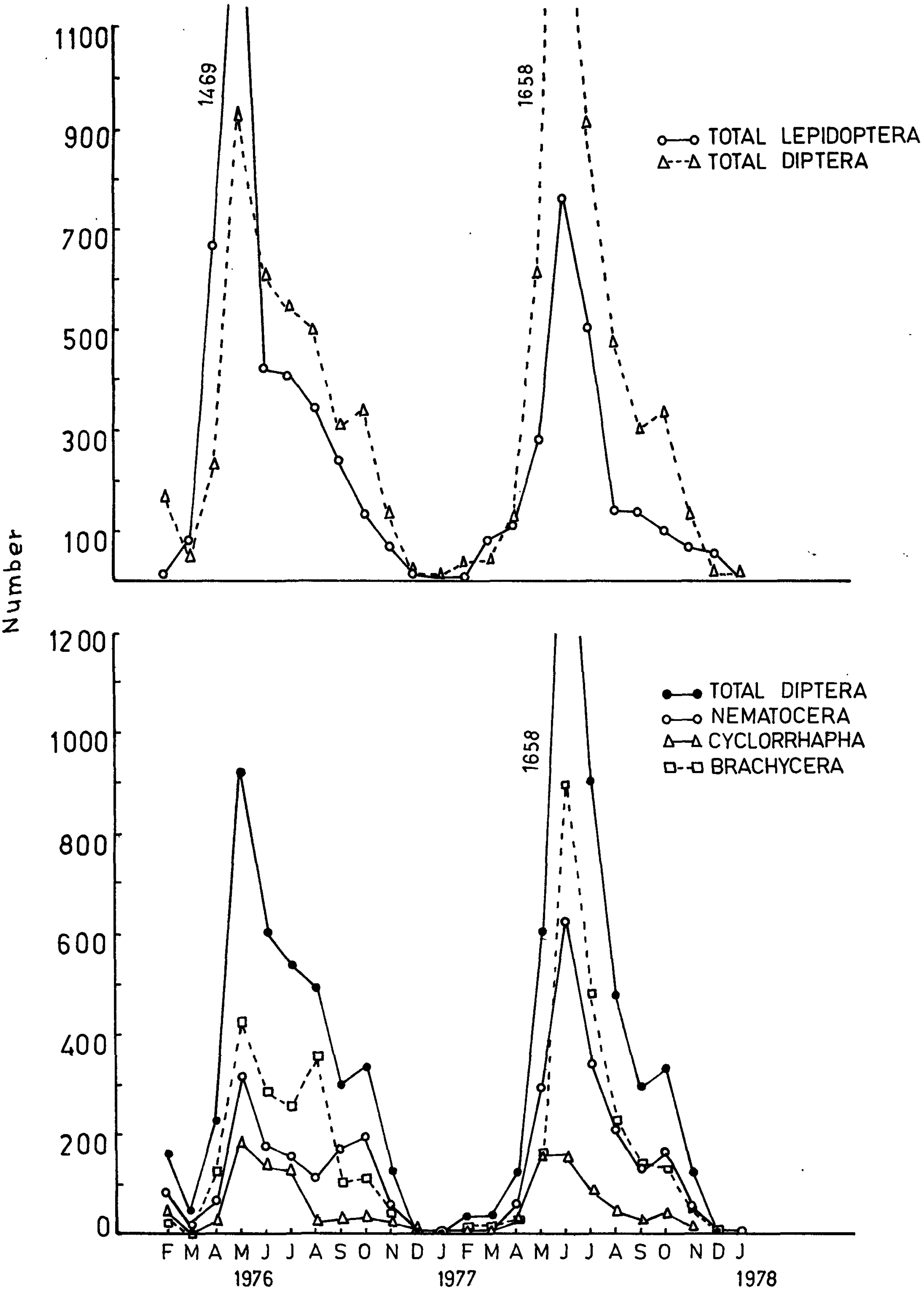
An analysis of the relationship between the monthly relative abundance of diptera and various environmental factors is presented in Table-IV which revealed that the maximum temperature had a positive significant correlation ($P < 0.05$) with the dipteran catch during 1976-77, whereas no signifiant relationship existed during 1977-78. The relationship between the minimum temperature and diptera caught was positively significant at $P < 0.01$ level during 1976-77 and at $P < 0.05$ level during 1977-78. The rainfall had a positive correlation, significant at $P < 0.01$ level during both the years, 1976-77 and 1977-78. 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 during 1977-78 and no significant relationship during 1976-77.

During the present investigation, the diptera caught in the light trap were identified only upto the sub-order level due to limitations of species identification. The diptera caught 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 1976-77 Brachycera had its peak of abundance in May, 1976 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, 1977. From January, 1977 onwards, it reappeared and gradually increased

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.


1100
900
700
500
300
100
1469
1658
TOTAL LEPIDOPTERA
TOTAL DIPTERA
Number
1200
1000
800
600
400
200
0
1658
TOTAL DIPTERA
NEMATOCERA
CYCLORRHAPHA
BRACHYCERA
F M A M J J A S O N D J F M A M J J A S O N D J
1976
1977
1978

till it reached a peak in June, 1977 representing 895 individuals (22.93 percent) and then it gradually decreased reaching its lowest in January, 1978 representing only 2 individuals (0.05 percent).

Nematocera showed its peak abundance in May, 1976 representing 317 individuals (9.72 percent). From June, 1976 it started decreasing with a slight increase in September reaching its second peak of abundance in October, 1976 representing 190 individuals (5.85 percent). Then it decreased reaching its minimum in January, 1977 representing only 3 individuals (0.09 percent). From February, 1977 onwards it started increasing gradually and reached its maximum abundance in June, 1977 representing 626 individuals (19.21 percent). Then it started decreasing gradually with a small peak of increase in October, 1977 representing 159 individuals (4.88 percent) and reached its minimal in January, 1978 representing only 2 individuals (0.06 percent).

Cyclorrhapha was caught maximum in May, 1976 representing 185 individuals (15.19 percent). Then it started decreasing with a slight increase in October, 1976 and disappeared completely in January, 1977. 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, 1977 and disappeared completely in December, 1977 with a negligible number (0.08 percent) in January, 1978.

An analysis of hourly abundance of diptera revealed that for 1976-77 they were caught maximum during 2200-2300 hrs.

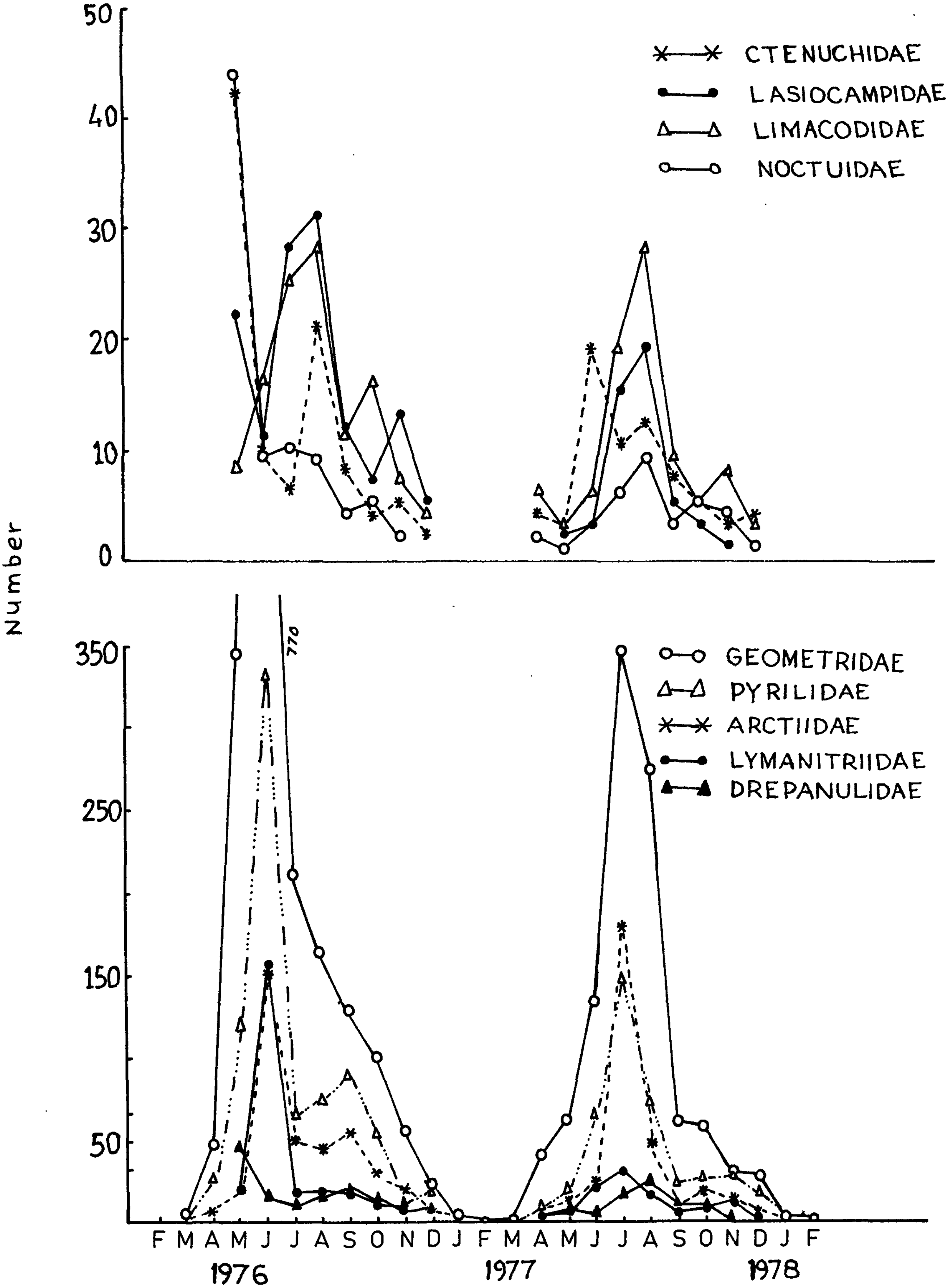
representing 13.82 percentage of total night catch followed by the period 0200-0300 hrs. representing 11.89 percent. The least catch was recorded during the hours 0500-0600, which represented only 0.48 percentage. However, during 1977-78 it was seen that they reached the peak of their abundance during 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, 1976 and June, 1977 recorded the most abundant, represented by 1469 and 757 individuals respectively. From June, 1976 the total Lepidoptera caught decreased gradually reaching a minimum in January, 1977 when only 3 individuals were caught. It started increasing gradually thereafter and reached the peak again in June, 1977 and declined till the minimum was observed in January, 1978.

An analysis of the relationship between the total moth catch and the different environmental factors is presented in Table-IVa,b. The maximum temperature during both the years and minimum temperature during 1976-77 had no significant relationship with Lepidoptera caught. However, the minimum temperature showed a significant relationship ($P < 0.05$) during 1977-78. The relationship between the total rainfall and Lepidoptera caught was positively significant ($P < 0.05$) during 1977-78. But there was no significant relationship during

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.



50
40
30
20
10
0
CTENUCHIDAE
LASIOCAMPIDAE
LIMACODIDAE
NOCTUIDAE
Number
350
250
150
50
770
GEOMETRIDAE
PYRILIDAE
ARCTIIDAE
LYMANITRIIDAE
DREPANULIDAE
F M A M J J A S O N D J F M A M J J A S O N D J F
1976
1977
1978

1976-77. There was no relationship either between the wind velocity or relative humidity and the 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, 1976 (770 individuals) and June, 1977 (337 individuals), during the study period. From June, 1976 onwards it started decreasing gradually and disappeared during January-February, 1977. It reappeared in March, 1977 and reached the peak in June, 1977, thereafter declining till it reached the lowest in January, 1978. In this family Acidalia Sp. was the most dominant followed by Craspedia remotata Guenea.

The family Geometridae was followed by the family Pyralidae in abundance (Fig. 8). The family Pyralidae represented two peaks, the larger in May, 1976 and the smaller in August, 1976 numbering 330 and 89 individuals respectively. It was minimum in February, 1976 with only two individuals. During 1977-78 this family was maximum in June, 1977 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, 1976 and June, 1977 representing 150,54 and 176 individuals respectively (Fig. 8). The minimum number was recorded during February and December, 1976, January and February, 1977 and

January, 1978 represented by cnly one individual. In this family *Asura undalosa* Walker was found to be 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, 1976 and June, 1977 representing 157 and 30 individuals respectively. The minimum number were recorded during February and March, 1976, November, 1976 to February, 1977, December, 1977 and January, 1978. *Euproctis divisa* Walker was the most dominant species.

The family Noctuidae represented peak periods of abundance in April, 1976 and July, 1977 numbering 47 and 24 individuals respectively (Fig. 8). The minimum number was recorded in October, 1976 and February, 1977. This family was completely absent during February and March and December, 1976 and January, November and December, 1977 and January, 1978. *Bleptina* sp. nr. *hadenalis* Moore was the most dominant species.

The family Limacodidae represented its peaks of abundance in July, 1976 and 1977 numbering each time 28 individuals. T The minimum number was recorded in November, 1976, April and November, 1977 representing 4 and 3 individuals respectively. The family was completely absent in February and March, 1976, December, 1976 to February, 1977 and December, 1977 and January, 1978. *Lenodora* Sp. was the most dominant group followed by *Thosea cana* Walker.

The family Lasiocampidae was maximum during July, 1976 and 1977 representing 31 and 19 individuals respectively. The minimum number was recorded during November, 1976 and October, 1977 and was completely absent during February and March, 1976, December 1976 to March, 1977, November, 1977 to January, 1978.

The family Drepanulidae was listed by Drepana pallida Moore. It was recorded maximum in April, 1976 with a larger peak (44 individuals) and June, 1976 and July, 1977 with smaller peaks (10 and 9 individuals respectively). It was completely absent during February and March, 1976, November, 1976, February, 1977 and December, 1977 to January, 1978.

The family Ctenuchidae was listed by Eressa affinis Moore which was recorded maximum in April, 1976 and May, 1977 with large peaks, and in July, 1976 and 1977 with small peaks. This family was recorded minimum during November, 1976, April and October, 1977 and completely absent during February and March, 1976, December, 1976, February, 1977 and December, 1977 and January, 1978.

An analysis of hourly catches of Lepidoptera is presented in Table-Va,b, which revealed during 1976-77 and 1977-78, the catch was highest during 2000-2100 hrs. representing 16.28 percent and 13.41 percent of the total night's catch respectively. The lowest catch was recorded during 0400-0500 hrs. representing only 1.86 percent and 2.76 percent in 1976-77 and 1977-78 respectively. The moth catch was completely nil during 0500-0600 hrs.

Coleoptera :

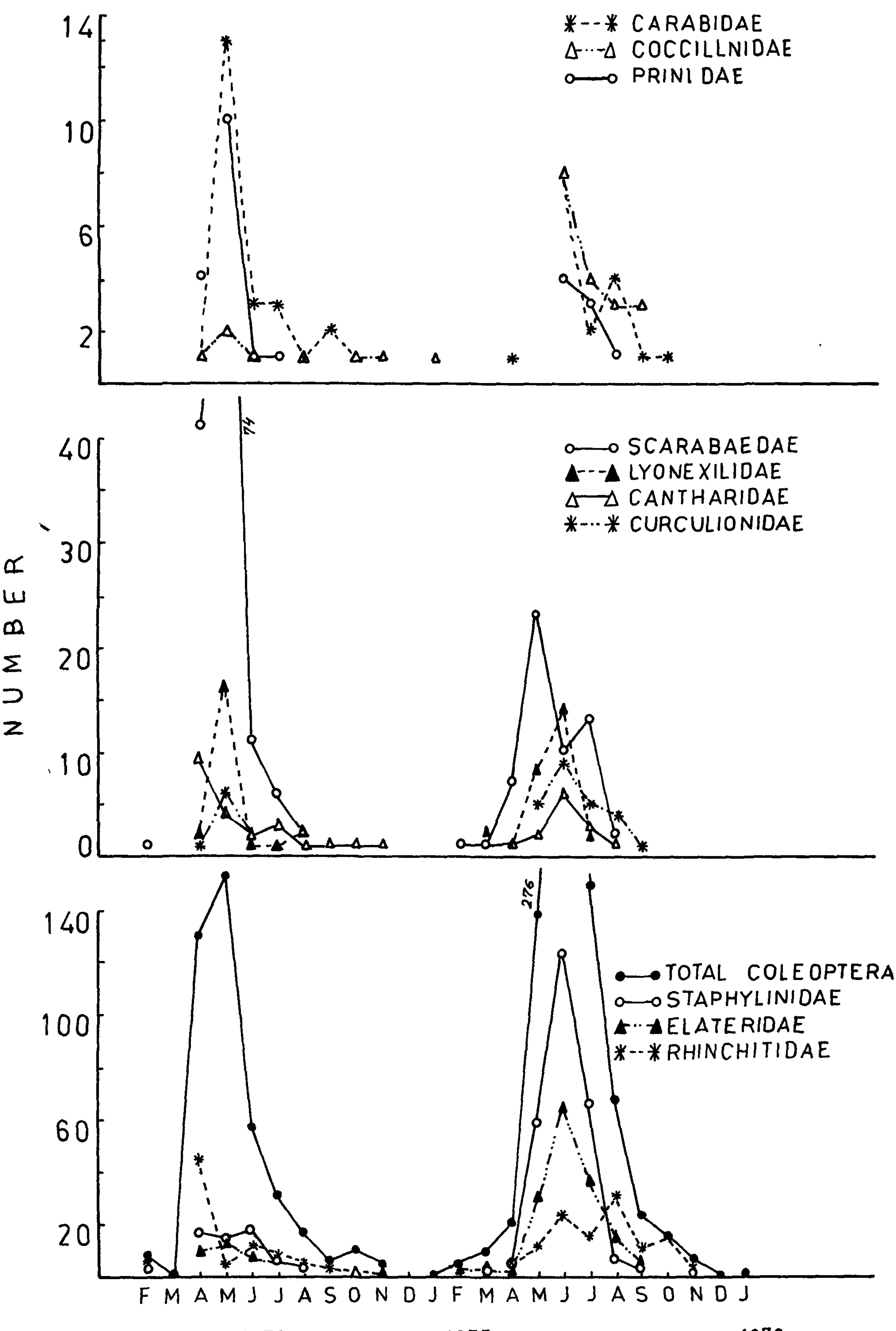
Coleoptera represented 426 (3.8%) individuals during the year 1976-77 and 681 (7.35%) during the year 1977-78 (Fig. 4). Monthly relative abundance of coleoptera with it families is presented in Fig. 9, a perusal of which revealed that the peak abundance occurred during May, 1976 representing 153 individuals. It was absent during March and December, 1976. It reappeared again in January, 1977 and gradually increased reaching its peak in the month of June, 1977 representing 275 individuals. Then it gradually decreased representing the minimum catch in the month of December, 1977 numbering only 3 individuals and completely disappeared in January, 1978.

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 caught during 1976-77. However, the relationship was positively significant ($P < 0.01$) for the following year 1977-78.

Coleoptera was represented by the families: Scarabaeidae, Elateridae, Rhinchitidae, Staphylinidae, Cantharidae, Curculionidae, Chrysonelidae, 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).

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



CARABIDAE
COCCILLNIDAE
PRINI DAE
SCARABAEDAE
LYONEXILIDAE
CANTHARIDAE
CURCULIONIDAE
TOTAL COLEOPTERA
STAPHYLINIDAE
ELATERIDAE
RHINCHITIDAE
NUMBER
74
276
14
10
6
2
40
30
20
10
0
140
100
60
20
F M A M J J A S O N D J F M A M J J A S O N D J
1976
1977
1978

Staphylinidae was at its peak of abundance in June, 1976 and 1977 representing 17 and 122 individuals respectively. From July, 1976 it started decreasing with complete disappearance in December, 1976 and January, 1977 and again it increased in number from March, 1977 reaching its peak in June. Then it started decreasing and disappeared completely in December, 1977 and January, 1978.

Rhinchitidae was maximum in April, 1976 representing 45 individuals. Then it started decreasing with a slight increase in June, 1976 and fell thereafter, It started increasing again from February, 1977 reaching its peak in June, 1977 representing 23 individuals. It was completely absent in March, 1976, December, 1976 and 1977 and January, 1977 and 1978.

Elateridae represented its peak of abundance in May, 1976 representing 13 individuals. Then it gradually decreased till it disappeared during December, 1976 and January, 1977. This group again made its appearance in February, 1977 and with a gradual increase reached its peak in June, 1977 representing 65 individuals. From July, 1977 it decreased gradually in number and disappeared thereafter.

Scarabaeidae is the only family which represented more in 1976-77 than that of 1977-78. It was at its peak of abundance in May, 1976 and 1977 representing 74 and 23 individuals respectively. From June, 1976 and July, 1977 onwards it decreased gradually. It was completely absent from September to January, during both the annual cycles. The remaining families represented maximum in May, 1976 and June, 1977 and were not represented in number 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 1976-77 and 16.74 percent of the total night catch in 1977-78, followed by 1900-2000 hrs. in 1976-77 representing 10.98 percent and 2100-2200 hrs. in 1977-78 representing 14.61 percent. The least catch was recorded during 0500-0600 hrs. which was nil in 1976-77 and 0.28 percent in 1977-78.

Hymenoptera :-

Hymenoptera represented 592 (5.4 percent) and 343 (3.7 percent) during 1976-77 and 1977-78 (Fig. 4). The monthly abundance of Hymenoptera is presented in Fig. 10, a perusal of which revealed the gradual increase from March, 1976, reaching a peak in June, 1976 representing 223 individuals (38.01 percent). From July, 1976 it started decreasing with a small peak of increase in September, 1976, representing 83 individuals (14.02 percent) reaching the minimum in January, 1977 representing 2 individuals (0.34 percent). In 1977-78, 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, 1977 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, 1976 representing 171 individuals (18.28%) of the total hymenoptera. Then it started decreasing with a small peak of increase in September, 1976 and reached minimum in December, 1976 and January, 1977 representing only 1 individual. Then it increased with a slight peak in September, 1977 representing 24 individuals. From October, 1977 it gradually decreased reaching a low ebb in Jabiary, 1978 when it was only 1 individual.

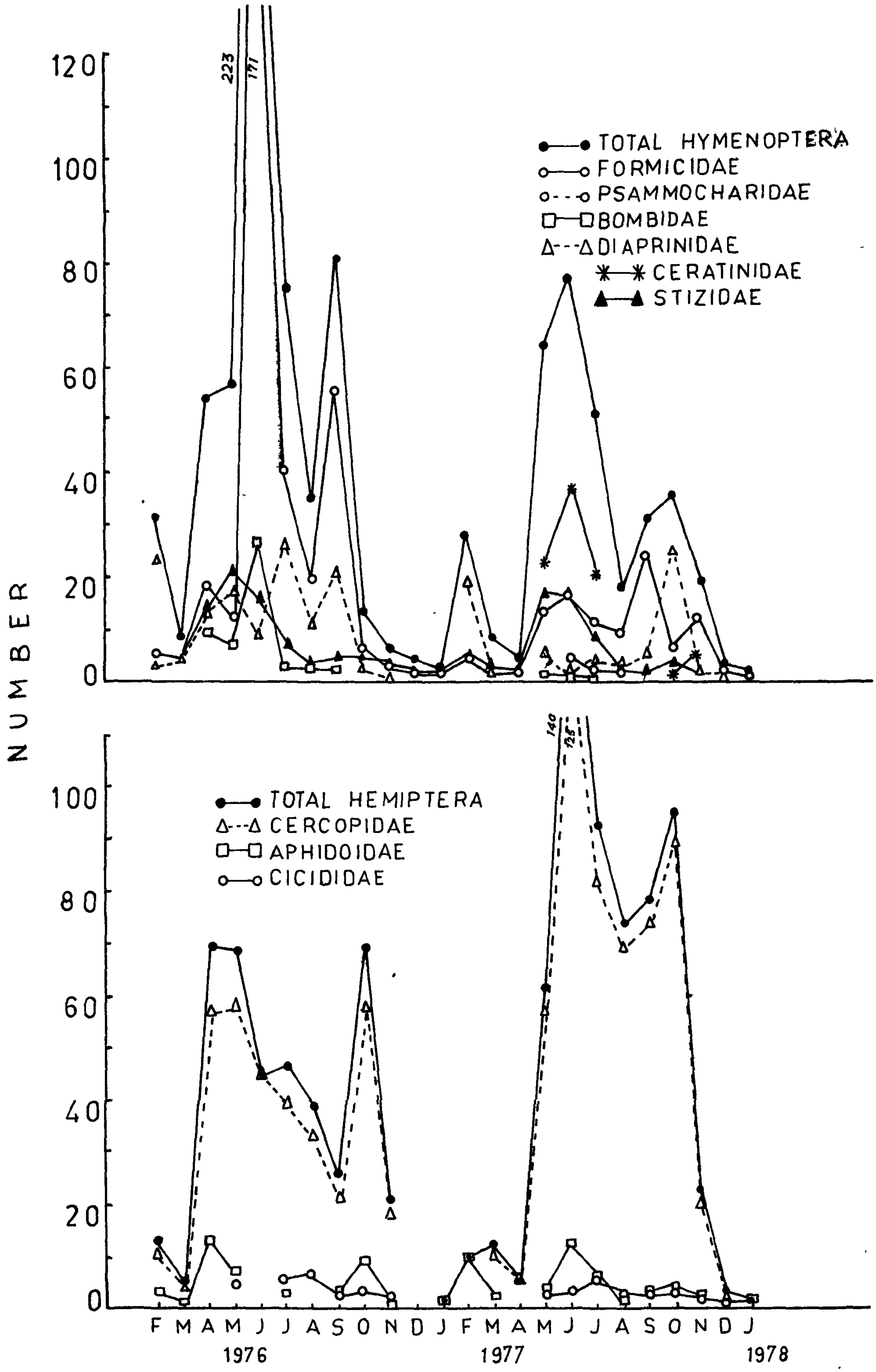
Diaprinidae was caught maximum during July, 1976 and October, 1977 representing 26 individuals (2.78%) and 25 individuals (2.67%) respectively. This family was completely absent during December and January for both the years.

Ceratinidae was maximum in June, 1977 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 during 1976-77 they were maximum during 2000-

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.



NUMBER
120
100
80
60
40
20
0
223
171
TOTAL HYMENOPTERA
FORMICIDAE
PSAMMOCHARIDAE
BOMBIDAE
DIAPRINIDAE
CERATINIDAE
STIZIDAE
140
125
TOTAL HEMIPTERA
CERCOPIDAE
APHIDOIDAE
CICIDIDAE
F M A M J J A S O N D J F M A M J J A S O N D J
1976
1977
1978

2100 hrs. representing 11.30 percent of the total night's catch, followed by 2200-2300 hrs. representing 8.60 percent. In June, 1976 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 night's 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. During 1977-78, the maximum catch was recorded during 2000-2100 hrs. representing 17.78 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 during the year 1976-77 and 595 (6.42%) during the year 1977-78 (Fig. 4). The monthly relative abundance of total hemiptera caught is presented in Fig. 11, a perusal of which revealed that during 1976-77 they were in peak abundance during April-May, 1976 representing 70 (16.67%) individuals and during October, 1976 with about 75 (17.86%) individuals. The least catch of hemiptera was recorded in January, 1977 for the period 1976-77. During 1977-78 from February, 1977 it started increasing reaching the maximum in June, 1977 representing 140 (23.58%) individuals. Then it decreased in number with a small peak of increase in October, 1977 representing a catch of 93 (15.63%) individuals. The least catch was recorded in January, 1978 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 the maximum temperature had a positive correlation ($P < 0.05$) with the seasonal abundance of Hemiptera. The minimum temperature also had a positive relationship, it being significant at $P < 0.05$ level during 1976-77 and $P < 0.01$ level during 1977-78. The total rainfall and relative humidity also showed a positive significant correlation ($P < 0.01$) during 1977-78 whereas, no relationship was seen during 1976-77. The wind velocity showed no relationship with their seasonal abundance for 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, 1976 representing 58 individuals (5.78%) each time. In 1977-78, the peak periods of abundance were June and October, 1977 representing 125 individuals (12.45%) and 90 individuals (8.96%) respectively. This group was entirely absent during December, 1976 to February, 1977 and January, 1978. 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 during 1976-77 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 least catch was recorded during 0500-0600 hrs. which represented only 0.25 percent. During 1977-78 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.

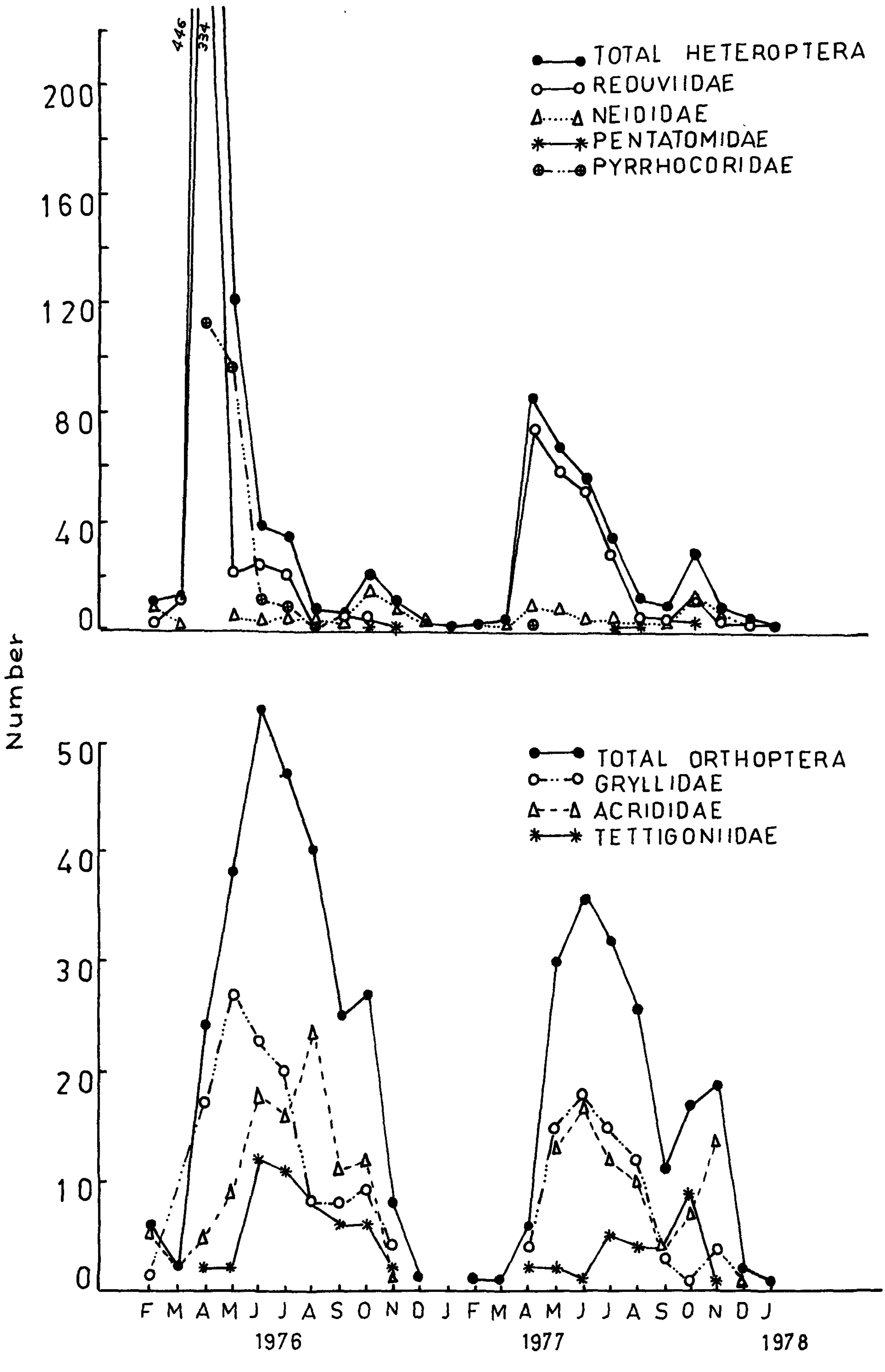
Heteroptera :-

Heteroptera represented 698 (6.36%) individuals during the year 1976-77 and 307 (3.31%) during 1977-78 (Fig. 4). The monthly total relative abundance of heteroptera is represented in Fig. 12, a perusal of which revealed that during 1976-77 the catch was maximum in April, 1976 representing 446 (63.61%) individuals. It then decreased till it again rose with a negligible peak of increase in October, 1976 and reached a low ebb in January, 1977. From February, 1977 onwards it gradually started increasing reaching its peak of abundance again in April, 1977 representing 84 individuals or 27.36% of the total catch of the year. Then it started gradually decreasing and before it reached the minimum in January, 1978 representing 2 individuals (0.65%) of the total catch of the year, it again had a small peak in October, 1977 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

Figure 12 showing the seasonal fluctuation of total Heteroptera, Reduviidae, Pyrrhocoridae, Neididae and Pentatomidae 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 study period.



446
334
TOTAL HETEROPTERA
REDUVIIDAE
NEIDIDAE
PENTATOMIDAE
PYRRHOCORIDAE
0
40
80
120
160
200
Number
TOTAL ORTHOPTERA
GRYLLIDAE
ACRIDIDAE
TETTIGONIIDAE
0
10
20
30
40
50
F M A M J J A S O N D J F M A M J J A S O N D J
1976
1977
1978

minimum temperature, relative humidity and wind velocity showed no significant correlation with the monthly abundance of heteroptera during both the years. The total rainfall also had no significant relationship with the heteroptera caught during 1976-77. However, the relationship was positively significant ($P < 0.01$) during 1977-78.

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, 1976 and 1977 representing 334 (32.81%) and 74 (7.27%) individuals respectively. From April, 1976 the population gradually decreased with negligible peak of increase in June, 1976 representing 24 individuals (2.36%) and disappeared completely in December, 1976. From January, 1977, it gradually started increasing with the peak of abundance in April, 1977. Then it gradually decreased reaching the minimum in January, 1978 representing only 2 (0.2%) individuals.

Pyrrhocoridae was caught maximum in April, 1976, then it gradually decreased and disappeared from November, 1976.

In 1977-78, 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 were trapped too less in numbers to show any seasonally significant changes.

An hourly analysis of heteroptera caught revealed that during 1976-77, 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 1977-78, the maximum heteroptera were caught at 2100-2200 hrs. representing 22.08 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 during 1976-77 and 181 individuals (1.95%) during 1977-78 (Fig. 4). The monthly total abundance of this group is represented in Fig. 13, a perusal of which revealed that during 1976-77 this group reached the peak of their abundance in June, 1976 representing 53 individuals (19.41%) of the total yearly catch. Then it decreased with a negligible increase in October, 1976 representing 27 individuals (9.89%) and reached its minimum in December, 1976 representing only 1 individual (0.37%) with total disappearance in January, 1977. Then the number gradually increased and reached the maximum in June, 1977 representing 36 individuals (19.89%). Then it started decreasing with a slight increase in November, 1977 representing 19 individuals (10.5%) and reached its minimum in January, 1978 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 the variation of minimum temperature had a very strong correlation ($P < 0.01$) with seasonal abundance of Orthopteran fauna during both years of 1976-77 and 1977-78. The maximum temperature showed a positively significant relationship during both the years, but the significance was at $P < 0.01$ level during 1976-77 and at $P < 0.05$ level during 1977-78. 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 for 1976-77 and at $P < 0.01$ level for 1977-78.

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 in maximum number during May, 1976 representing 27 individuals (5.96%). Then it gradually started decreasing, finally making its disappearance in

December, 1976 to March, 1977. It reappeared in April, 1977 and reached the maximum in June, 1977 representing 18 individuals, 3.97% of total orthoptera catch. Then it started decreasing, reaching its minimum in December, 1977 represented by only 1 individual (0.22%), and finally disappeared from January, 1978.

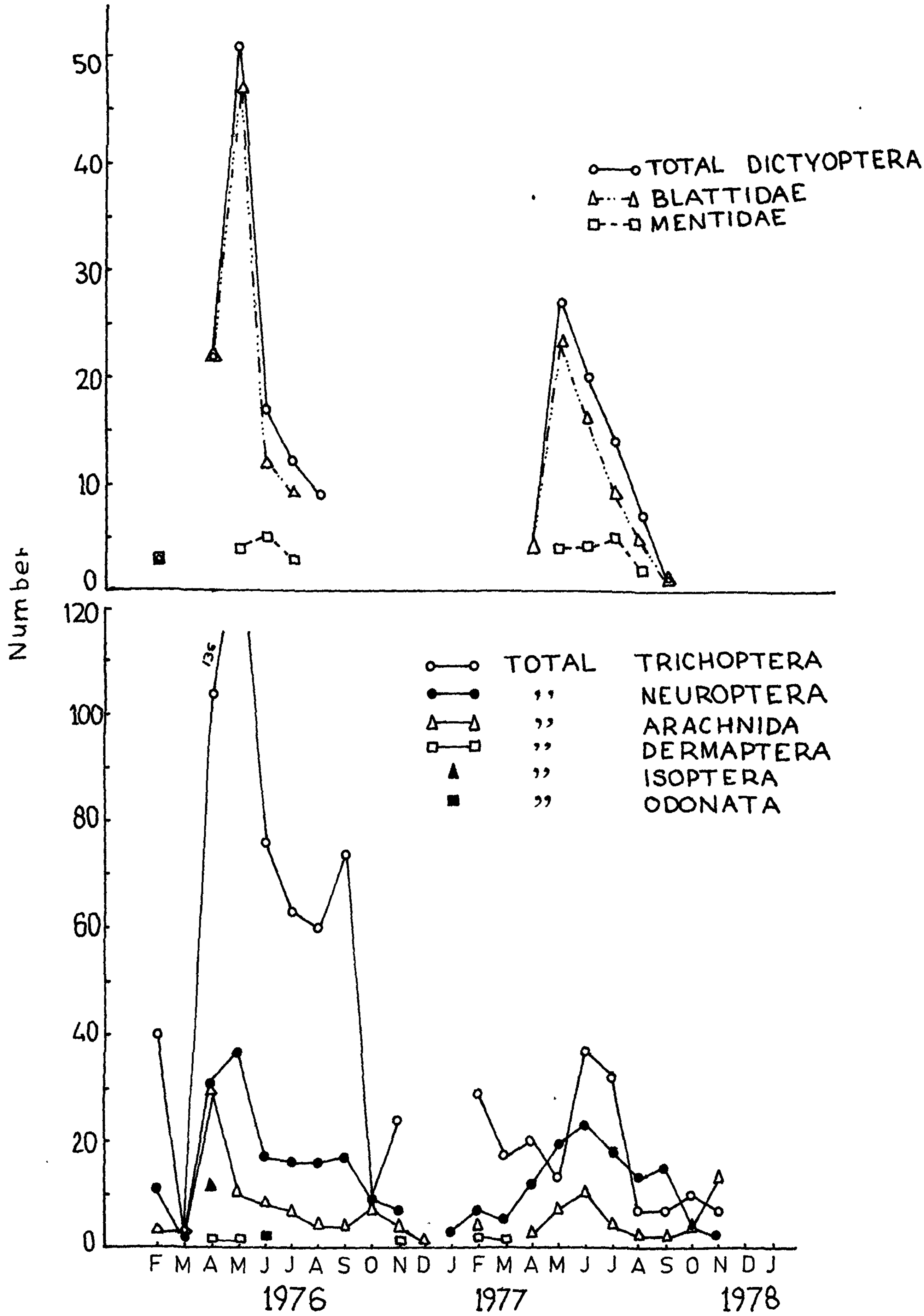
An hourly analysis of total orthoptera caught revealed that during 1976-77 they were caught maximum at 2000-2100 hrs. representing 20.15 percent followed by 1900-2000 hrs. representing 16.12 percent. During 1977-78, the maximum catch was recorded during 1900-2000 hrs. representing 28.33 percent followed by 1800-1900 hrs. representing 18.89 percent. The least catch was recorded at 0400-0500 hrs. representing 3.3 percent, with complete disappearance at 0500-0600 hrs. during 1976-77. During 1977-78 the least catch was recorded during 0200-0300 hrs. (0.56%) with a complete disappearance at 0400-0500 hrs.

Dictyoptera :-

Dictyoptera represented 114 individuals during 1976-77 and 70 individuals during 1977-78 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 during 1976-77 they were present only in February, 1976 and from April to August, 1976. They were trapped maximum in May, 1976 representing 51 individuals, 44.74% of the total dictyoptera caught and minimum in February, 1976 representing only 3 individuals, 2.63% of the total yearly catch of dictyoptera. During 1977-78, they

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.



TOTAL DICTYOPTERA
BLATTIDAE
MENTIDAE
TOTAL TRICHOPTERA
" NEUROPTERA
" ARACHNIDA
" DERMAPTERA
" ISOPTERA
" ODONATA
Number
136
50
40
30
20
10
0
120
100
80
60
40
20
0
F M A M J J A S O N D J F M A M J J A S O N D J
1976
1977
1978

were only trapped from April to September, 1977, showing their peak of their abundance in May, 1977 representing 27 individuals, 38.57%. They were recorded minimum in September, 1977 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 1977-78 and no relationship existed during 1976-77. The wind velocity also showed a positive significant correlation ($P < 0.05$) with dictyoptera abundance during 1977-78 with no significant relationship during 1976-77.

The order dictyoptera was represented by two families Blattidae and Mantidae, the former representing 157 individuals, 83.96% of the total dictyoptera 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, 1976 and reached its peak of abundance in May, 1976 representing 47 individuals, 26.13% of the total dictyopteran catch and minimum was recorded in July and August, 1976 each month representing 9 individuals (4.81%). Then it reappeared in April, 1977 and reached its peak of abundance in May, 1977 representing 12.3% of the total dictyoptera catch. The minimum catch recorded was in September, 1977 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, 1976 and from May to July, 1976 and from May to August, 1977. They were represented in numbers too few to show any significant seasonal variations.

An hourly analysis of dictyoptera caught revealed that they were recorded maximum during 2000-2100 hrs. representing 20.69 percent of total night catch and minimum was recorded at 0300-0400 hrs. which represented only 0.86 percent during 1976-77. In 1977-78 the maximum catch was recorded 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 during 1976-77 and 179 individuals during 1977-78 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 in maximum numbers in May, 1976 representing 136 individuals, 23.09% of the total yearly catch of trichoptera. Then it gradually decreased with a slight increase in number in

September, 1976, representing 74 individuals, (12.56%) and reached a minimum in October, 1976 representing 9 individuals, (1.53%). During 1977-78 it appeared in February, 1977 and had its peak of abundance in June, 1977 representing 37 individuals, (20.67%). The minimum number was recorded in November, 1977 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 year 1976-77 of study whereas no significant relationship during 1977-78. The wind velocity and relative humidity had no correlation with their seasonal abundance.

An hourly analysis of abundance of trichoptera (Table-V a,b) revealed that during 1976-77 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 1977-78 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.

<u>Neuroptera</u> :-

Neuroptera represented 166 individuals during 1976-77 and 118 individuals during 1977-78 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 in maximum numbersin May, 1976 representing 37 individuals, (22.29%) of the total yearly catch of neuroptera. Then they started decreasing reaching a minimum in January, 1977 representing 3 individuals, (1.81%). From February, 1977 onwards it increased in number gradually and reached its peak of abundance in June, 1977 representing 23 individuals, (19.44%). It then started decreasing and reached the minimum in November, 1977 representing only 2 individuals (1.69%). In both the years there was a slight peak during September. They were completely absent during December, 1977 and January, 1978.

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 during 1977-78, with no relation during 1976-77. 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 during 1976-77 and 1977-78 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 during 1976-77 and 48 individuals during 1977-78 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, 1976 representing 29 individuals, 36.25% of the total yearly catch of arachnida. They then gradually decreased with a small peak of increase in October, 1976 representing 7 individuals, (8.75%) and reached minimum in December, 1977 representing only 1 individual, (1.25%). Arachnida was completely absent in January, 1977. During 1977-78 they represented a small peak of abundance in June, 1977 representing 10 individuals, (20.83%). Then it decreased till September and increased thereafter reaching the maximum peak catch in November, 1977 representing 13 individuals, 27.08% of the total yearly arachnid catch. The minimum was recorded in April, August and September, 1977 each month representing 2 individuals, 4.17%. They were completely absent during January, March, December, 1977 and January, 1978.

An analysis of relationship between monthly abundance of arachnida and various environmental 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 during 1976-77 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. During 1977-78 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 both during 1976-77 and 1977-78 (0.03%) of the total catch of insects (Fig. 4). hey were recorded in April, May and November, 1976, each month representing one individual (Fig. 15). During 1977-78 they were present only in February and March, 1978. 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, 1976 and 2400-0100 hrs. and 0300-0400 hrs. in February, 1977. 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, 1976 representing 11 individuals, 0.1% of the total yearly insect catch (Fig. 4). They were caught in maximum numbers at 1800-1900 hrs. representing 6 individuals, 54.5% of the total catch, followed by 2000-2100 hrs.

representing 3 individuals, 27.27%, 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, 1976 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.

DISCUSSION

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 urders 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 1976-1977 than during 1977-1978 (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 catche 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 one 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 (Hágen, 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, 1976 the total number caught was 3069 and in June, 1977 it was 3090, which was very close in abundance. 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 regularity of environmental factors like rainfall and temperature for insect increase and decrease respectively, (Cantello et al, 1973; F.ith, 1975). Further 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) where he reported that 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 overall 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, 1976 and June, 1977. 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 1976-77, showed a similar trend during the succeeding year (Fig. 8). This discrepancy in 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 Artiidae 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 caught was during the rainy months of May, 1976 and June, 1977 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 1976-77 and 1977-78 respectively) and minimum temperature (r = +0.7119 and +0.6396 during 1976-77 and 1977-78 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, got its support 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) and Owen (1969) 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 for 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).

To summarise and to draw upon some salient features from the present work, its findings are reported here to form general conclusions. A great many works 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 contrast 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 to as sub-tropical where temperature fluctuations was 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 of the first annual cycle and the variety 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 low 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 extremeties. 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 continously over several years for proper forestry management.

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DECOMPOSER ARTHROPODS IN SOIL

INTRODUCTION

As one of the important components of ecosystems soil, had recently 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, Protoura, 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 opinions 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 Diem's (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 numerous other publications such as Ramann (1911), Cameron (1913), 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-Deboutteville (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 worker's 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 rainforests 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 to be particularly characteristic of temperate coniferous forest with more humus formation. In such habitats the 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, 1949a,b). The degree of hygrophilia of these species being the best criterion for their 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; Baduri 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 was 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 (Singh and Singh, 1975). As the area under study comprised of pine forests our study was restricted only to the pine forest floors (Reddy and Alfred, 1977).

MATERIALS AND METHODS

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 (Plate 4a). Samples were collected monthly and the time confined to 0900 and 1000 hrs. 10 sample units were taken at random, on each sampling occassion (Plate 4b). A rectangular iron sampler of 5x5x10 cm was used for removing the samples. A total of 200 sample 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 physicochemical factors.

Soil temperature was measured by an ordinary mercury thermometer at 5 cm depth and at soil surface 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).

Plate 4a showing the 1965 plantation of 12 year old trees where soil sampling and litter decomposition studies were done.

b showing soil profile, of the above with the litter and humus layers.

RESULTS

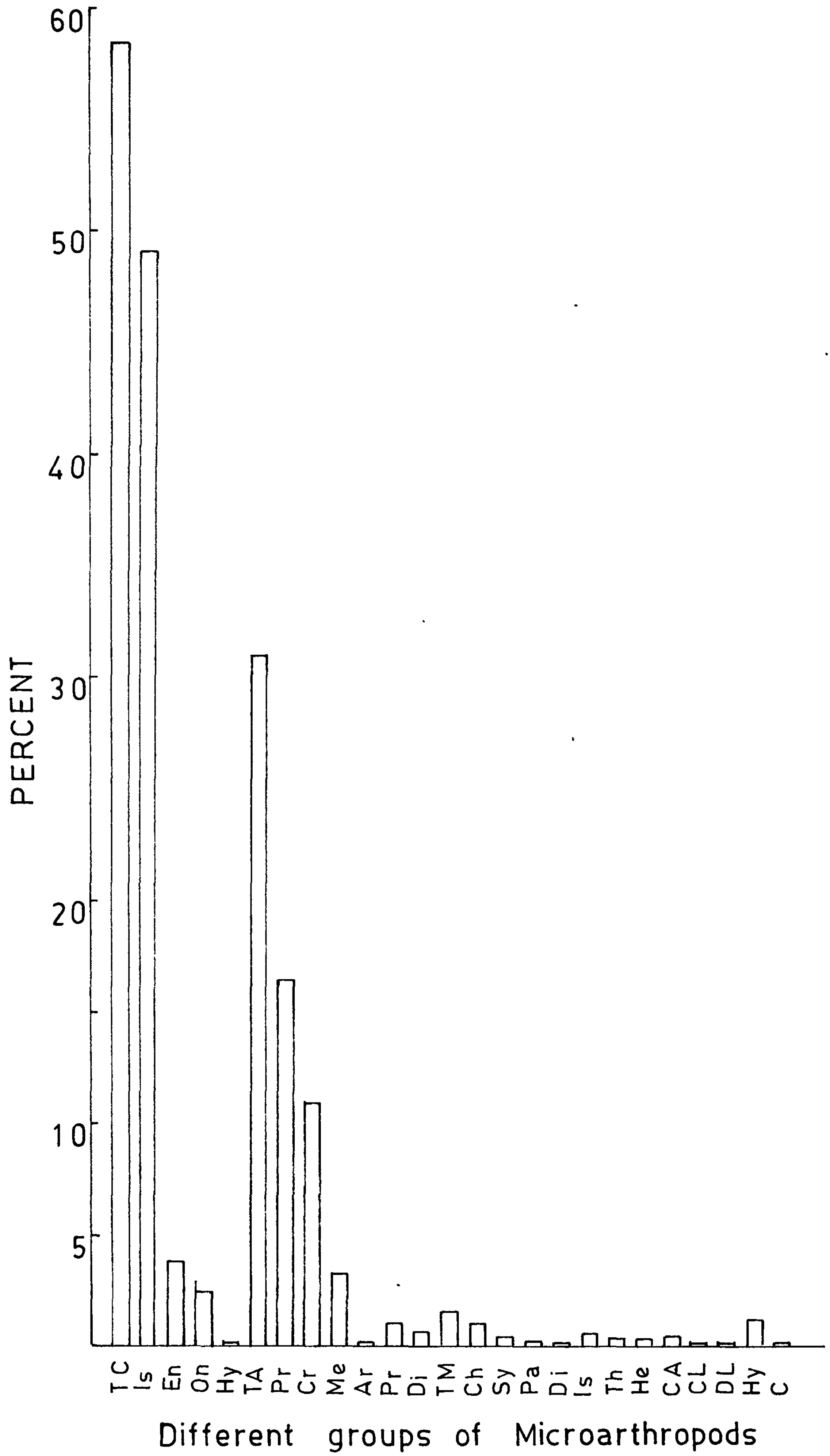
The term "microarthropods" as used in the present investigation designated all arthropods extracted from soil (Price, 1973). These ranged in size from less than 0.4 mm for most prostigmatids, including the juveniles of Acarina to 7 mm as in Diplopoda and Chilopoda. The extracted soil fauna were counted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

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
Pra	= Protura	Hy	= Hymenoptera
Dip	= Diplura	C	= Calanoids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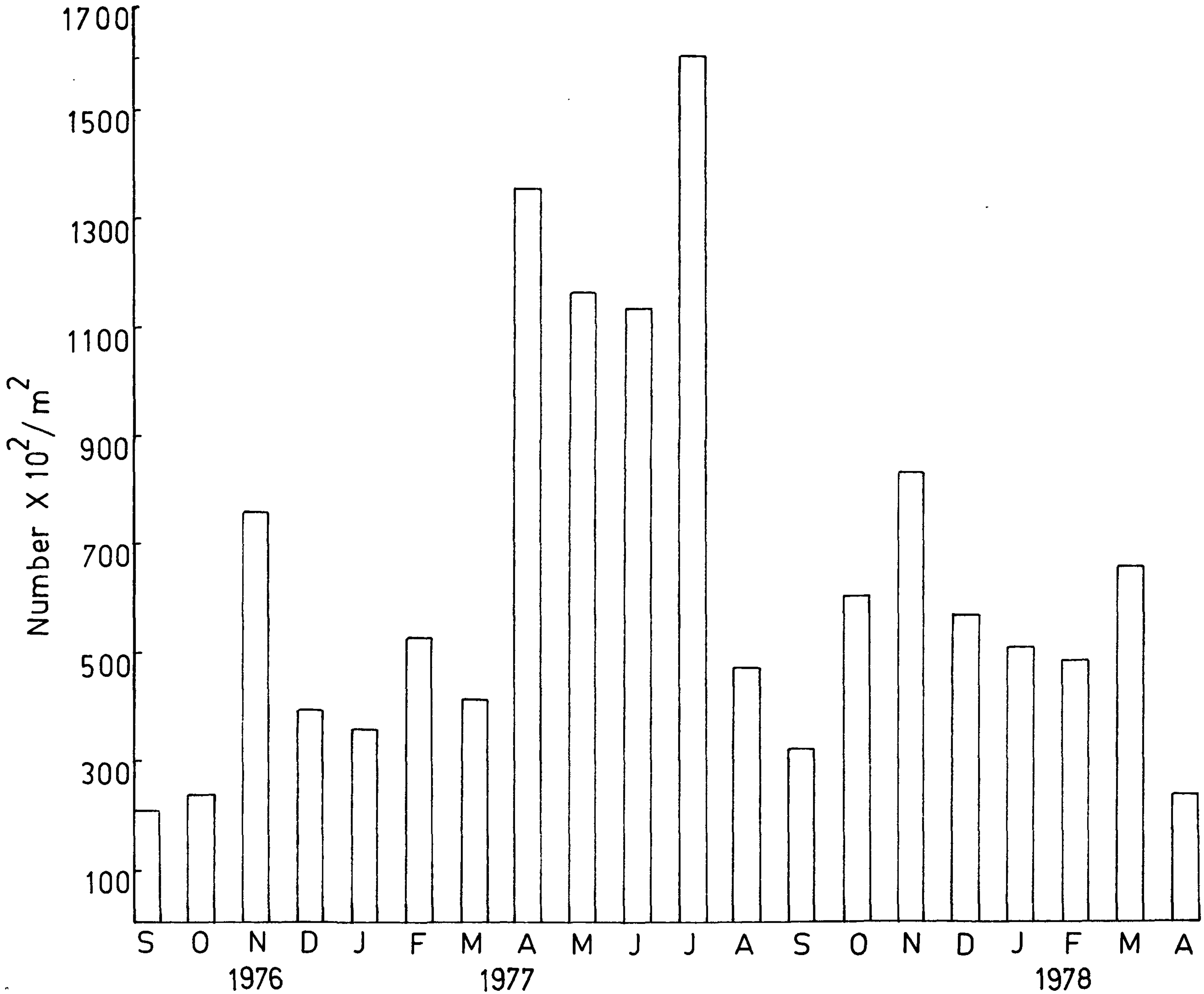
Different groups of Microarthropods

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 were 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 208×10^2 to $1600 \times 10^2/m^2$, maximum during the month of July and minimum in the month of September for the first year of study (September, 1976 to August, 1977). The month of April, 1977 had a peak representing $1356 \times 10^2/m^2$. But during the second cycle

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



Number X $10^2/m^2$
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1300
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900
700
500
300
100
S O N D J F M A M J J A S O N D J F M A
1976
1977
1978

(September, 1977 to April, 1978) the minimum number of $240 \times 10^2/m^2$ was in the month of April, 1978 and the maximum occurred in the month of November, 1977 representing $836 \times 10^2/m^2$.

The seasonal abundance of the total Collembola group (Fig. 18) represented by all the five families (Fig. 19) reached the peak of abundance in the month of July, 1977 ($1312 \times 10^2/m^2$) and minimum in the month of September, 1977. Besides that it had another smaller peak during the months of April and May, 1977. During the second year of investigation, the Collembola population was maximum in the month of October, 1977 and minimum in the month of April, 1978. 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, 1976 and the abundance fluctuated upto the month of March, 1977 and suddenly increased in the month of April, 1977 reaching a small peak of $1052 \times 10^2/m^2$ and then with a slight decrease in the month of May-June, 1977 reached the largest peak in the month of July, 1977 representing $1260 \times 10^2/m^2$. Then it suddenly decreased to $208 \times 10^2/m^2$. 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, 1978 and September, 1977 representing 56×10^2 and $80 \times 10^2/m^2$ respectively and maximum in the month of October representing $372 \times 10^2/m^2$

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 among Collembola. The family did not show any significant seasonal variation (Fig. 19). The maximum number was recorded in the month of November, 1976 representing $56x10^2/m^2$ followed by August, 1977 representing $40x10^2/m^2$ and was recorded minimum during the month of January and March, 1977. During next year of investigation the maximum number recorded was in the month of November, 1977 representing $80x10^2/m^2$ individuals and minimum in the month of April, 1978.

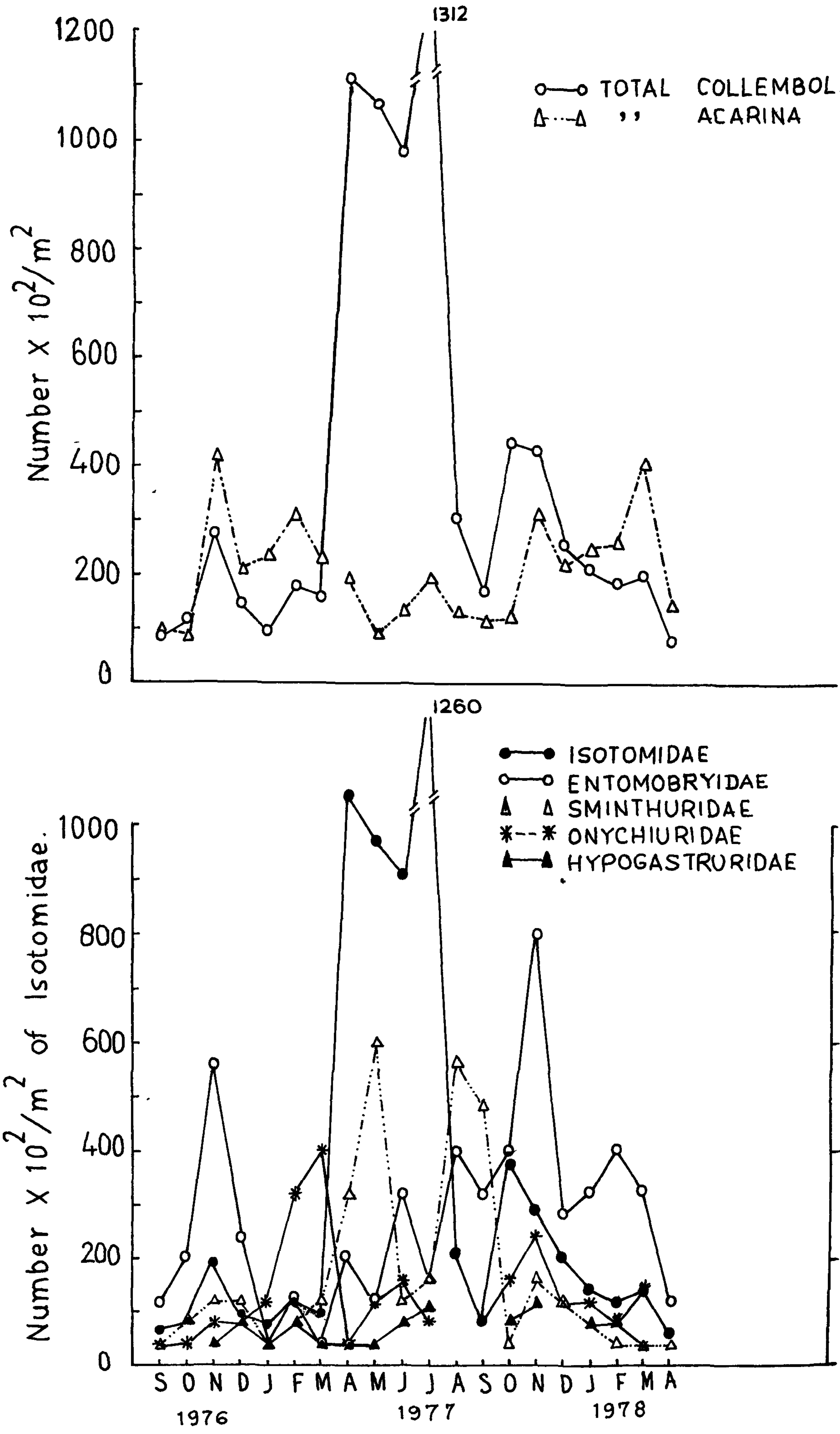
The family Sminthuridae was next to Entomobryidae in order of abundance. The monthly catches of this family also did not show any significant variation (Fig. 19). The peaks recorded was in the month of May and August, 1977 representing $60x10^2/m^2$ and $56x10^2/m^2$ respectively. The minimum number was recorded during the months of September, 1976 and January, 1977. During the second cycle, the maximum numbers recorded were in the month of August, 1977 and minimum in the months of February, March and April, 1978.

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, 1977 and in November, 1977 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

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 Hypogastruridae found in the soil during the entire study period.


1312
TOTAL COLLEMBOLA
,, ACARINA
Number X 10²/m²
0
200
400
600
800
1000
1200
1260
ISOTOMIDAE
ENTOMOBRYIDAE
SMINTHURIDAE
ONYCHIURIDAE
HYPOGASTRURIDAE
Number X 10²/m² of Isotomidae.
0
20
40
60
80
100
S O N D J F M A M J J A S O N D J F M A
1976
1977
1978

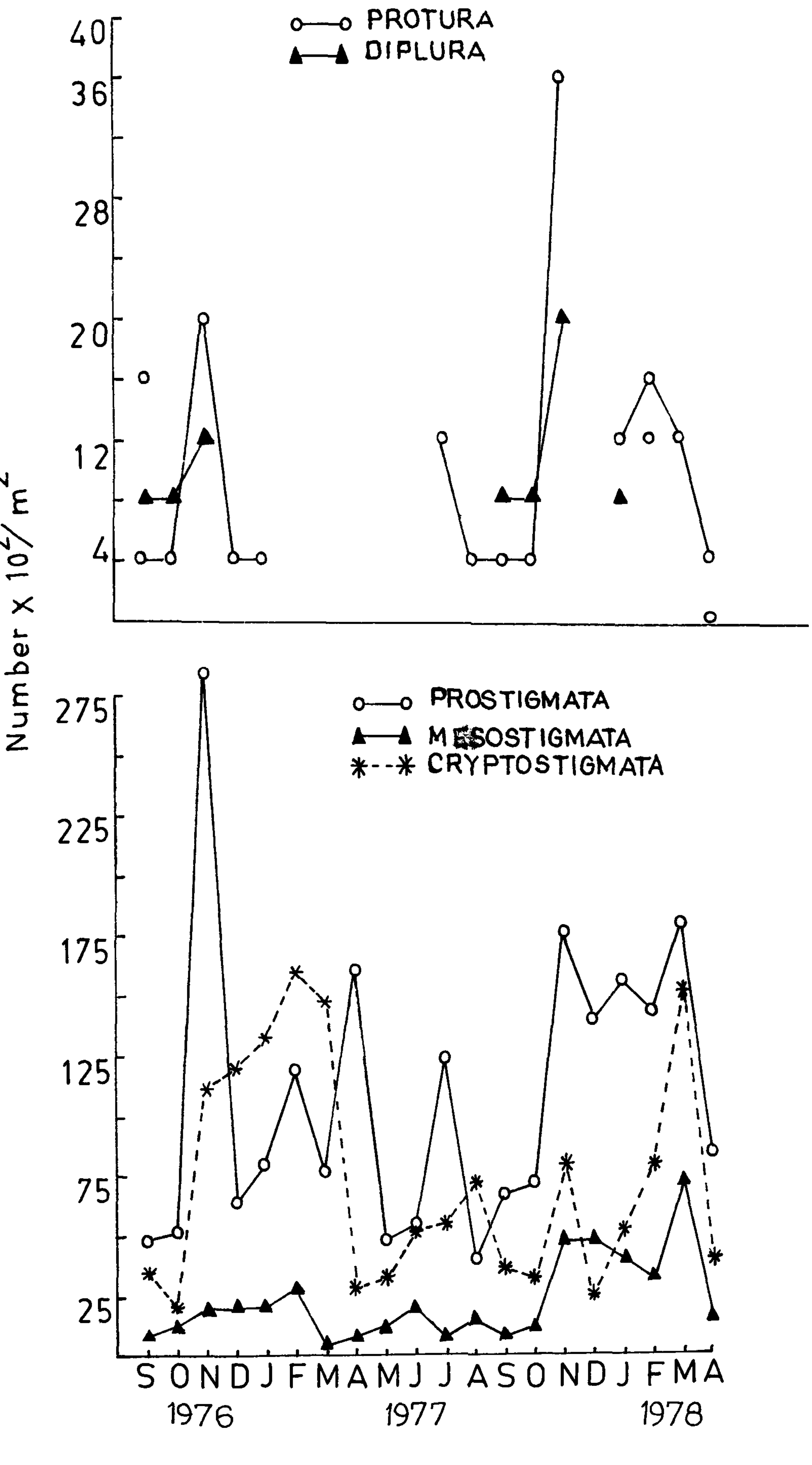
$84x10^2/m^2$ to $416x10^2/m^2$, the minimum in the month of October, 1976 followed by a sudden increase in the month of November, 1976 reaching the maximum. A second peak of abundance, $308x10^2/m^2$ was recorded in the month of February, 1977. During the second year of investigation, the minimum number of Acarina recorded was in the month of September, 1977, $112x10^2/m^2$ reaching a small peak of $308x10^2/m^2$ in the month of November, 1977. 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). The Prostigmata population reached the maximum in the month of November, 1976 representing $284x10^2/m^2$ and minimum in the month of August, 1977, $40x10^2/m^2$ (Fig. 21). A small peak representing $160x10^2/m^2$ was recorded in the month of April, 1977. During the second year, the minimum number recorded was in the month of September, 1977 and maximum in the month of November, 1977 and March, 1978. 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 group. The Cryptostigmatid mites recorded were minimum in the month of October, 1976 representing $20x10^2/m^2$ and suddenly increased in the month of November, 1976 (Fig. 21) and gradually reached the peak in the month of February, 1977. Then it gradually started decreasing with a small peak in the month of August, 1977. During the second year the number gradually increased from the month of August, 1977 and reached a small peak in the month of

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.



PROTURA
DIPLURA
40
36
28
20
12
4
Number x 10²/m²
PROSTIGMATA
MESOSTIGMATA
CRYPTOSTIGMATA
275
225
175
125
75
25
S O N D J F M A M J J A S O N D J F M A
1976
1977
1978

November, 1977 representing $80 \times 10^2/m^2$. It then suddenly decreased to a minimum in the month of December, 1977 representing $24 \times 10^2/m^2$. From January, 1978 onwards it gradually started increasing and reached the peak in the month of March, 1978 representing $152 \times 10^2/m^2$, after which it decreased.

The Mesostigmata mites of the Acarina group 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, 1976 representing $20 \times 10^2/m^2$ and were recorded nil during the period from February to June, 1977. During the second year, the number reached maximum in the month of November, 1977 representing $36 \times 10^2/m^2$ and were minimum during the month of August, September and October, 1977 and April, 1978 (Fig. 20).

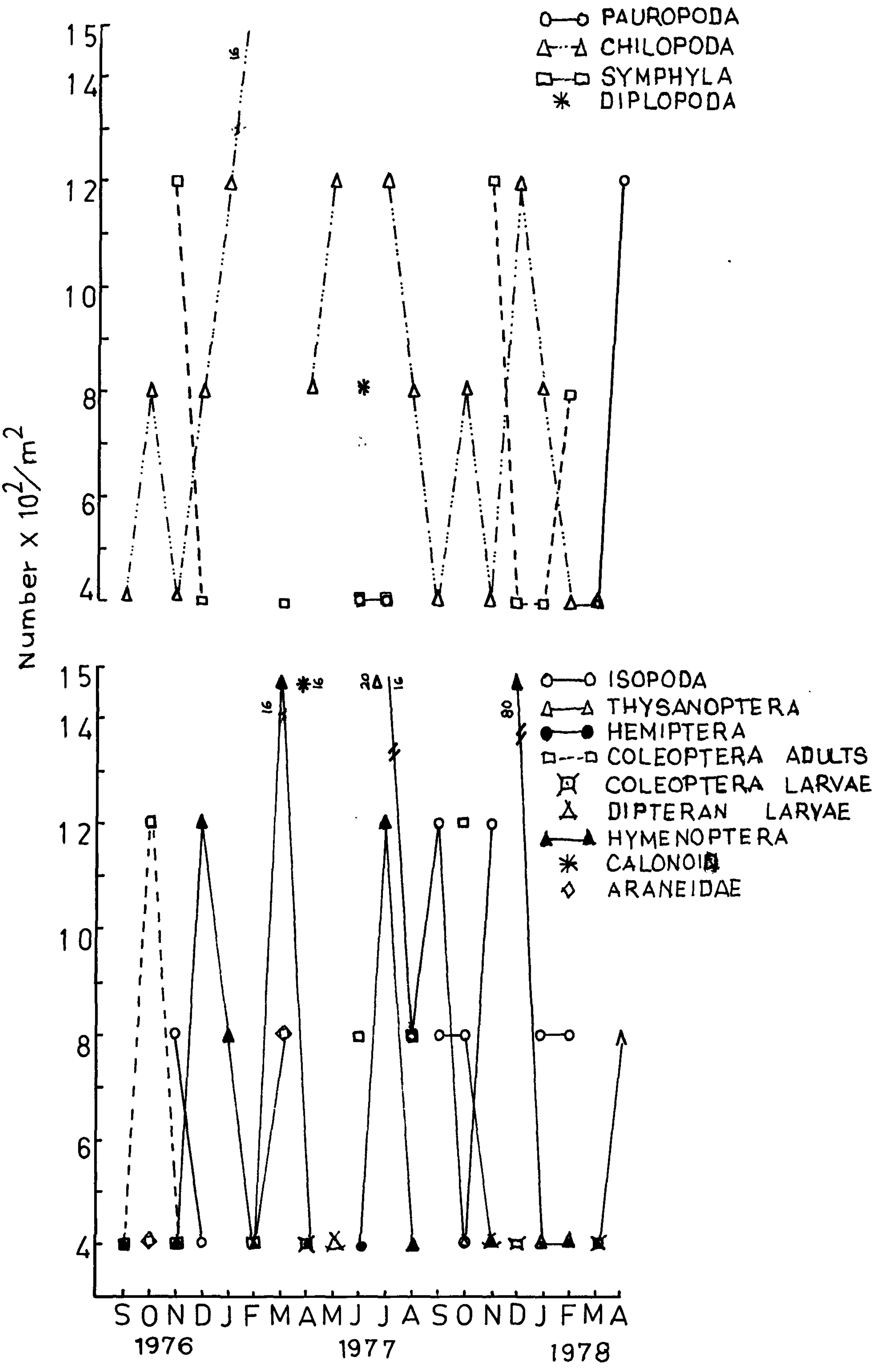
The Diplura were represented by very negligible numbers. They were recorded maximum in the month of November, 1976 representing $12 \times 10^2/m^2$ and were nil from the month of January to August, 1977. During the second year of investigation, the maximum Diplura population was recorded in the month of November, 1977 and decreased to minimum in the month of February, 1978. But in the month of March, 1978, it again showed a peak representing $16x10^2/m^2$ and then decreased to $4x10^2/m^2$ in the month of April, 1978 (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, 1977 representing $24x10^2/m^2$ and minimum during the months of September, 1976 and March, 1977. They further showed a small peak in the month of July, 1977 representing $20x10^2/m^2$. During the second year they were in an increased state of abundance from November, 1977 to April, 1978 and were recorded nil in the month of April, 1978. The group Chilopoda were represented by very few individuals to detect any change in the monthly fluctuation. The family Symphyla was represented by very negligible numbers but the maximum was distinct, and was 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, 1977 and from January to March, 1978 during the entire period of investigation. The group Diplopoda was recorded only in June, 1977 for the entire study period.

The other groups Formicidae, Isopoda, Thysanoptera, Hemiptera, Coleoptera adults and larvae, diptera larvae, Araneidae and Calanoids were very poorly represented (Fig. 23), and were so few to allow detection of any change in seasonal abundance. However, these groups when collectively

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.



PAUROPODA
CHILOPODA
SYMPHYLA
DIPLOPODA
ISOPODA
THYSANOPTERA
HEMIPTERA
COLEOPTERA ADULTS
COLEOPTERA LARVAE
DIPTERAN LARVAE
HYMENOPTERA
CALONOIDA
ARANEIDAE
Number X $10^2/m^2$
S O N D J F M A M J J A S O N D J F M A
1976
1977
1978

represented as miscellaneous, they exhibited considerable variation in monthly fluctuations (Fig. 23). The miscellaneous group was maximum in the month of July, 1977 representing 64x $10^7/m^2$ and minimum in the month of May, 1976. During the succeeding year, this group was represented maximum in December, 1977 and minimum in April, 1978. The maximum number represented during December, 1978 was due to the colony of Hymenoptera which represented nearly 87% for that month (Fig. 23).

Physical factors

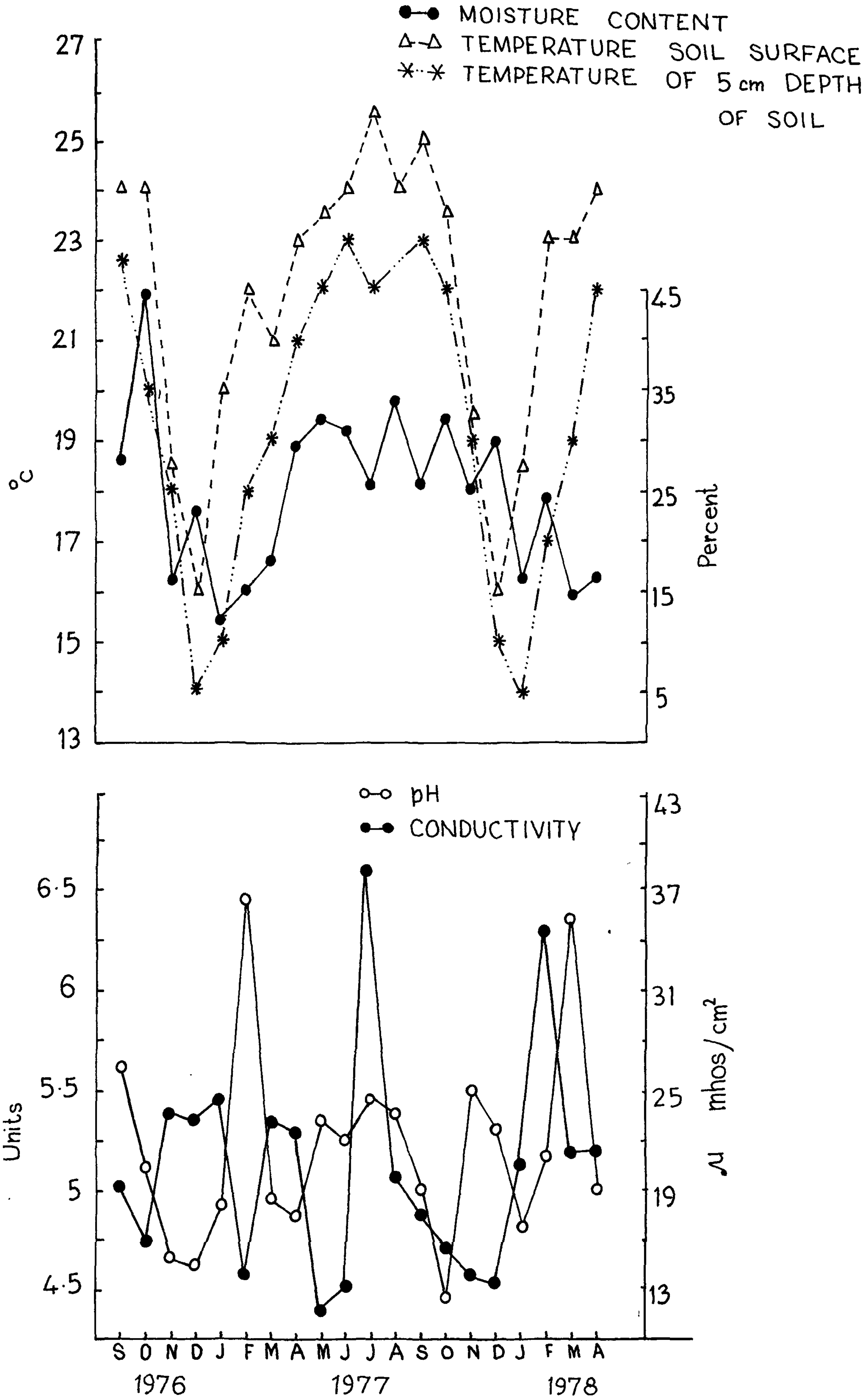
The seasonal variation in physical factors for the study period is represented in Fig. 24. The temperature of the air inside the forest canopy, temperature at soil surface and at 5 cm depth of the soil, during the period of study varied considerably, the range being 17.0°C to 25.5°C, 16.0°C to 25.5°C and 14.0°C to 24.0°C respectively. The maximum air temperature and temperature at soil surface was recorded during July to September, 1977 and minimum during December, 1976 and December, 1977. The temperature at 5 cm depth was recorded maximum in the month of August, 1977 and minimum in December, 1976 and 1977. All these temperatures showed a definite trend of decrease starting from September, 1976 reaching the minimum in the month of December. From January onwards a gradual increase was recorded reaching the maximum during July, August and September, 1977 (Fig. 24a).

The monthly variation in the percentage of moisture content of the soil (Fig. 24a) showed a considerable variation. It ranged from 12% to 44.67%. The maximum percentage of moisture content was recorded during October, 1976 and the minimum

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

a Temperature of the soil surface, temperature at 5 cm depth and moisture.

b Conductivity and pH.



MOISTURE CONTENT
TEMPERATURE SOIL SURFACE
TEMPERATURE OF 5 cm DEPTH OF SOIL
27
25
23
21
19
17
15
13
°C
45
35
25
15
5
Percent
pH
CONDUCTIVITY
6·5
6
5·5
5
4·5
Units
43
37
31
25
19
13
µ mhos/cm²
S O N D J F M A M J J A S O N D J F M A
1976
1977
1978

during January, 1977. Besides that a few smaller peaks were seen during the months of May, August, October, 1977 and February, 1978,

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, 1977 and minimum in the month of October, 1976. Besides that, the pH showed another peak of increase during the month of March, 1978. The monthly variation in pH during the present study was considerable (Fig. 24b).

The conductivity ranged from 14.88 to 41.3 μmhos/cm^2. The minimum conductivity was recorded in the month of May, 1977 and maximum in the month of July, 1977. A second peak of increase was recorded in the month of February, 1978 representing 37.45 μmhos/cm^2.

Chemical factors

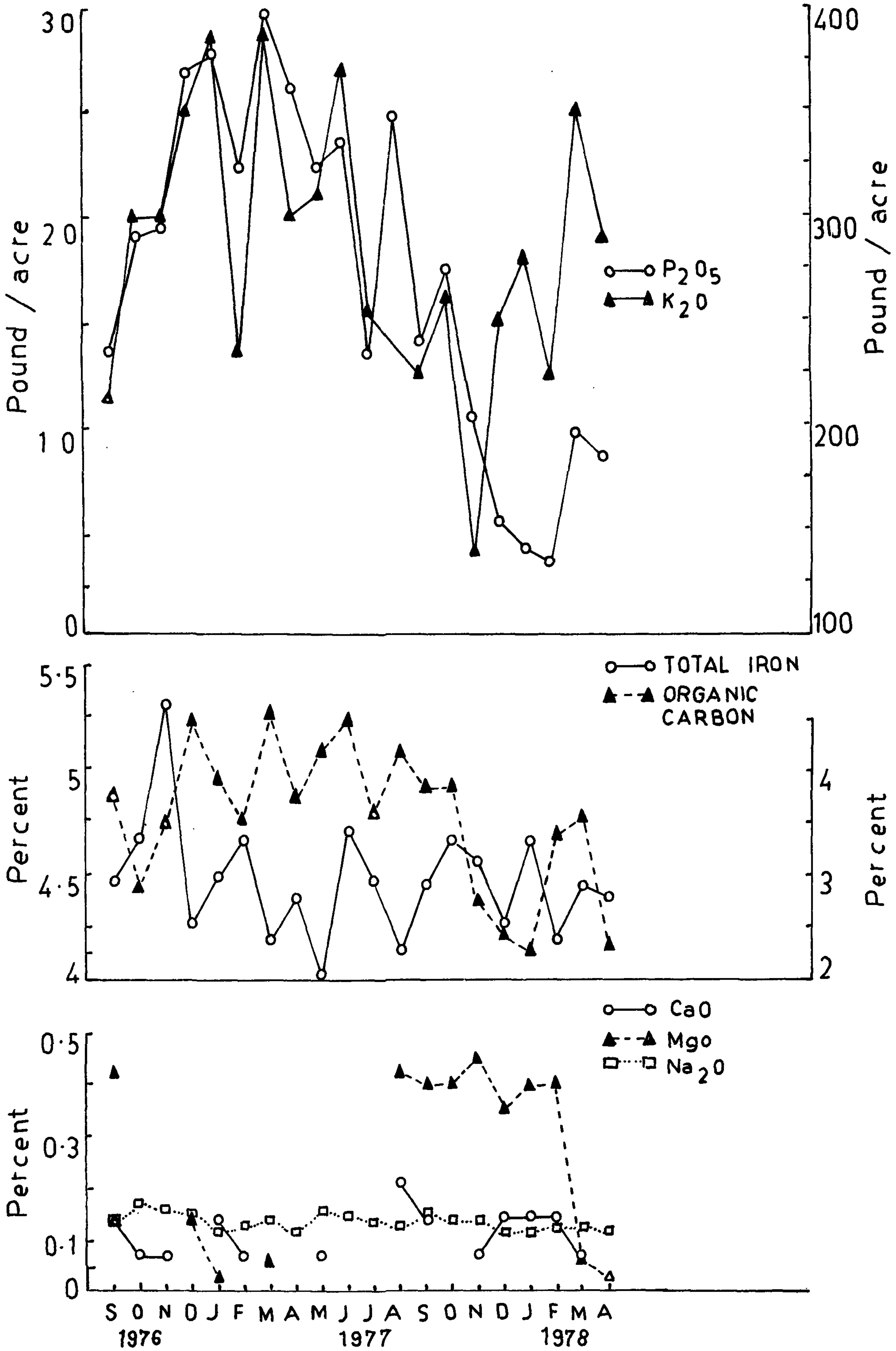
Phosphorus (P_2O_5)ranged from 3.6 to 29.6 pound per acre, the maximum being in the month of March, 1977 and minimum in the month of February, 1978 (Fig. 25a). Pottasium (K_2O) was very abundant comparatively and ranged from 140 poundsper acre to 650 pounds per acre, the maximum being in the month of August, 1977 and minimum in the month of November, 1977. A few smaller peaks of maxima were recorded during the months of January, March and June, 1977 and March, 1978 (Fig. 25a). The percentage of organic carbon ranged from 2.25% to 4.58%, the maximum being in the month of March, 1977 and minimum in the month of January, 1978. Besides that, the percentage of organic carbon also had a peak during June, 1977 (Fig. 25b). There was very little monthly variation in percentage of

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


30
20
10
0
Pound / acre
400
300
200
100
Pound / acre
P2O5
K2O
5·5
5
4·5
4
Percent
4
3
2
Percent
TOTAL IRON
ORGANIC CARBON
0·5
0·3
0·1
0
Percent
CaO
Mgo
Na2O
S O N D J F M A M J J A S O N D J F M A
1976
1977
1978

total iron content. It ranged from 4.06% to 5.43%, the maximum being in the month of November, 1976 and minimum in the month of May, 1977.

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, 1977, and the trace was recorded during December, 1976, March and April, 1977, May and June, 1977, October, 1977 and April, 1978. Magnesium (Mgo) content ranged from trace to 0.45%. The maximum amount was recorded in November, 1977. The content of Sodium (Na_2O) ranged from 0.12% to 0.17%, the maximum being recorded in the month of October, 1976 and minimum in the months of January, April and December, 1977 and January and April, 1978.

DISCUSSION

Drift (1951) reported $3365x10^2/m^2$ of arthropods in a beach forest soil, while Harding (1969) and Price (1973) found $2150x 10^2/m^2$ in an oak woodland and more than $2207x10^2/m^2$ in pine forest soil respectively. In the present study where a maximum of $1600x10^2/m^2$ 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 $1020x10^2/m^2$. Drift (1963) and Greenslade and Greenslade (1968) reported $514x10^2/m^2$ and $920x10^2/m^2$ respectively from tropics and compared their estimates with those of earlier tropical workers and reported that there was no significant diffference. The present study site located at an altitude of Ca 1175 m approached to near temperate climatic regimes, but still the total microarthropod densities reported fell between tho$e 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, 1977 while it was minimum for the same month during 1978. 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 of nearly 89.54%. Among these two, Collembola dominated Acarina and was 58.42% during the total study period and ranged between 24×10^2 and $1312 \times 10^2/m^2$. Such an abundance of Collembola has also been reported earlier by other workers like Tragardh (1929) - $1200 \times 10^2/m^2$; Kaczmarek (1973) - 170×10^2 to $220 \times 10^2/m^2$; Price (1973) - $1461 \times 10^2/m^2$ and Tamura (1976) exceeds the order 105 individuals/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

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

TABLE VIIa

Physical Factors	Total Micro-Arthropods	Total Collembola	Total Acarina	Total Myriapoda	Arthropods 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
* = $P < 0.05$
** = $P < 0.01$

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 maxima 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. In such cases, 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 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 s 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 factors except Mgo which did show some relation to Entomobryidae.

The group dominant next to Collembola during the present investigation was Acarina. Though so, it represented only half of the total Collembola in relative abundance. As a group, 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 a common finding (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, not 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 in 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 found in Wallwork (1959); Evans et al (1961) and Madge (1965). As species could not be identified during the present study, no conclusions could be drawn from the seasonal fluctuations of the whole group as Usher (1975) had clearly pointed out 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 from them.

Though the trend of fluctuation was more or less similar as for Collembola, the effect of the various abiotic factors had a very significant relationship on the total Acarina population. A very interesting observation revealed from the present study showed, 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. As for 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. Though 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. One could not go far too wrong if along with the above two factors rainfall was also 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 clubbed 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

Table VIIb Coefficient correlation between the monthly abundance of Isotomidae, Entomobryidae, Sminthuridae, Prostigmata, Mesostigmata, Cryptostigmata 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
* = $P < 0.05$
** = $P < 0.01$

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 among the microarthropods during the present investigation. Except for Protura, Chilopoda and Hymenoptera which were a little more than 1% of the total microarthropods, all the others were 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, 1977 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.

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DECOMPOSER ARTHROPODS IN LITTER

INTRODUCTION

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) stated 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.

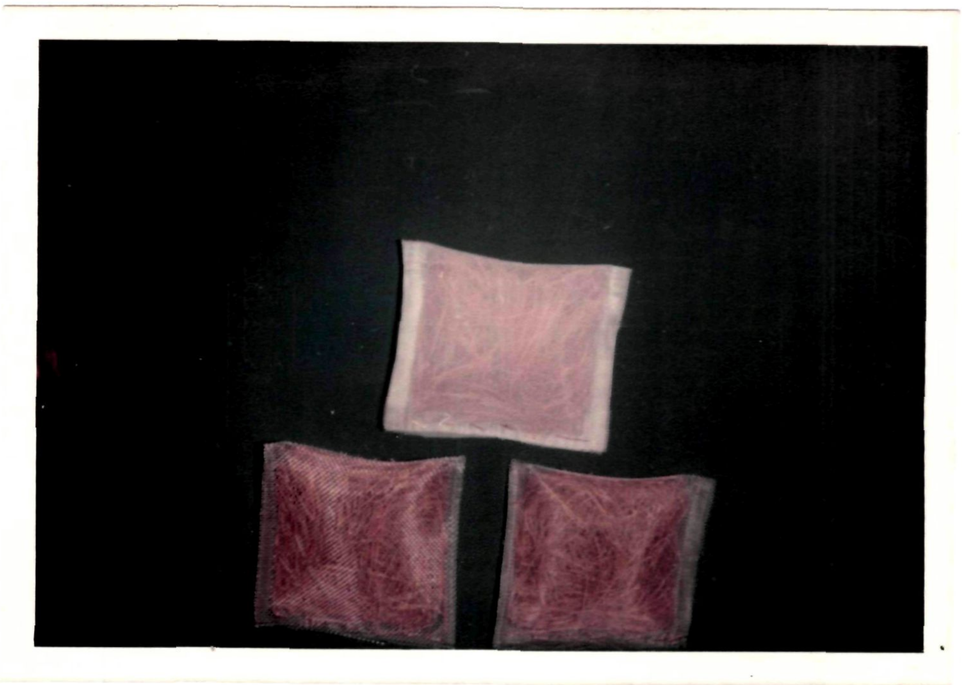
Mitchell (1978), was of the opinion that insects were very essential in pulverizing plant parts and felt that flora or surface phenomenon alone would be a very slow process. Reddy and Alfred (1978a,b) reported the microarthropods associated with pine litter and related them to the rate of decomposition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

MATERIALS AND METHODS

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 (Plate 5a). 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 (Plate 4a). Thereafter, three bags of each mesh size were collected from the experimental site (Plate 5b) 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).

Plate 5a showing the litter bags of 3 different mesh sizes of 3.0 mm^2, 1.0 mm^2 and 0.3 mm^2 containing litter

b showing the litter bags in the study site.



RESULTS

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 207×10^2 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.

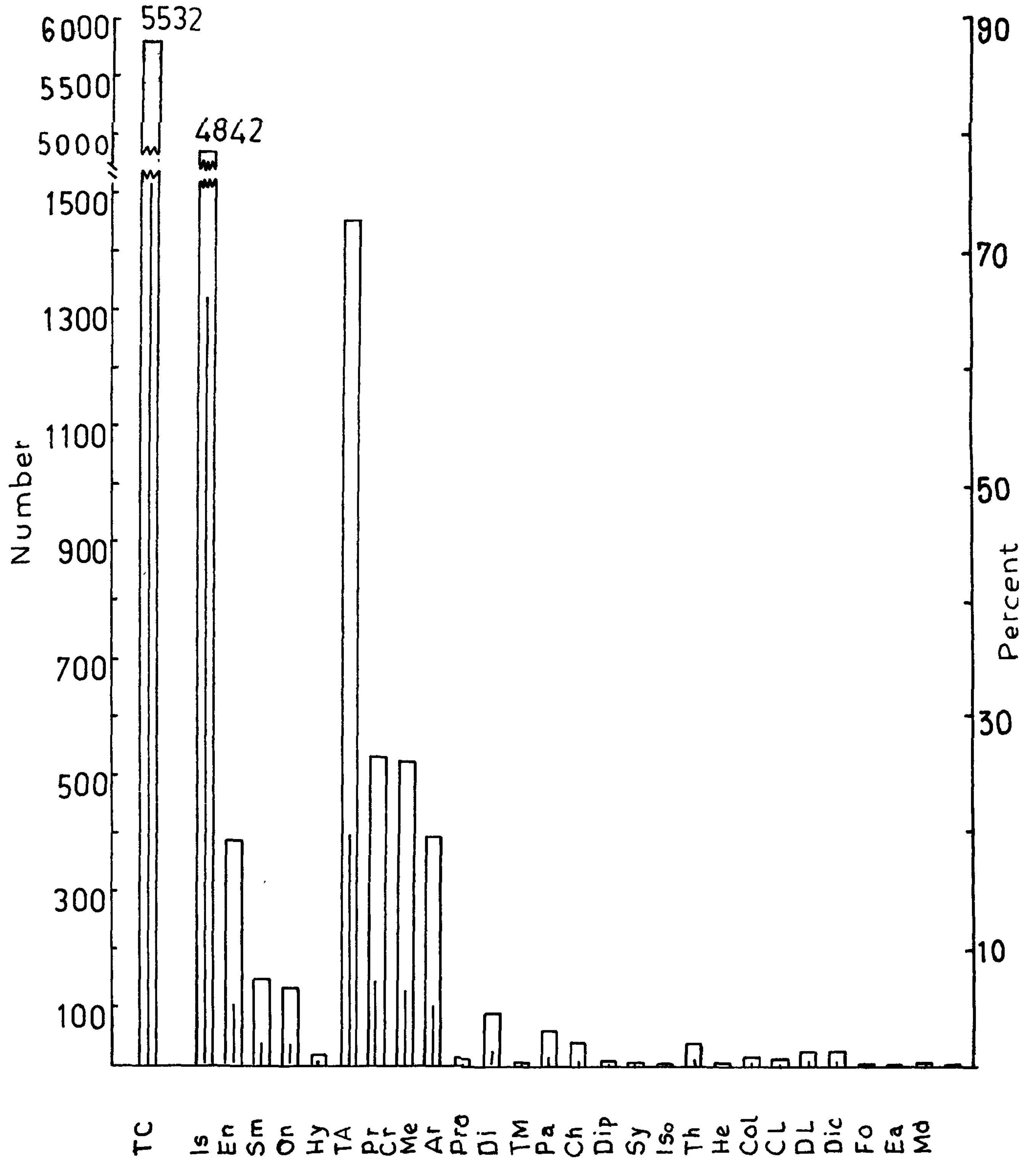
The quantitative composition of litter microarthropods collected from the maximum mesh sized bags is presented in Fig. 26a. It was seen that the Collembola and Acarina constituted 95.47% of the total litter microarthropod fauna in the maximum mesh sized bags. Collembola was the dominant group representing 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

Figure 26a showing the qualitative and quantitative composition of the various microarthropods found in the maximum mesh sized (3.0 mm^2) litter bags during the entire study period.

TC = Total Collembola
Is = Isotomidae
En = Entomobryidae
Sm = Sminthuridae
On = Onychiuridae
Hy = Hypogastruridae
TA = Total Acarina
Pr = Prostigmata
Cr = Cryptostigmata
Me = Mesostigmata
Ar = Araneidae
Pra = Protura
Dip = Diplura
Mo = Molluscs

TM = Total Myriapoda
Ch = Chilopoda
Sy = Symphyla
Pa = Pauropoda
Di = Diplopoda
Iso = Isopoda
Th = Thysanoptera
He = Hemiptera
CA = Coleoptera Adults
DL = Diptera Larvae
Hy = Hymenoptera
Dic = Dictyoptera
Ej = Earthworm juveniles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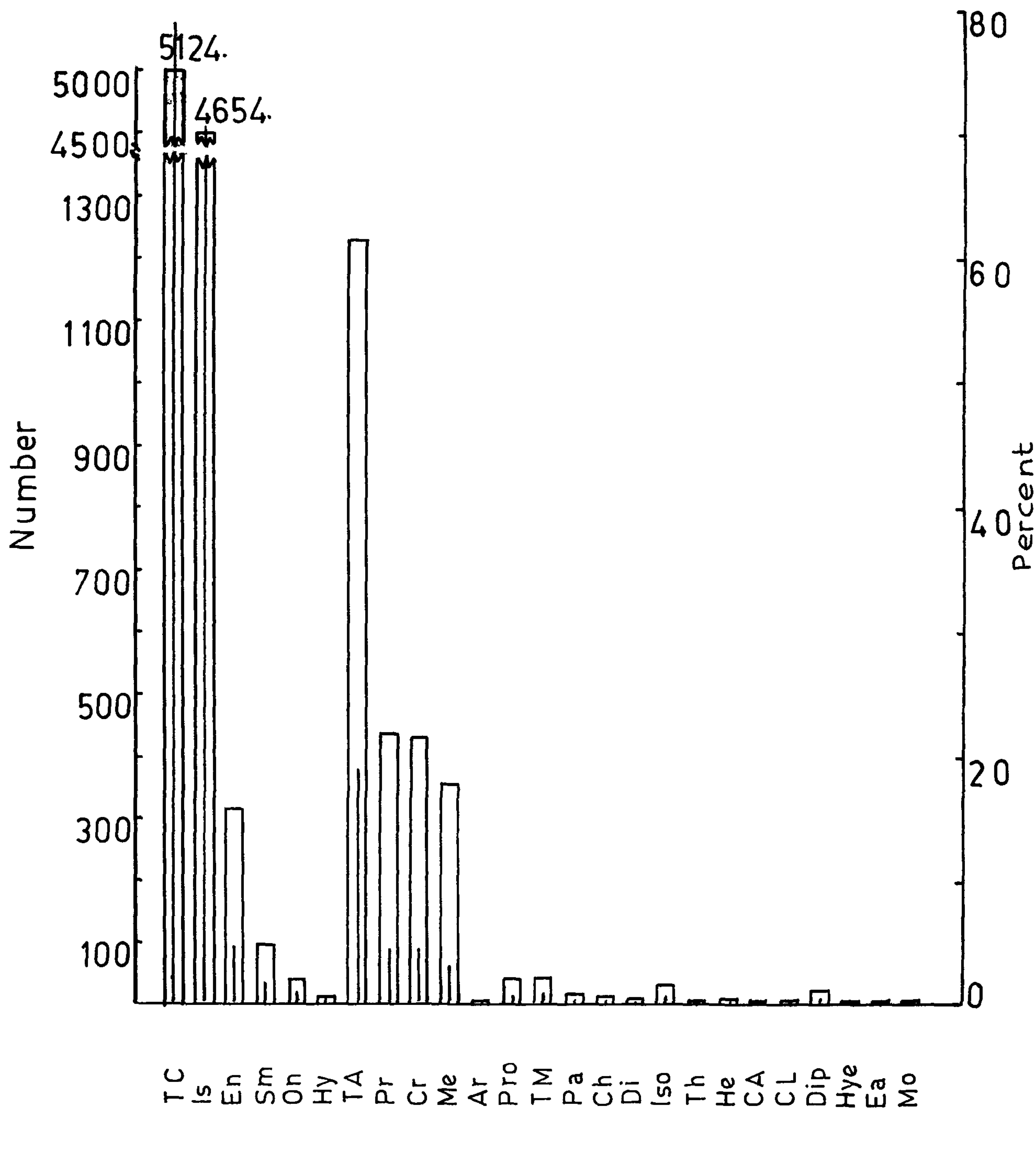
most dominant group representing 78.3%, followed by Acarina with 18.78%. Among the different families of the group Collembola once again, Isotomidae was the predominant group forming 71.11% followed by Entomobryidae with 7.79%, Sminthuridae with 1.49%, Onychiuridae with 0.64% and Hypogastruridae being poorly represented with only 0.22%. Among the different sub-orders of the group Acarina, Prostigmata representing 6.66%, and Cryptostigmata with 6.60% were the dominant groups. The group Mesostigmata was only 5.6%. Collembola together with Protura and Diplura forming the group Apterygota represented 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 Thysanoptera 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

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
Pre	= Protura	Dic	= Dictyoptera
Dip	= Diplura	Ej	= Earthworm juveniles
Mc	= Molluscs		



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of the group Collembola, Isotomidae was the dominant group representing 66.02% followed by Entomobryidae representing 4.08%, Sminthuridae representing 1.81%, Onychiuridae representing 1.11%, while Hypogastruridae represented only 0.29%. The group Apterygota 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 Cryptostigmata 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 0.34%, 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.

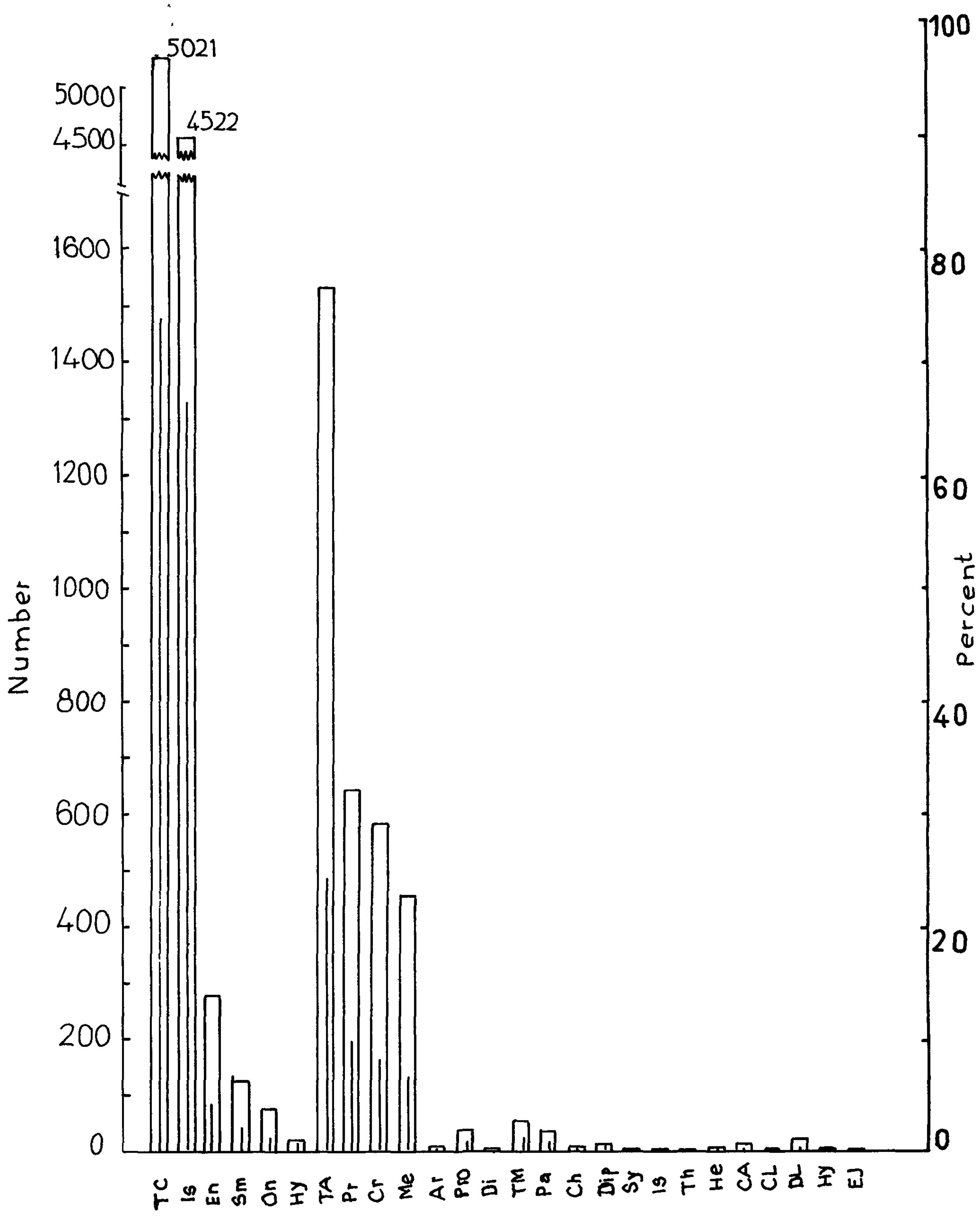
The maximum number of 7319 litter microarthropods were recorded in maximum mesh sized bags and a minimum of 6544 was recorded in the medium mesh sized bags. Collembola and Acarina the major groups of litter microarthropod fauna, collectively represented a maximum number of 6987 in maximum mesh sized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

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
Is = Isotomidae
En = Entomobryidae
Sm = Sminthuridae
On = Onychiuridae
Hy = Hypogastruridae
TA = Total Acarina
Pr = Prostigmata
Cr = Cryptostigmata
Me = Mesostigmata
Ar = Araneidae
Pra = Protura
Dip = Diplura
Mo = Molluscs

TM = Total Myriapoda
Ch = Chilopoda
Sy = Symphyla
Pa = Pauropoda
Di = Diplopoda
Iso = Isopoda
Th = Thysanoptera
He = Hemiptera
CA = Coleoptera Adults
DL = Diptera Larvae
Hy = Hymenoptera
Dic = Dictyoptera
Ej = Earthworm juveniles



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Pauropoda, 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 had a maximum number of Hypogastruridae, Prostigmata, Cryptostigmata, Mesostigmata, Diplopoda and Hymenoptera. The groups Diplura and Symphyla were maximum in both the maximum abd 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 minimum 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).

<u>Maximum mesh sized bags</u> :-

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,1977 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, 1978.

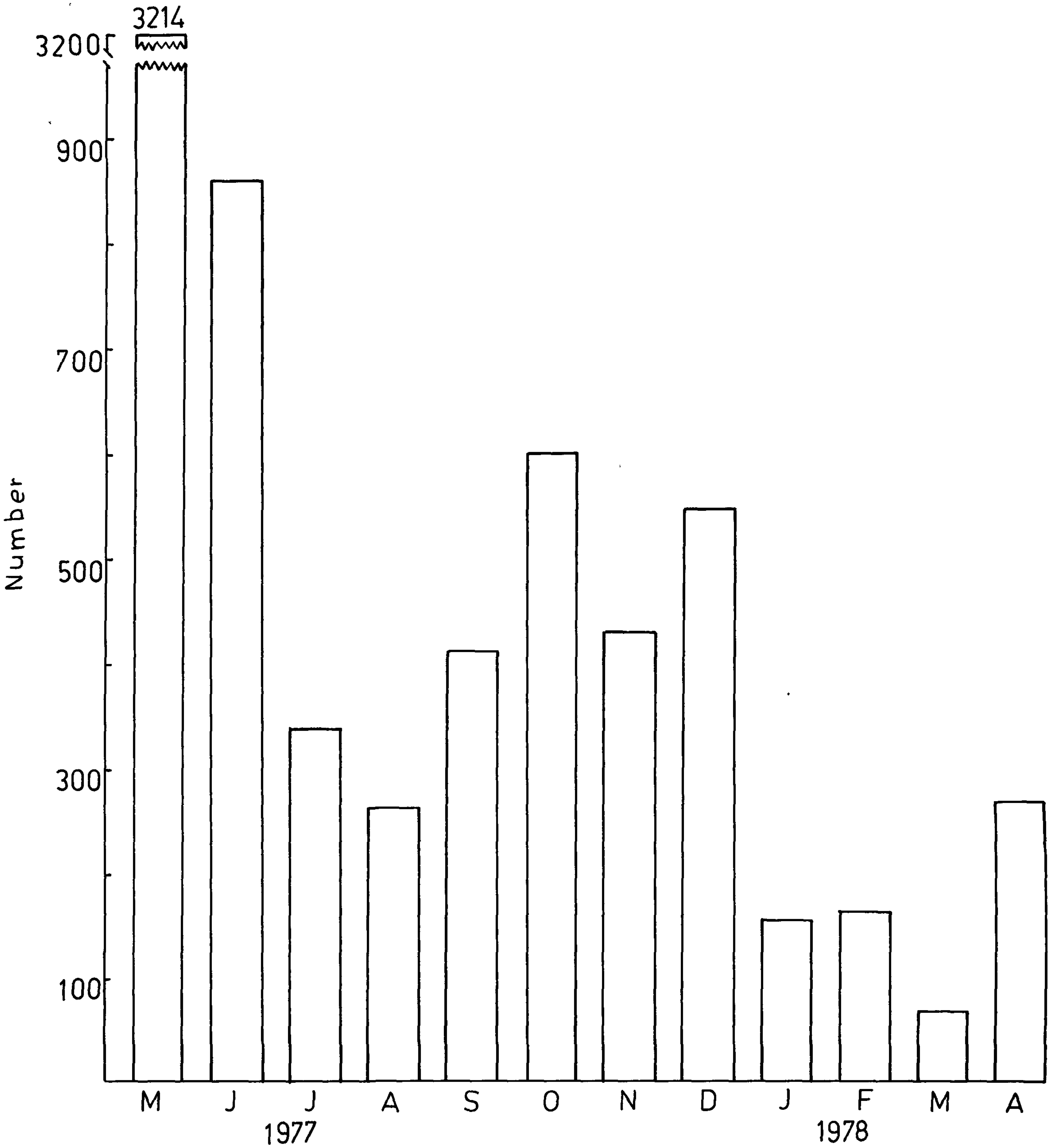
Table VIII Abundance of litter microarthropods, showing maximum and minimum density in the different mesh sized litter bags.

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*

** = Maximum; * = Minimum.

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.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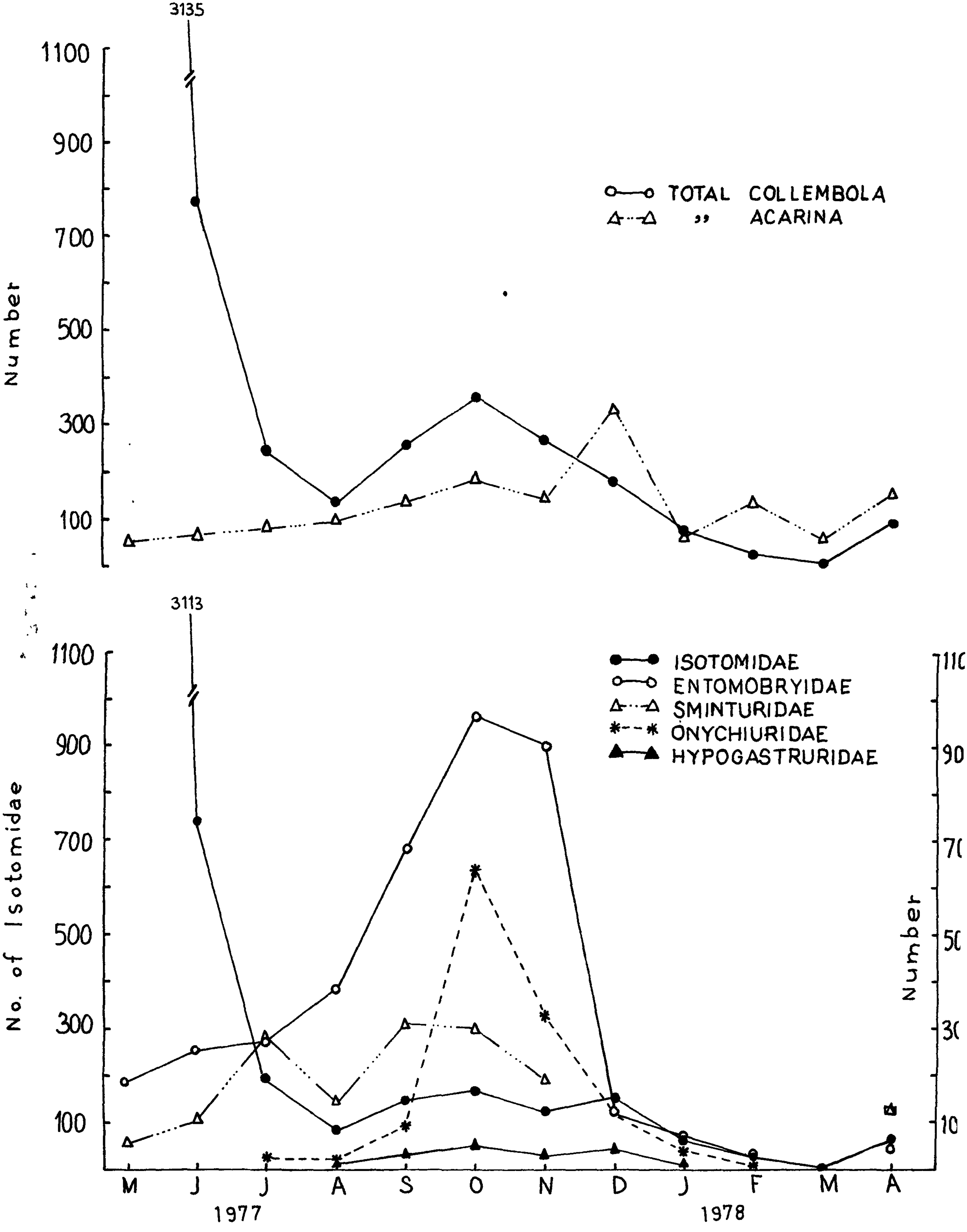
Collembola and Acarina were the major dominant groups and collectively ranged from 60 to 3185 in numbers and followed the same trend in fluctuation as that of the total microarthropods (Fig. 28a).

The total Collembola varied between 2 and 3135 in numbers during the different months and were recorded maximum in May, 1977 and minimum in March, 1978 with a small peak in October, 1977. Isotomidae the most dominant group of Collembola ranged from 2 to 3113 in numbers and were maximum in May, 1977 and minimum in March, 1978. They showed two small peaks of increase during the months of October and December, 1977. The family Entomobryidae ranged from 0 to 96 individuals and represented a gradual increase from May, 1977 reaching a peak in October, 1977 and then gradually decreased to nil in March, 1978. Sminthuridae ranged from 0 to 31 individuals, the maximum encountered were in the months of July, September and October, 1977 and were completely absent from December, 1977 to March, 1978. The family Onychiuridae ranged from 0 to 64 in numbers, the maximum occurring in October, 1977 and were recorded nil during May and June, 1977 and March, 1978. The family Hypogastruridae ranged from 0 to 5 in numbers, being maximum in October and December, 1977 and were completely absent during May to July, 1977 and from February to April, 1978 (Fig. 29a).

The group Protura ranged from 0 to 35 individuals the maximum being recorded in October and December, 1977 and were nil during May to July, 1977 and during February and March, 1978. Diplura were completely absent throughout the annual cycle except during December and January, 1978 (Fig. 30a).

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



3135
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900
700
500
300
100
Number
TOTAL COLLEMBOLA
,, ACARINA
3113
1100
900
700
500
300
100
No. of Isotomidae
ISOTOMIDAE
ENTOMOBRYIDAE
SMINTURIDAE
ONYCHIURIDAE
HYPOGASTRURIDAE
Number
M
J
J
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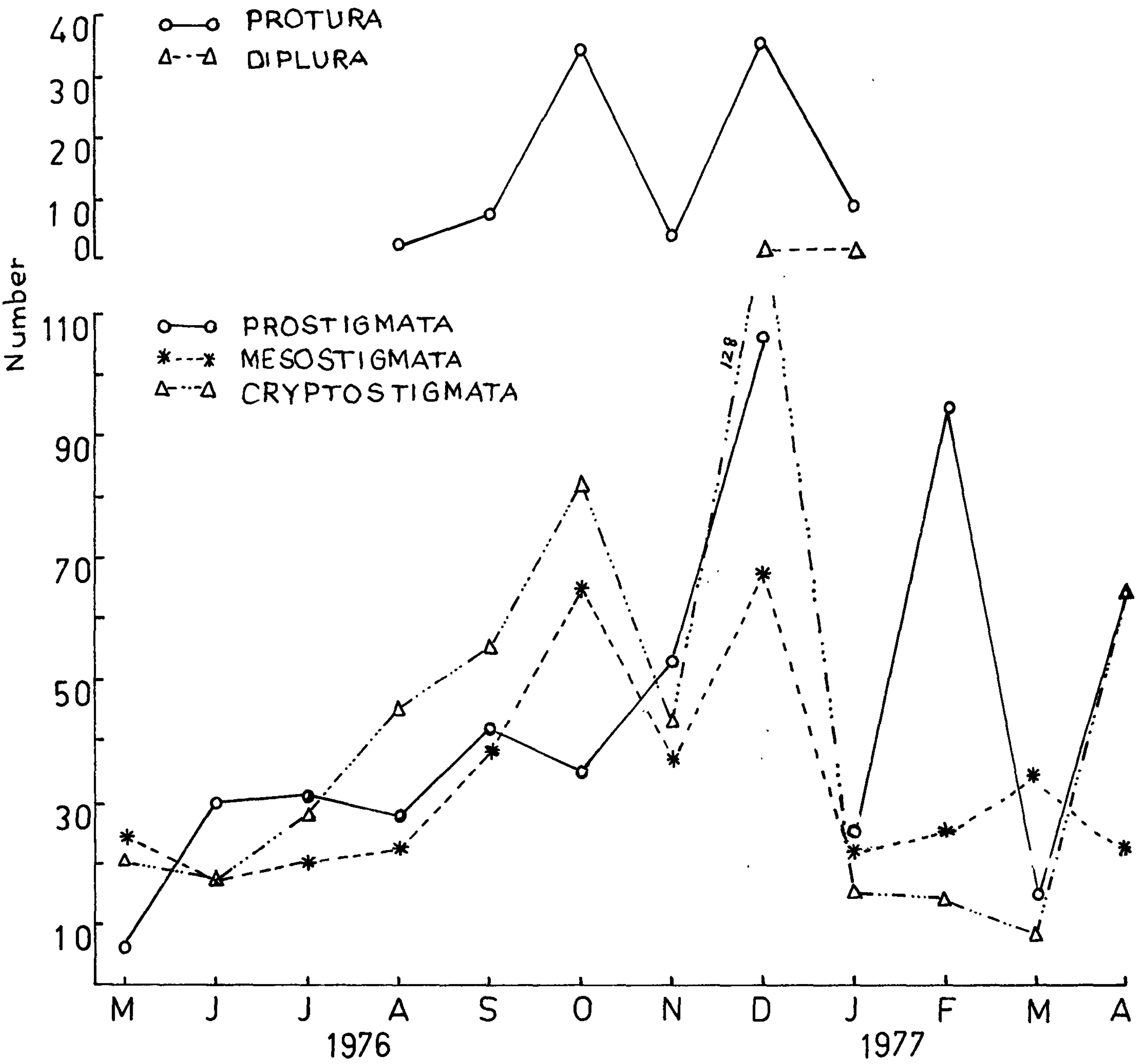
1977
1978

The second dominant group Acarina ranged from 50 to 331 in numbers over the seasons, the maximum being recorded in December, 1977 and minimum in May, 1978. It had small peaks of increase during October, 1977 and February and April, 1978 (Fig. 28a). Prostigmata the dominant group among Acarina, ranged between 6 and 106 individuals, the maximum being recorded in December, 1977 and minimum in May, 1977. There was another large peak of increased abundance during February, 1978. The group Cryptostigmata ranged from 8 to 127 in numbers, the maximum being recorded in December, 1977 and minimum in March, 1978. There was a second peak of abundance during October, 1977. Mesostigmata ranged between 17 to 68 in numbers being maximum in December, 1977 and minimum in June, 1977 (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, 1977 (Fig. 33a).

The group Myriapoda ranged from 1 to 16 individuals, the maximum being recorded was in October and November, 1977 and minimum in May and December, 1977 and February, 1978. Pauropoda was the dominant among Myriapoda and ranged from 0 to 12 in numbers, the maximum being recorded in October and November, 1977. They were completely absent during May, July and August, 1977. 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, 1977, being absent during May, November, December, 1977 and January, February and March, 1978. Chilopoda were maximum during August, October and November, 1977 and

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.



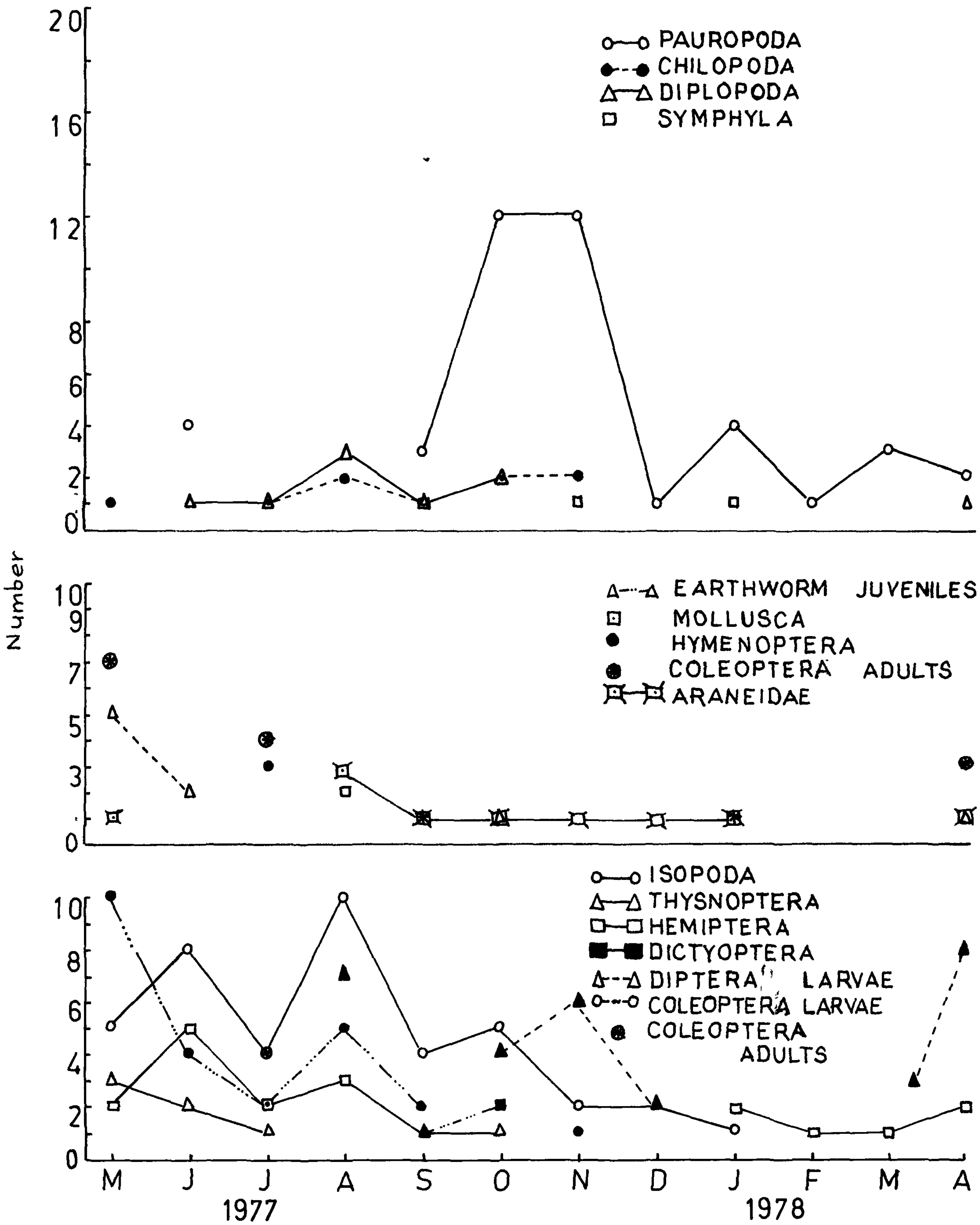
PROTURA
DIPLURA
PROSTIGMATA
MESOSTIGMATA
CRYPTOSTIGMATA
Number
128
M J J A S O N D J F M A
1976
1977

absent during June and December, 1977, January and April, 1978. The Symphyla were completely absent throughout the annual cycle except in September and November, 1977 and January, 1978 (Fig. 32a).

The group Isopoda ranged from 0 to 10 in numbers and were maximum in August, 1977 and were completely absent from February to April, 1978. Thysanoptera and Hemiptera had a range of 0-3 and 0-5 individuals respectively. Thysanoptera were recorded maximum in May, 1977 and were completely absent in August, November and December, 1977 and from January to April, 1978. Hemiptera were recorded maximum during June, 1977 and were nil from October to December, 1977 and January, 1978. The Coleoptera adults and larvae ranged between 0 to 7 and 0 to 10 respectively. They were both maximum during May, 1977 and the adults were absent from June and August, 1977 and October to December, 1977 and February and March, 1978. The larvae were absent during October and December, 1977, January and March, 1978. The Diptera larvae number ranged from 0 to 8, the maximum during August, 1977 and April, 1978 and were completely absent from May to July, 1977, September, 1977 and January and February, 1978. Dictyoptera were absent during the entire annual cycle except during September and October, 1977. The juvenile earthworms ranged from 0 to 5 in numbers, the maximum recorded in May, 1977 and were completely absent from July to September, November and December, 1977, January, 1978 to March 1978. The molluscans were recorded in very negligible numbers only in May and August, 1977 (Fig. 33a).

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.



PAUROPODA
CHILOPODA
DIPLOPODA
SYMPHYLA
EARTHWORM JUVENILES
MOLLUSCA
HYMENOPTERA
COLEOPTERA ADULTS
ARANEIDAE
ISOPODA
THYSNOPTERA
HEMIPTERA
DICTYOPTERA
DIPTERA LARVAE
COLEOPTERA LARVAE
COLEOPTERA ADULTS
Number
M J J A S O N D J F M A
1977
1978

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 the same type of fluctuation as that in the maximum mesh sized bags. The total microarthropods ranged from 19 to 3209 in numbers, the maximum recorded in the month of May, 1977 and minimum in March, 1978. They further showed two smaller peaks of abundance in the months of September and November, 1977. Collembola and Acarina together ranged between 15 and 3198 and followed the trend in fluctuation of total litter microarthropods for this mesh sized bags (Fig. 28b).

The total Collembola numbers ranged from 0 to 3165 and were recorded maximum in May, 1977 with a gradual decrease to nil in March, 1978. In between it had two small peaks of increase in September and November, 1977. The family Isotomidae ranged from 0 to 3138 in numbers and was maximum in May, 1977 and were absent in March, 1978. They had similar peaks of abundance like total microarthropods and Collembola. The family Entomobryidae ranged from 0 to 105 individuals. From June, 1977 the number gradually increased reaching a peak in September, 1977 and gradually decreased to nil in March, 1978 with a small peak during November, 1977. The family Sminthuridae ranged from 0 to 23 in numbers, the maximum being recorded in September, 1977 and were completely absent in May, 1977 and from December, 1977 to March, 1978. The family Onychiuridae ranged from 0 to 19 in numbers, maximum being in October, 1977 and were completely absent during May and June, 1977 and from December, 1977 to March, 1978. The family Hypogastruridae

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

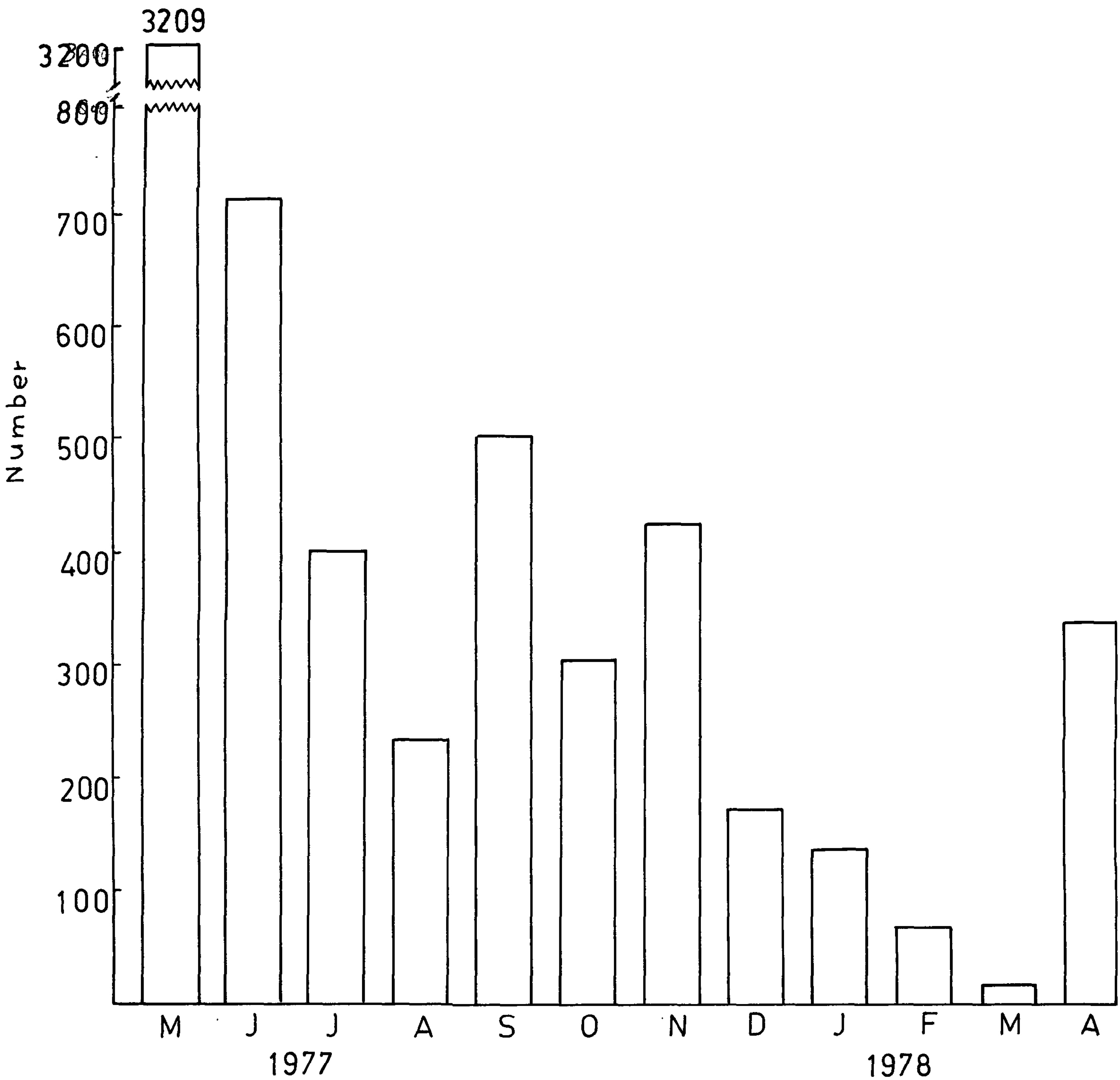
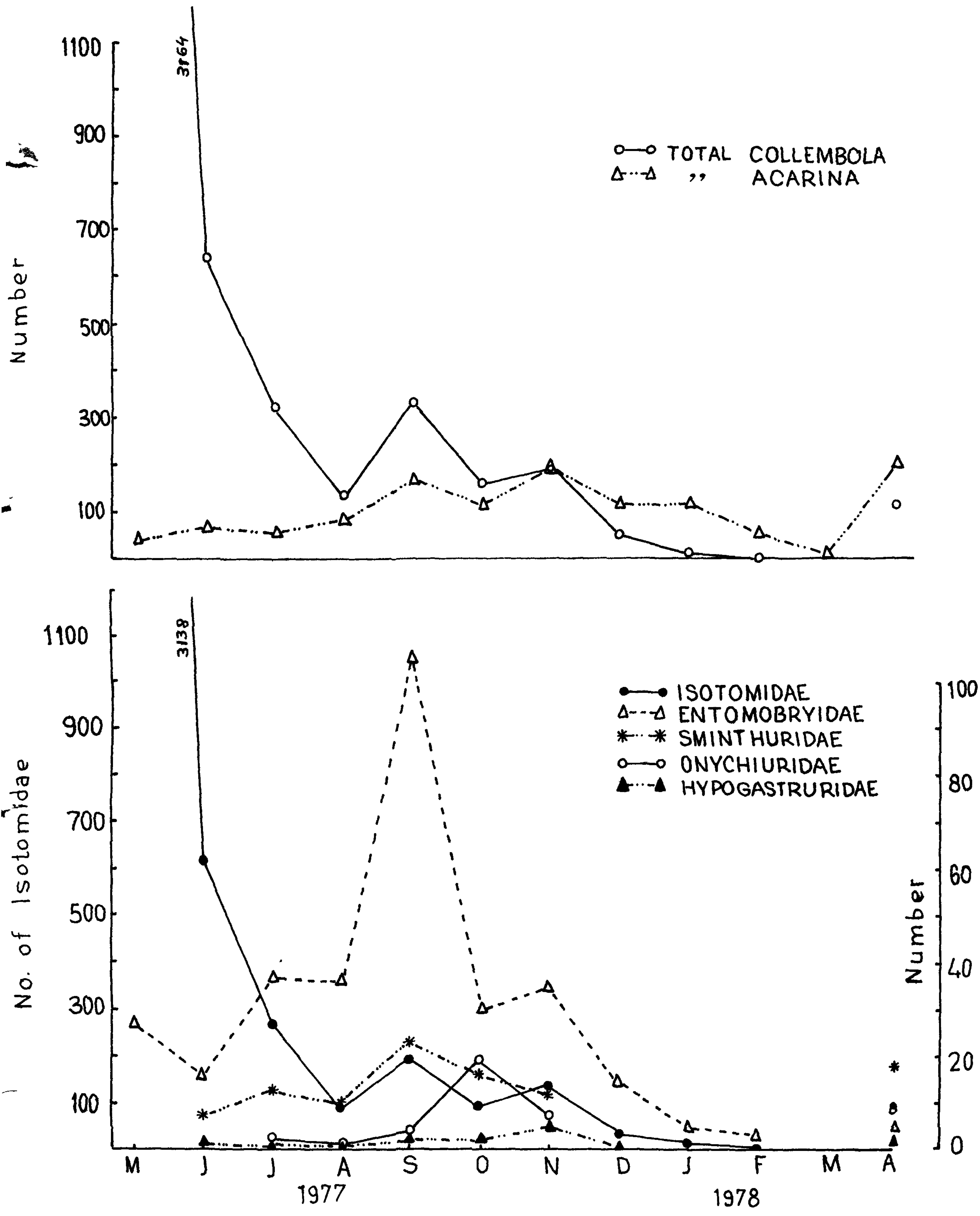

3209
3200
800
700
600
500
400
300
200
100
Number
M
J
J
A
S
O
N
D
J
F
M
A
1977
1978

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 Hypogastruridae found in the medium mesh sized (1.0 mm^2) litter bags during the entire study period.



TOTAL COLLEMBOLA
,, ACARINA
Number
3764
1100
900
700
500
300
100
ISOTOMIDAE
ENTOMOBRYIDAE
SMINTHURIDAE
ONYCHIURIDAE
HYPOGASTRURIDAE
No. of Isotomidae
3138
Number
100
80
60
40
20
0
M J J A S O N D J F M A
1977
1978

ranged from 0 to 5 in numbers, the maximum recorded being in November, 1977 and were completely absent in May, 1977 and from January to March, 1978 (Fig. 29b).

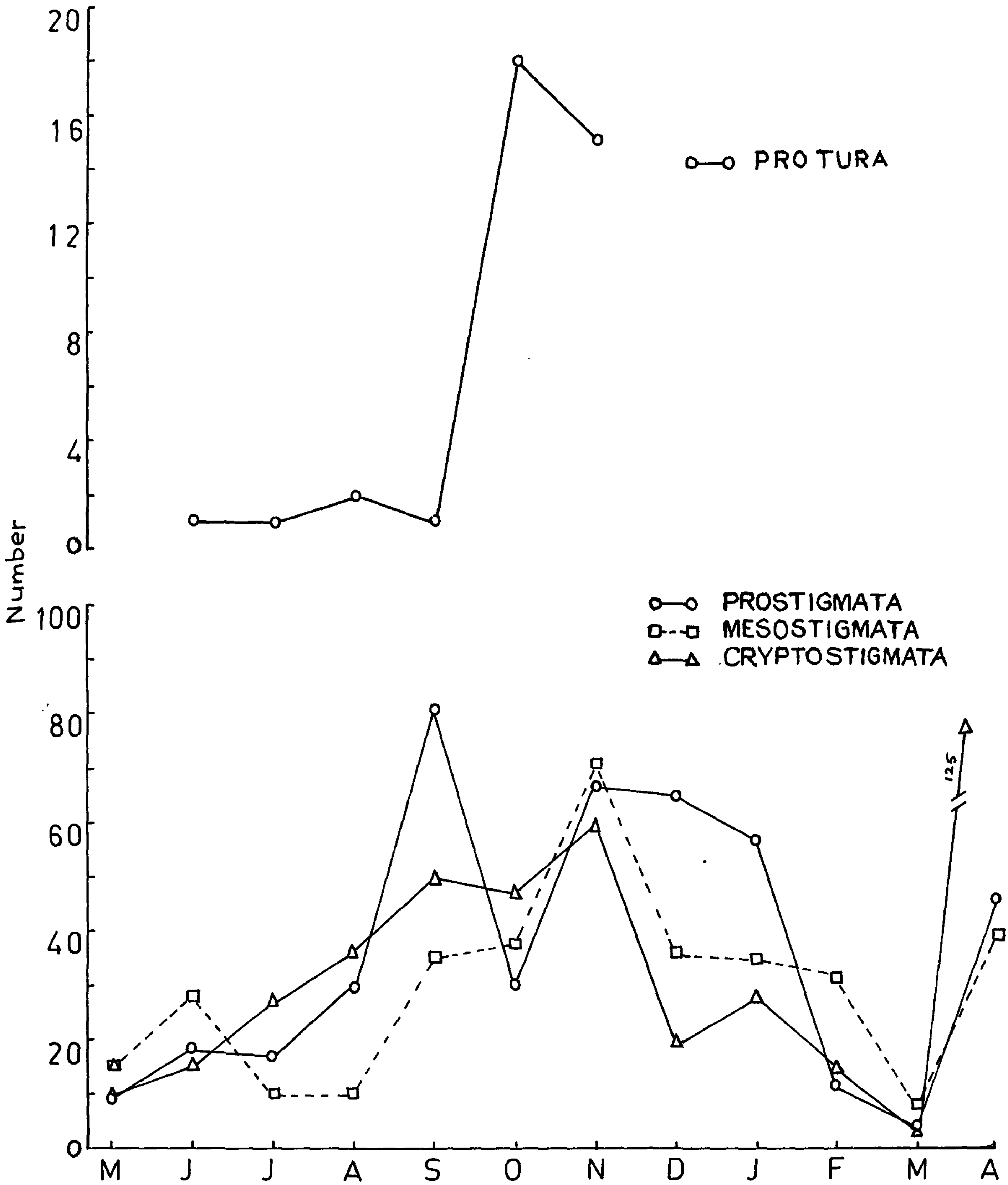
The group Protura ranged from 0 to 18 in numbers, maximum being in the month of October, 1977 and were absent in May, 1977 and from December, 1977 to March, 1978. The Diplura were completely absent throughout the annual cycle (Fig. 30b).

The total Acarina ranged from 15 to 211 in numbers and from May, 1977 onwards it gradually increased till September, 1977 and then decreased in October, 1977, it reached the peak in November, 1977. Then it gradually decreased to minimum in March, 1978 and increased to maximum in April, 1978 (Fig. 28b). The number of Prostigmata ranged from 4 to 81, the maximum being in the month of September, 1977 and minimum in March, 1978. The number of Cryptostigmata ranged from 3 to 125. They gradually increased from May, 1977 and with a small peak in November, 1977, decreased to minimum in March, 1978 with a sudden range of increase to maximum in April, 1978. The number of Mesostigmatid mites ranged from 8 to 71, the maximum was during November, 1977 and minimum in March, 1978 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, 1977 and were absent during May to July, 1977 and November and December, 1977 and February and March, 1978 (Fig. 33b).

The total Myriapoda ranged from 0 to 11 individuals. They were maximum in numbers during November, 1977 and absent

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.

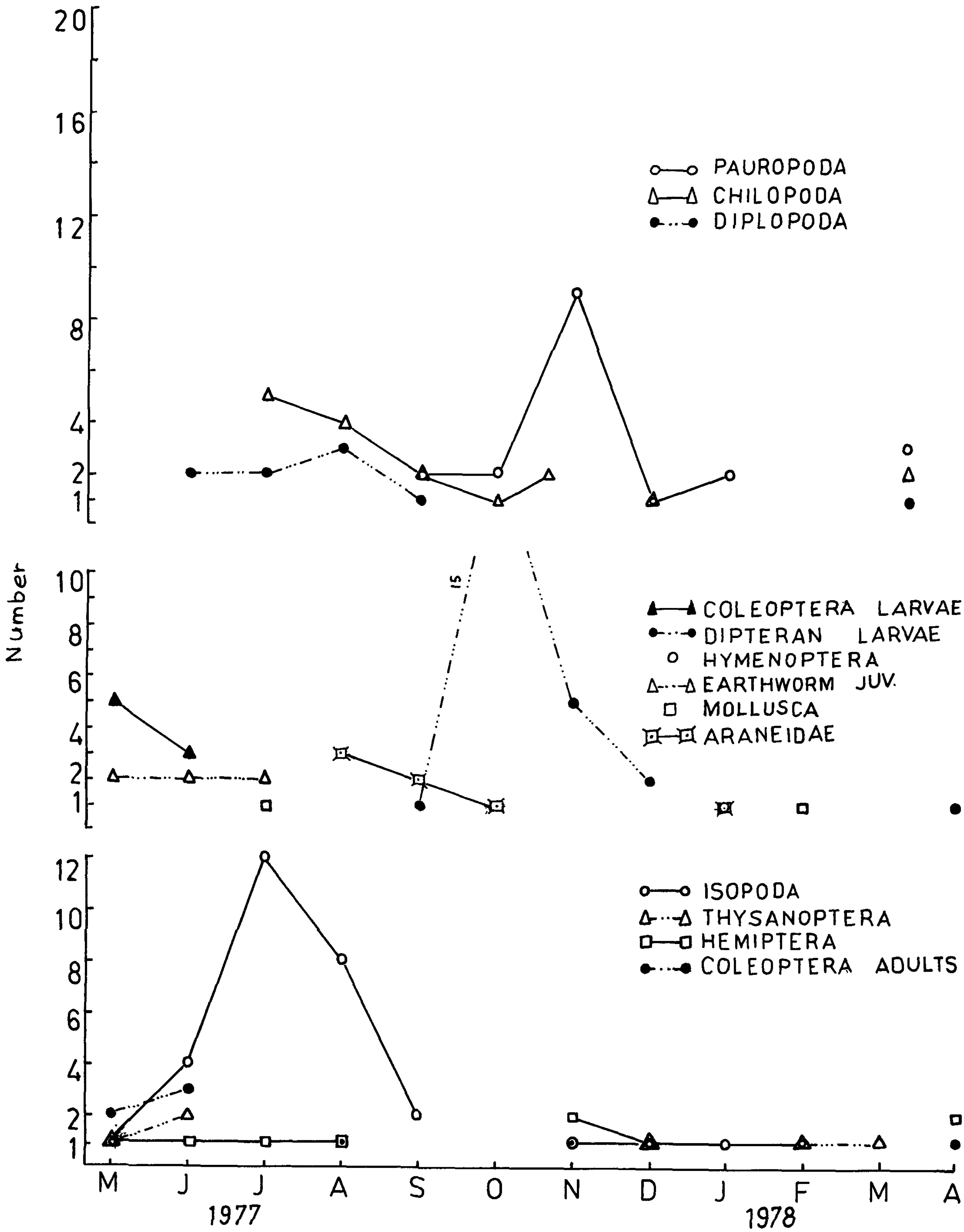

PROTURA
PROSTIGMATA
MESOSTIGMATA
CRYPTOSTIGMATA
Number
125
0
4
8
12
16
20
0
20
40
60
80
100
M J J A S O N D J F M A
1977
1978

during May, 1977 and February, 1978. In the group Chilopoda, the numbers ranged from 0 to 5, the maximum being recorded in July, 1977. They were entirely absent during May, June and December, 1977 and February and March, 1978. The Diplopoda number ranged from 0 to 3, the maximum in August, 1977 and were recorded nil during May, 1977 and from October, 1977 to March, 1978. The group Symphyla were completely absent. Pauropoda ranged from 0 to 9 in numbers. The maximum was recorded in November, 1977 and were recorded nil from May to August, 1977 and February and April, 1978 (Fig. 32b).

The number of Isopoda ranged from 0 to 11 in numbers, the maximum encountered were in July, 1977. This group was nil in October, 1977 and during March and April, 1978. Both the groups Thysanoptera and Hemiptera ranged from 0 to 2 in numbers, the former being maximum in June, 1977 and absent during July to November, 1977 and January and April, 1978 while the latter was maximum in November, 1977 and April, 1978 and absent during September, October, 1977 and January to March, 1978. The Coleoptera adults and larvae ranged from 0 to 3 and 0 to 5 respectively. The adults were maximum in June, 1977 and absent during July, September and December, 1977, and January to March, 1978. The larvae were maximum in May, 1977 and recorded nil from July, 1977 to April, 1978. The Diptera larvae numbers ranged from 0 to 15, the maximum being recorded in October, 1977 and absent completely during May to August, 1977 and from January to March, 1978. The Juvenile earthworms were only two in numbers every month from May to July, 1977 and absent throughout the remaining annual cycle. Mollusca were nil for

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.



PAUROPODA
CHILOPODA
DIPLOPODA
COLEOPTERA LARVAE
DIPTERAN LARVAE
HYMENOPTERA
EARTHWORM JUV.
MOLLUSCA
ARANEIDAE
ISOPODA
THYSANOPTERA
HEMIPTERA
COLEOPTERA ADULTS
Number
15
M J J A S O N D J F M A
1977
1978

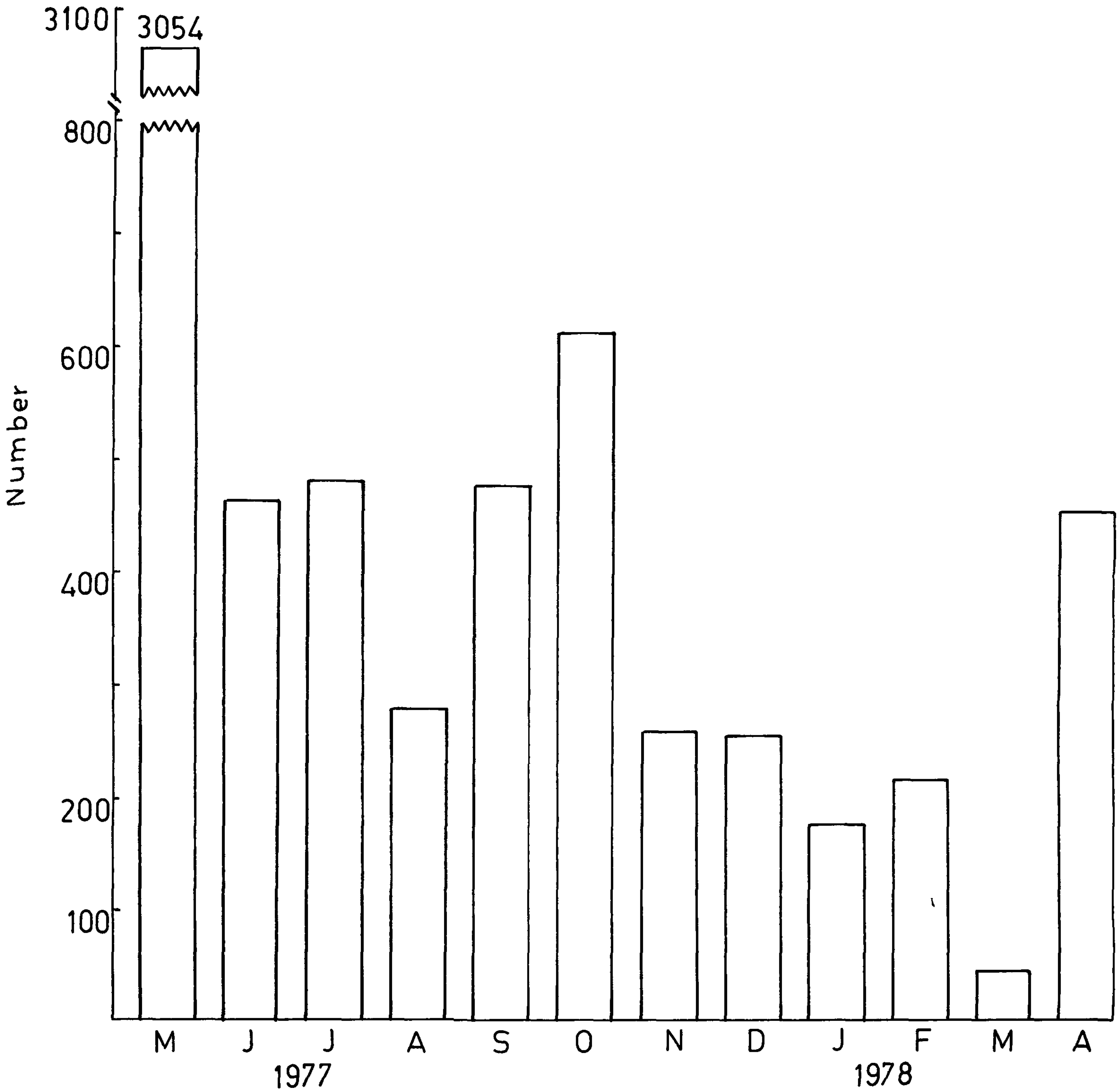
most of the period, except in July, 1977 and February, 1978, when they represented only one individual each time (Fig. 33b).

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, 1977 and minimum in March, 1978 with a small peak of abundance in October, 1977. 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, 1977 and minimum in March, 1978 with a small peak of increase in October, 1977. The family Isotomidae numbers ranged from 2 to 3003. It was encountered maximum in May, 1977 and minimum in March, 1978 with a small peak of abundance during October, 1977. The family Entomobryidae ranged from 0 to 105. It gradually increased from May, 1977 till it reached a small peak in July, 1977, fell and then reached the maximum in September, 1977 and thereafter decreased gradually to nil in March, 1978. The range for the family Sminthuridae was 0 to 30, the maximum being in September, 1977. They were completely absent during December, 1977 to March, 1978. The family Onychiuridae and Hypogastruridae ranged from 0 to 23 and 0 to 10 respectively. The maximum number of Onychiuridae

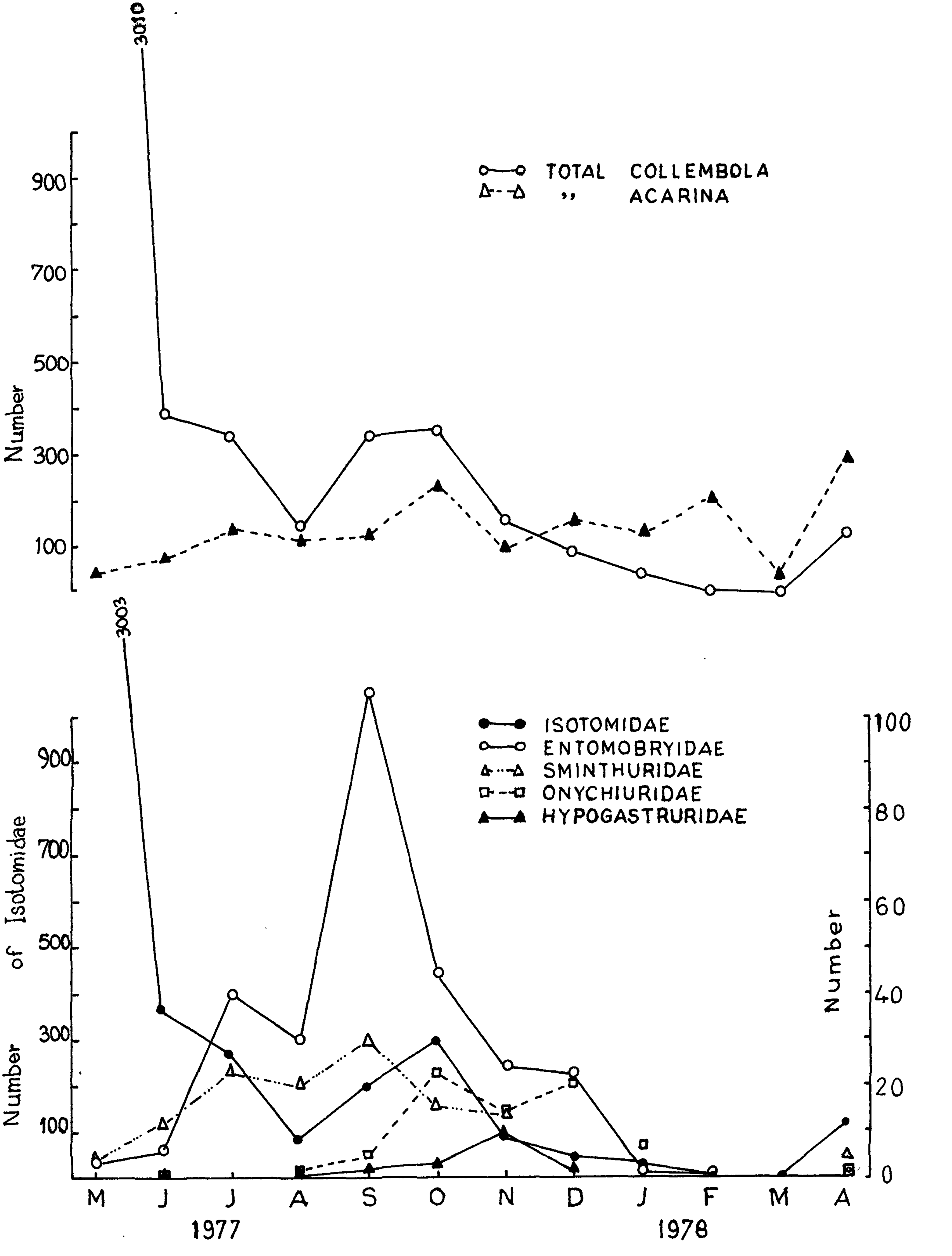
Figure 27c showing the seasonal fluctuation of total microarthropods found in the minimum mesh sized bags ($0.3\ mm^2$) during the entire study period.



3100
3054
800
600
400
200
100
Number
M
J
J
A
S
O
N
D
J
F
M
A
1977
1978

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.



3010
TOTAL COLLEMBOLA
,, ACARINA
Number
900
700
500
300
100
3003
ISOTOMIDAE
ENTOMOBRYIDAE
SMINTHURIDAE
ONYCHIURIDAE
HYPOGASTRURIDAE
Number of Isotomidae
Number
100
80
60
40
20
0
M J J A S O N D J F M A
1977
1978

was recorded in October, 1977 while the maximum number of Hypogastruridae was recorded in November, 1977. They were both recorded nil during May and July, 1977 and February and March, 1978 (Fig. 29c).

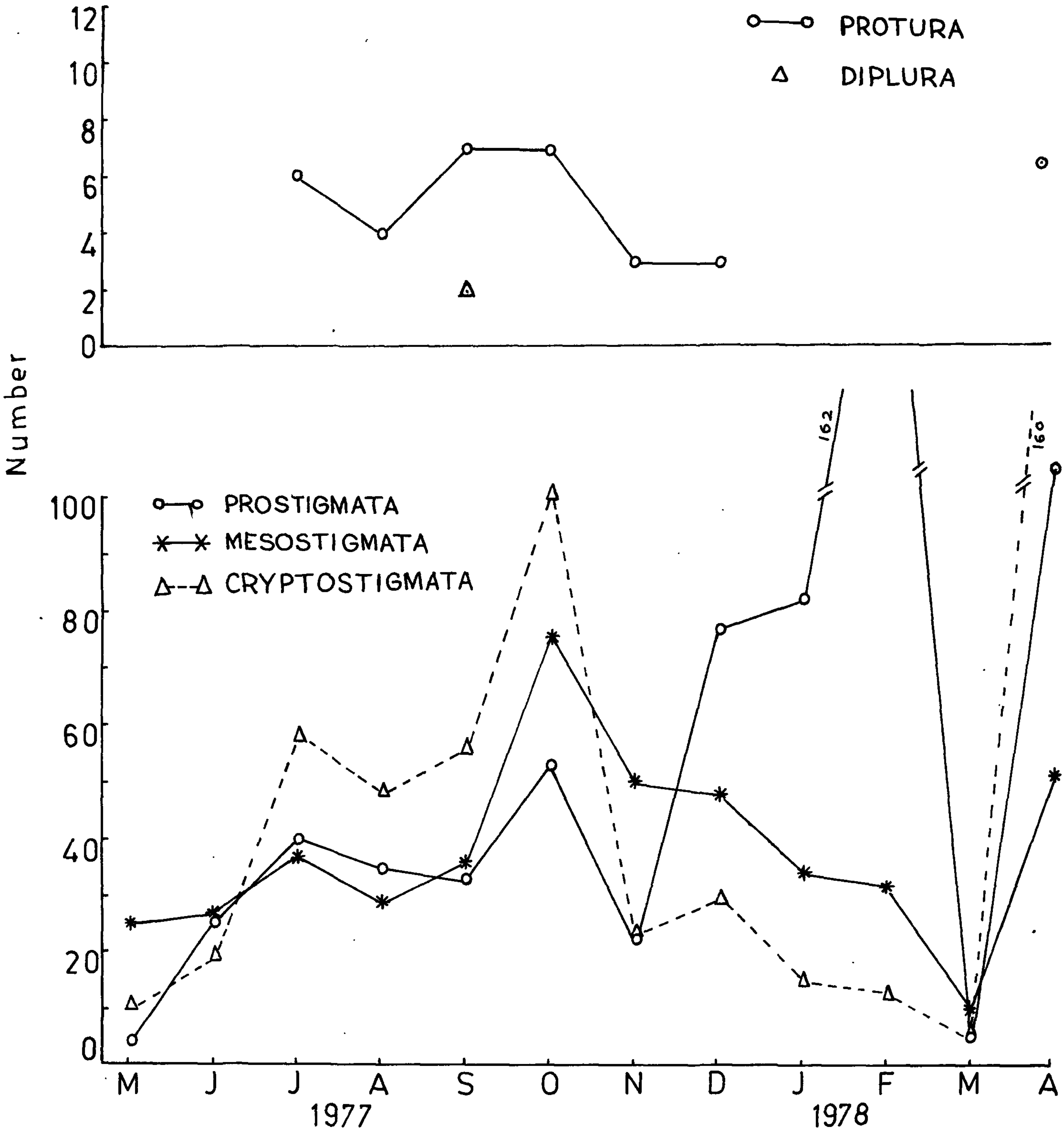
The number of Protura ranged from 0 to 7, the maximum recorded being in September and October, 1977 and April, 1978. They were completely absent during May and June, 1977 and from January to March, 1978. The Diplura were recorded only in September, 1977 when they were two in numbers (Fig. 30c).

The group Acarina ranged from 39 to 299 in numbers, the minimum being in May, 1977 and maximum in April, 1978. Besides it showed two smaller peaks of abundance during October, 1977 and February, 1978 (Fig. 28c). The sub-order Prostigmata ranged from 4 to 162 in numbers, the minimum being recorded in May, 1977 and maximum in February, 1978. Besides, they showed small peaks of abundance in July, 1977, October, 1977 and April, 1978. Cryptostigmata ranged from 5 to 160 in numbers, the maximum being recorded in April, 1978 and the minimum was in March, 1978 with a small peak of increase in October, 1977. Mesostigmata ranged from 10 to 76 numbers, being maximum in October, 1977 and minimum in March, 1978 with a sudden increase forming a small peak in April, 1978 (Fig. 31c). The group Araneidae ranged from 0 to 5 numbers. The maximum was encountered during August, 1977 and were absent from May, June, 1977 and September to December, 1977 and from January, February and April, 1978 (Fig. 33c).

The total Myriapoda ranged from 0 to 17 individuals, maximum being recorded in October, 1977 with a small peak in

Figure 30c showing the seasonal fluctuation of total 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.



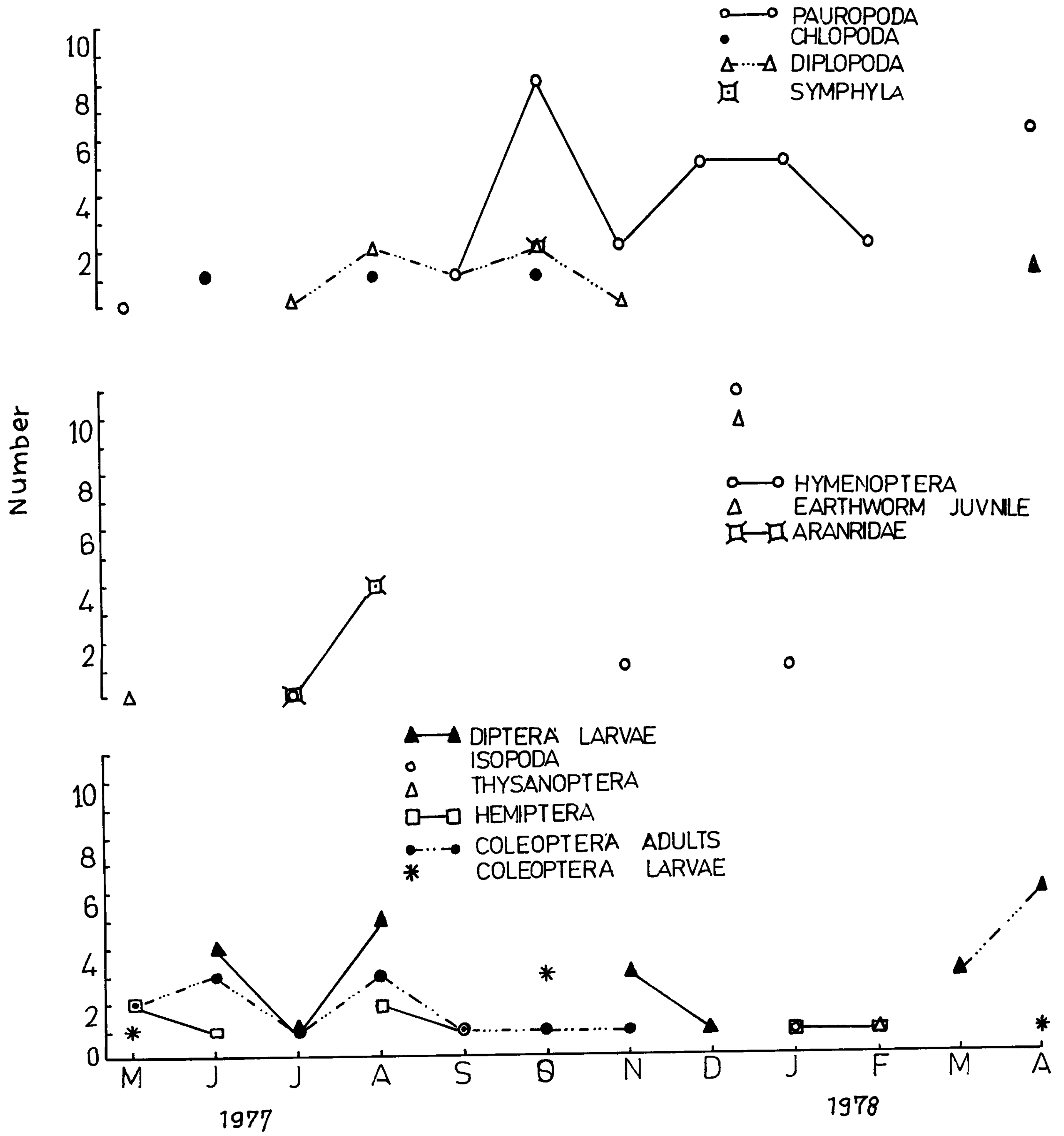
PROTURA
DIPLURA
Number
PROSTIGMATA
MESOSTIGMATA
CRYPTOSTIGMATA
162
160
0
2
4
6
8
10
12
20
40
60
80
100
M
J
J
A
S
O
N
D
J
F
M
A
1977
1978

April, 1978 and were recorded nil in March, 1978. The number of Pauropoda ranged from 0 to 9, maximum being recorded in October, 1977 and were recorded nil during June to August, 1977 and March, 1978. The Diplopoda numbers ranged from 0 to 3, the maximum being recorded in August and October, 1977, while recorded nil during May and June, 1977 and from December, 1977 to March, 1978. The number of Chilopoda recorded each time was only two in number during June, August and October, 1977 and April, 1978. Symphyla were recorded 3 in number only in October, 1977 and absent throughout (Fig. 32c).

The group Isopoda was recorded only one each time in July and September, 1977 and January, 1978. Thysanoptera was recorded only in December, 1977 and February, 1978, one individual each time. The group Hemiptera ranged from 0 to 2 in numbers, maximum in May and August, 1977 and were nil in July, 1977 and from October, 1977 to January, 1978 and April, 1978. Both Coleoptera adults and larvae ranged from 0 to 3 in numbers, the maximum recorded being in June and August, 1977 for adults and in October, 1977 for larvae. Adults were absent during December, 1977 to March, 1978 and larvae were absent from June to September and November, 1977 and from January to March, 1978. The range of Diptera larvae was from 0 to 6 numbers, the maximum being recorded in April, 1978. A second peak of increase was recorded in August, 1977 and were absent during May, September and October, 1977 and January and February, 1978. Hymenoptera was recorded two in numbers each time in November, 1977 and January, 1978. A juvenile earthworm was recorded only once in May, 1977 as one individual (Fig. 33c).

Figure 32c showing the seasonal fluctuation of Pauropoda, Diplopoda, Chilopoda and Symphyla found in the minimum mesh sized (0.3 mm^2) litter bags during the entire study period.

Figure 33c showing the seasonal fluctuation of Hymenoptera, Araneidae, Isopoda, Thysanoptera, Hemiptera, Coleoptera adults and larvae, Diptera larvae, Dictyoptera, earthworm juveniles and mollusca found in the minimum mesh sized (0.3 mm^2) litter bags during the entire study period.



PAUROPODA
CHLOPODA
DIPLOPODA
SYMPHYLA
Number
HYMENOPTERA
EARTHWORM JUVNILE
ARANRIDAE
DIPTERA LARVAE
ISOPODA
THYSANOPTERA
HEMIPTERA
COLEOPTERA ADULTS
COLEOPTERA LARVAE
M J J A S O N D J F M A
1977
1978

Physical Factors :-

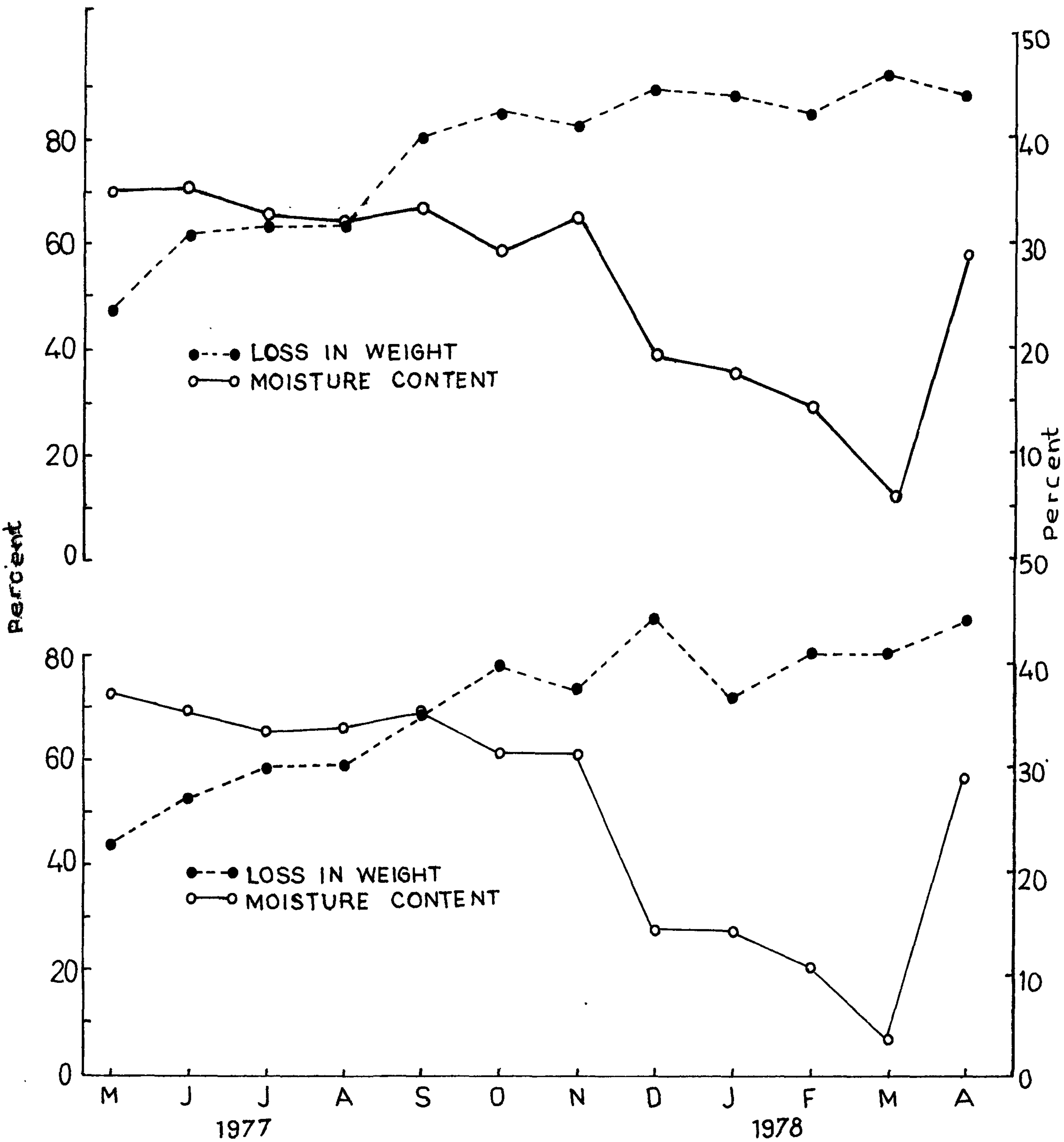
The physical factors recorded during the present investigation were temperature, moisture and weight loss in the litter bags. The seasonal variation in temperature is presented in Fig. 34d. It ranged from 16°C to 25.5°C. The maximum temperature was recorded in June, 1977 and minimum in November, 1977. 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 70.67%±1.01, the maximum recorded being in May, 1977 and minimum in March, 1978. The mean percentage loss in weight of litter ranged from 22.45%±0.19 to 43.56%±0.66, the former being in May, 1977 and the latter in April, 1978. 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, 1977 while lowest in March, 1978. The percentage loss in weight of litter ranged from 23.3% to 43.75%, the lowest being in the month of May, 1977 and the highest in the month of April, 1978. 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, 1977 and minimum in March, 1978. The weight loss in the litter bags ranged from 22.16% to 43.75%, the minimum recorded during May, 1977 and the ..

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.

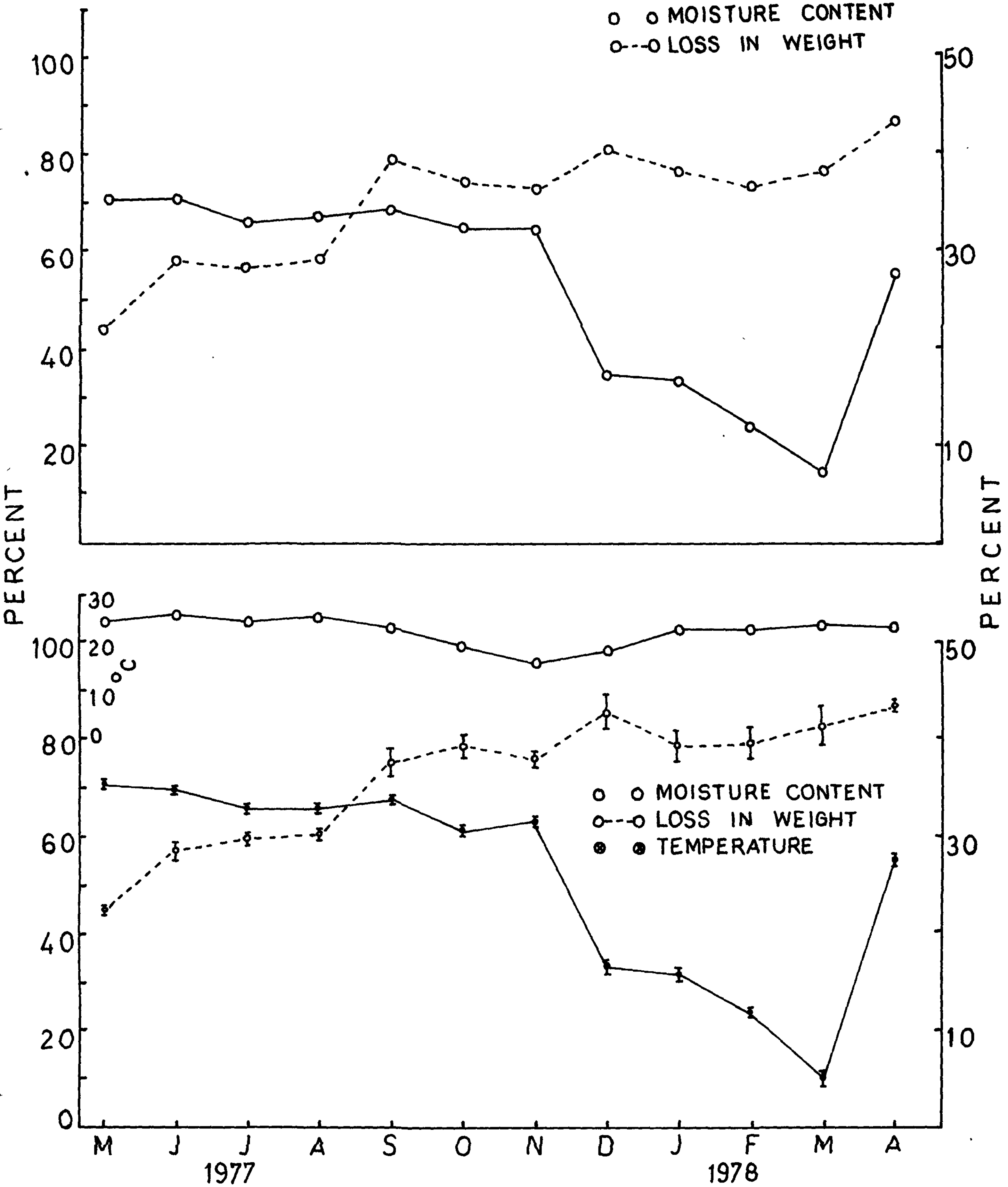
Figure 34b showing the seasonal fluctuation of various physical factors of litter - moisture content and weight loss in percent in the medium mesh sized ($1.0\ mm^2$) litter bags during the entire study period.



LOSS IN WEIGHT
MOISTURE CONTENT
LOSS IN WEIGHT
MOISTURE CONTENT
Percent
Percent
0
20
40
60
80
150
10
20
30
40
50
M
J
J
A
S
O
N
D
J
F
M
A
1977
1978

Figure 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.



o o MOISTURE CONTENT
o---o LOSS IN WEIGHT
PERCENT
PERCENT
°C
o o MOISTURE CONTENT
o---o LOSS IN WEIGHT
⊗ ⊗ TEMPERATURE
M J J A S O N D J F M A
1977
1978

maximum in April, 1978. 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, 1977 and minimum in March, 1978. The loss in litter weight ranged from 21.88% to 43.18%, the minimum being in May, 1977 and the maximum in April, 1978. In these bags the average rate of decomposition was 34.68%.

DISCUSSION

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 results in field experiments, the litter had 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 with 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 litter weight loss. The most abundant organisms in dry funnel extracts of plant litter have been Collembola and Acarina, where, 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 was 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 to draw conclusions of their role in such an ecosystem. The present study also revealed both Collembola and Acarina constituting 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 than 5%. Such findings were also 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 be at least two possible reasons for such rhythms. One, the activity of Collembola during the warmer periods and Acarina during winter and the second, the feeding habits of these two groups, for, the litter gets primarily broken down by Collembola and at 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 and the family Isotomidae dominated over the other four families in terms of population numbers. However, their number being maximum was misleading, as, over the season, 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 used in the present study was above 3000 in all mesh sizes and this occurred during the month of May. Similarly least was recorded in all the mesh size 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-IXa,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 corraborated by the fact that this was an indication of the dominance of one family Isotomidae under Collembola (Table-IXa,b).

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

TABLE IXa

Microarthropod Groups	Maximum mesh sized litter bags ($3.0\ mm^2$) 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 IXb Coefficient correlation and multiple correlation between monthly abundance of litter microarthropods and various physical factors in the medium mesh sized bags.

TABLE IXb

Medium mesh sized litter bags (1.0 mm^2)

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

TABLE IXc

Microarthropod Groups	Minimum mesh sized litter bags ($0.3\ mm^2$) 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

* = $P < 0.05$

** = $P < 0.01$

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 the 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 of 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, and excluded 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 a burst of activity of microarthropods, particularly Collembola and Acarina was due to the preceding fungal waves. 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. In conclusion, our study revealed that litter, its decomposition and its breakdown into elements, was only possible when both the fauna and flora acted synergestically.

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GENERAL DISCUSSION AND CONCLUSION

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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 at the beginning of the thesis, to the ecologists, the landscape was organised by nature into a mosaic of systems called ecosystems. Inspite 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 was 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 out 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 factors 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 (Heal and Perkins, 1976).

Concluding Remarks

With the above mentioned background, a general overview of the study undertaken prompted certain conclusions to be drawn. The first two chapters 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 last two chapters 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, 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 a similar effect while treating them at either sub-order and 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 faunal populations on detrital processing was comminution which exposed greater surface area for microbial attact (Drift and Witkamp, 1960; McBrayer et al, 1974; Mitchell, 1978). The present investigation not only confi ed these findings, but also gets support in 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 studied. The average turnover rate for the trophic levels studied, changed during the season as temperature and moisture changed and 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 forcing a formal relationship between two levels. On one hand community dynamics were interpreted whenever possible as population phenomena, on the other, 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 have 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 utilized in the main classes of the forest community? How do members of the Shillong pine forest compare with other forest systems in the tropics and elsewhere? What do comparisons between successional and climax species show?

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No. of Publications	:	7 papers 3 focal theme notes 20 abstracts

APPENDICES

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SOIL BIOLOGY AND ECOLOGY IN INDIA

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Some Observations on the Earthworm Population and the Biomass in a Sub-Tropical Pine Forest Soil

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ABSTRACT

Monthly fluctuations in the biomass and population density of earthworms in a pine forest soil of Shillong, North-Eastern India were studied during the period April-September, 1976. The earthworms were extracted both by the wet formalin method and by handsorting, to ensure adequate sampling and to avoid underestimations of population size. The population size was related to soil pH and moisture. Maximum abundance was recorded in July and minimum in April, 1976. The high and low values in population size coincided with the maximum and minimum levels in soil moisture during this period. The soil pH was on the acidic side (5.80 to 6.25) which explains the comparatively small earthworm population in this soil. Relationships of population size to soil pH and moisture were tested statistically and significant correlations were established and discussed.

INTRODUCTION

EARTHWORMS form a major proportion of the invertebrate biomass in the soil particularly in temperate regions. The pioneering work of Darwin (1881) on earthworms sparked off a great upsurge of interest in these animals during the late 19th and early 20th century, even though the work was on morphology and detailed histology rather than on basic biology and ecology. The earthworms are secondary decomposers and their role in fragmentation and breakdown of dead plant and organic material is well established. (Raw, 1959, 1962; Health and King, 1964; Satchell and Lowe, 1967; Pearel *et al.*, 1966; Barley and Keining, 1964 and Medge, 1966). The part, these organisms play in humification of leaf litter and organic debris has been extensively studied (Guild, 1955; Barley, 1961; Satchell, 1967; Raw, 1960 and Van Rhee, 1963). As an attempt to study the earthworm population structure, Block and Banage, 1968; El-Duweini and Ghabbour, 1965; Guild, 1951, 1952; Nakamara, 1968; Raw, 1960: Van Rhee and Nathans, 1961; Svendsen, 1955: Waters, 1955 and Zicsi, 1962; have estimated population densities in different ecosystems.

In India, ecological observations on earthworms are few, and even these investigations have been mostly on damage caused by earthworms to agricultural crop and measures of control (Puttarudraiah and Sastry, 1961). This investigation considers some aspects of earthworm population and biomass in the pine (*Pinus khasya* Royle) forest soil of Meghalaya.

Study area: The study was confined to one of the cultivated pine forests of the Government of Meghalaya in Shillong (25.34°N and 91.56°E) at an elevation of 1250 m. The dominant undergrowths of the forest were *Eupatorium* and *Artemisia.*

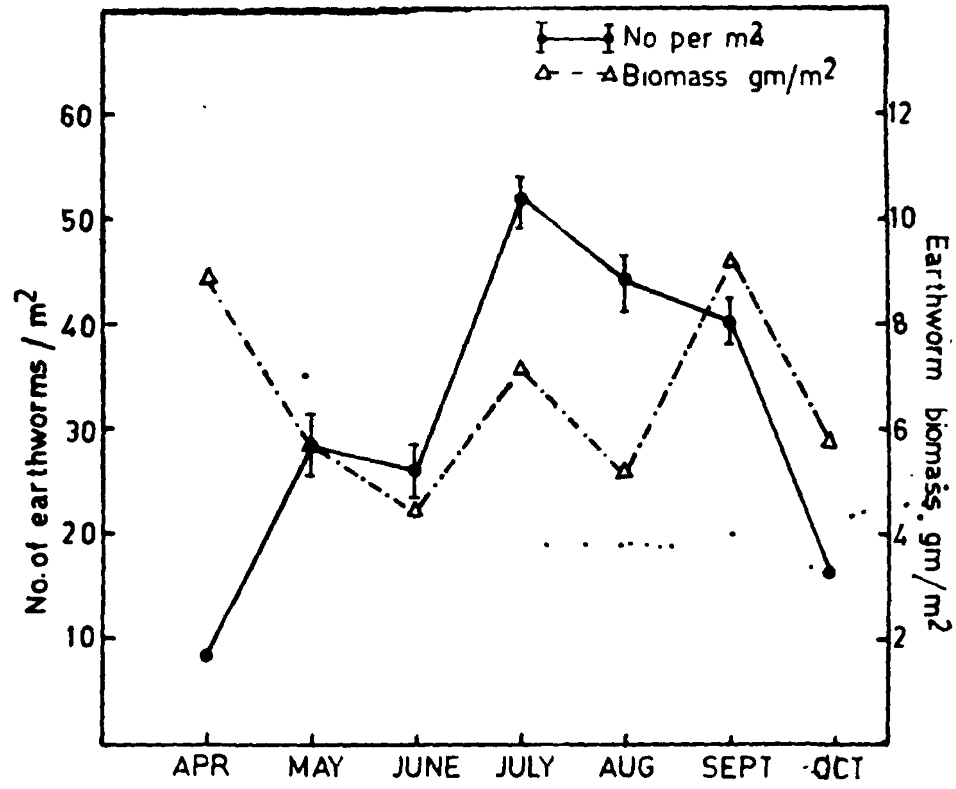
Material and Methods

Population and biomass estimates were made every month from April to November 1976. The litter and surface twigs were removed in five randomly selected patches of 625 cm^2 area. A dilute solution of formalin (0.55 per cent) was sprayed on each quadrat until the soil was saturated. The earthworms were picked up as they appeared over a period of twenty minutes. The worms were washed immediatly and stored in polythene bags along with some soil. After extracting the worms with formalin, the soil in each quadrat was carefully dug up to a depth of 10 cm. This soil was thoroughly examined and any worms present in it were hand-picked. This was done to ensure thorough sampling of each quadrat. In the laboratory the earthworms were once again washed in water, dried with blotting paper and weighed fresh and the biomass per unit area was calculated (standing crop). The worms were relaxed by adding drops of rectified spirit and the length of the stretched worms were recorded. The worms were preserved in 10 per cent formalin for taxanomical investigation.

For statistical parameters, methods outlined by Woolf (1968) were followed.

Results and Discussion

It has been seen that the members of the family Lumbriculidae and Acanhodrillidae were the most dominant in the study area. It can be seen from Fig. 1 that the highest density of worms (52/m^2) occurred in July and the minimum density (8.8/m^2) in April. This corresponds to the maximum and minimum levels in soil moisture. A significant correlation between soil moisture and earthworm abundance was established (Table II). Moisture levels in the soil microenvironment are governed by macro environmental factors namely rainfall.



ig.1 Monthly variation in numbers and biomass of earthworms experimental forest site.

TABLE I

Coefficient of correlation values between pH, moisture and earthworm populations

Metric traits	Coefficient of correlation
Body length and body weight	0.978
Earthworm population and moisture (soil)	0.925
Earthworm population and pH (soil)	0.988
Soil moisture and soil pH	0.988

All the values are significant at 1 per cent probability level.

pH limits earthworm distribution (Petrov, 1946, and Edwards and Lofty, 1972). The forest soil under the present study being acidic, the abundance of these earthworms was less (Table II).

It is well known that earthworm density and activity fluctuates during annual cycles. However, Gates (1961) observed that earthworms were mainly

TABLE II

Climatological data for the study area with per cent of total earthworms extracted

Months	Per cent of total earthworms	Moisture	pH
April	4.52	20	5.85
May	14.07	30	5.95
June	13.07	25	5.80
July	26.13	35	6.25
August	22.11	28	5.95
September	20.10	28	6.15

active during May to October in both monsoon tropical climate of Burma and the humid sub-tropical climate of India. Cocoon production also seem to be seasonal even in the sub-tropical climate of India Bahl (1922) reported that although *Pheritima* sp. produce cocoons throughout the year, peak production occurred between March to June, before the rain in July and August. Cocoon production was lowest during these rainy months.

The experimental area always has undecomposed litter on the surface. This was only to be expected when acidity of the soil restricts earthworm population to low densities. Although the bulk of the humification process is due to micro-organisms and microarthropods of the soil, the process is accelerated by the passage of the organic material through the guts of earthworms (Edwards and Lofty, 1972). They have shown that most species of litter mites are incapable of feeding on raw litter and they change from fungal-feeding to litter-feeding only when the litter has reached a certain stage of decay. Moreover, soil micro-arthropods can complete the process of mineralisation as essential for nutrient recycling, only when the litter is fragmented and incorporated by the earthworms. Earthworms form an important link in this series of events by breaking down the organic matter, thus enhancing the mineralisation process. This study on the population density and biomass is useful for further work on the role of earthworms in pine litter decomposition.

The authors are thankful to Prof. R. G. Micheal and Prof. P. S. Ramakrishnan, Heads of the Zoology Department and Botany Department respectively for providing necessary facilities. They are also thankful to North Eastern Hill University and University Grants Commission for financial assistance.

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Microarthropods Associated in the Decomposition Process of Pitter Litter of Meghalaya Pine (*Pinus khasya* Royle) Forests

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ABSTRACT

A study was made during the period May–August, 1976 of the microarthropods associated with the decomposition of the litter of pine forests of Meghalaya, North-East India. For this, five forest sites of different age group plantations of 1970 (young plantation), 1965, 1961 (High altitude *i.e.* 1190 metres) and 1961 (Low altitude *i.e.* 900 metres) and 1955 (Oldest plantation) were selected.

Observations were recorded on the differences in microarthropod abundance, their easonal fluctuations in numbers and their role on litter decomposition in relation to lifferent environmental conditions, such as the litter moisture, temperature, pH etc., at different sites. It was found that among microarthropods Collembola and Acarina play the most active role in the decomposition process of the pine litter under natural conditions.

Interesting correlations were obtained between the litter moisture, pH and the abundance of microarthropods (Collembola and Acarina) in litter bags. The significance of these data is discussed.

Many species of soil microarthropods play a key role in the mineralization of litter. Information on their life habits, feeding behaviour, distribution and population changes is quite meagre and accumulated very slowly. This is mainly due to methodological problems. Litter bags have been employed to investigate whether the microarthropods of litter and soil layers are discrete populations with little intermingling and whether the composition of the litter fauna is a function of litter type. Litter bags are used to follow the succession of microarthropod species involved in the decomposition process of litter. Although the litter bag method has the advantages of permitting 1. complete separation of the litter and mineral soil components and 2. evaluation of the effect of mesh size of bag, the difficulties encountered are, the nylon bags which are commonly used are subject to damage and decay. Fibreglass bags are now being used in litter decomposition studies abroad but these are not available in India.

Microarthropods associated with the decomposition of pine litter in five different cultivated stands were studied in this investigation. The effect of different environmental factors such as moisture and pH on the densities of these organisms was analysed.

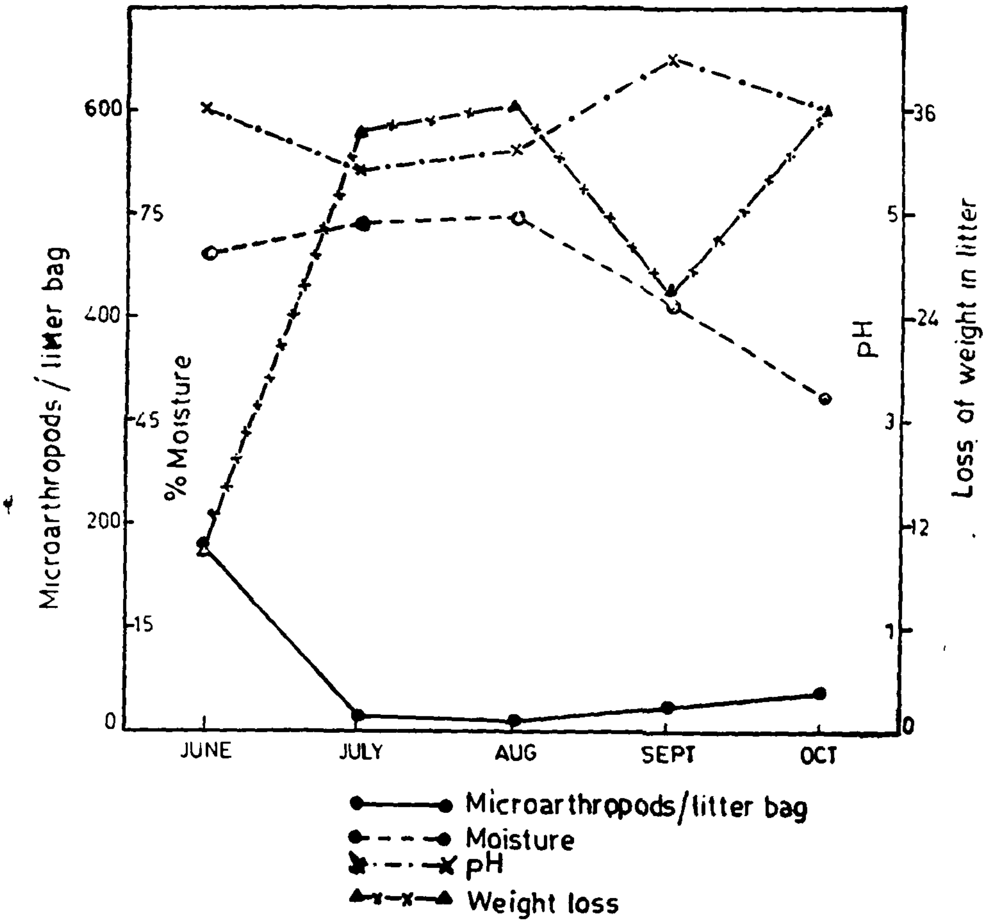

Fig. 1

Study areas

This study was conducted in five cultivated pine forests of different age groups in Shillong (25.34°N and 91.56°E), India. These five pine stands are at slightly different altitudes *viz.*, 1955 plantation at 1250 metres, 1970 plantation at 1225 metres, 1965 and one 1961 plantation at 1200 metres and another 1961 plantation at 950 metres. The common dominant undergrowths of all the experimental sites are *Artemisia* and *Eupatorium*.

Material and Methods

Nylon bags of 1 mm mesh size and 1 dm^2 were used for the present study. The choice of the mesh size and bag dimension is based on the report of

Crossley and Hogland (1962). Freshly-fallen pine needles were collected at the time of needle fall in April (1976). The needles were cut into uniform lengths of 5 cm and air dried. 10 g of air dried litter was then placed in each of the 1 dm^2 nylon bags. A total of 180 bags were prepared out of which 36 bags were placed in each of the five plantations (1955 plantation, 1965 plantation,

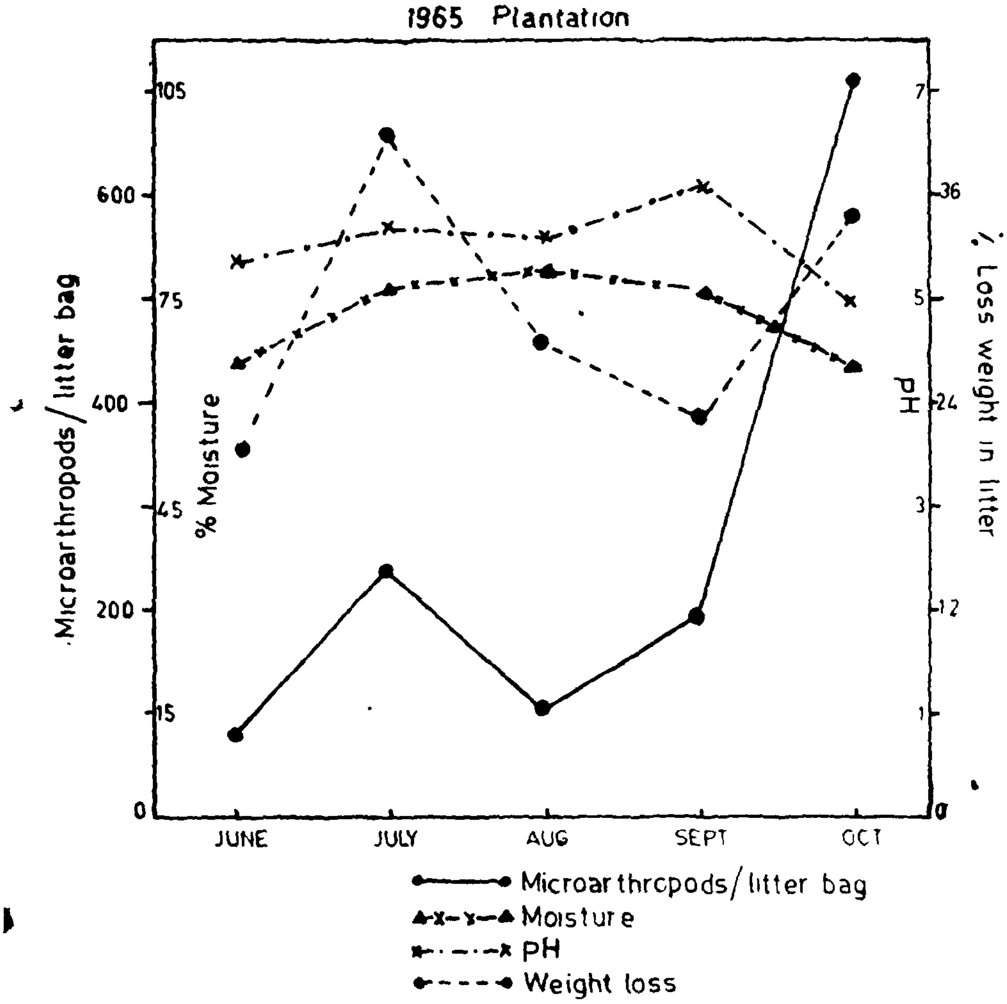

Fig. 2

1970 plantation, and 1961 plantations at two different elevations), under the litter of the forest floor. Thereafter, three bags were collected from each site every 30th day for a period of five months. Immediately on removal, the litter bags were sealed individually in polythene bags. The moisture content was determined by ovendrying to a constant weight at 105°C. The pH was recorded using a pH meter (Toshniwal type CL 43). Microarthropods were extracted by a modified Tullgren funnel (Macfadyen 1955). The extracted microarthropods were categorised as Collembola, Acarina and miscellaneous group.

1970 Plantation

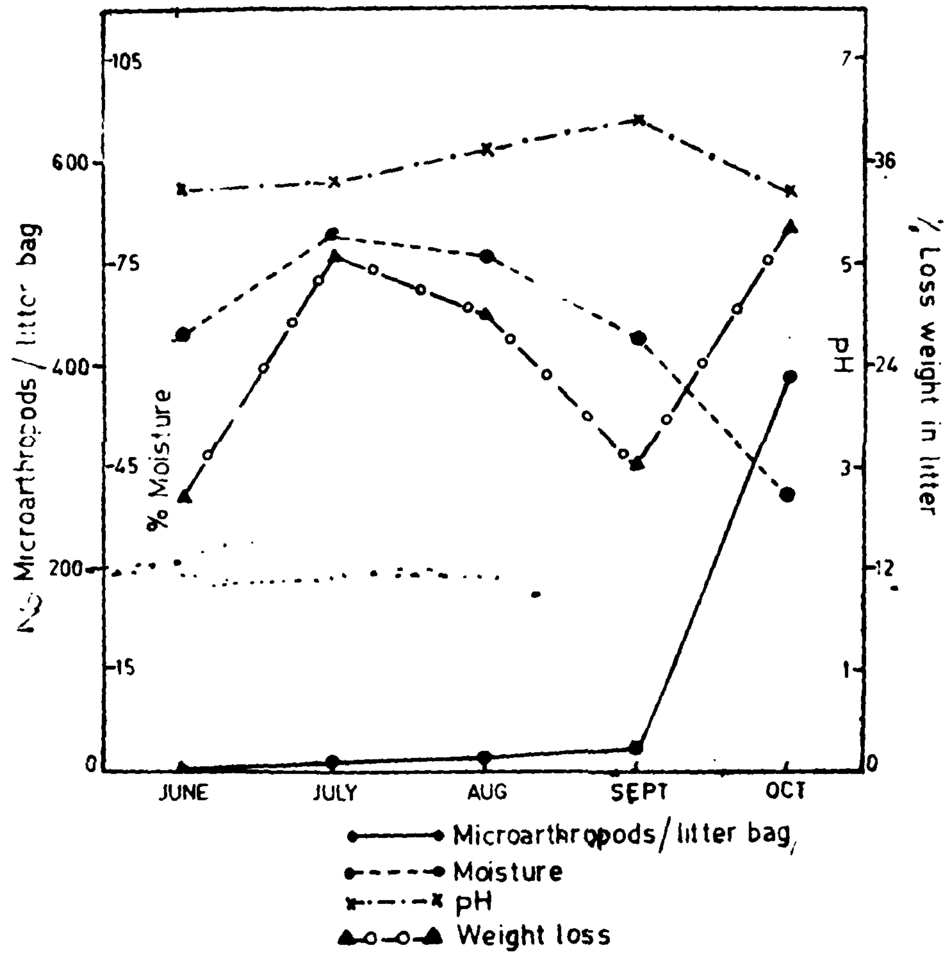

Fig. 3

Results and Discussion

A perusal of Table I in which the population densities of the three categories of microarthropods are summarised, reveals that the Acarina and Collembola are abundant with fluctuating densities, all through the five months (15th May to 15th Oct. 1976). Of the five plantations the greatest microarthropod abundance was observed in the 1965 plantation at 1200 m which has a thick tree density and rich litter layer. In contrast to this, very low densities of microarthropods were recorded in the 1961 (1200 m) plantation and 1955 (1250 m) plantation, which had been suffered from natural forest fire in March-April, 1976. The microarthropod density in the 1970 (1225 m) plantation and

1961 (950 m) plantation fall between these two extremes. This may be related to the comparatively moderate litter fall in these plantations. Quite a few of the litter bags used were found to be damaged. Other larger arthropods such as isopods, Symphyla and chironomid larvae (Diptera) were frequently found in such bags. These bags registered a marked weight loss as could be expected. The high densities of Collembola and Acarina recorded in October were due to addition of young ones and not by immigration, since gravid females and developing young ones were observed in the bags.

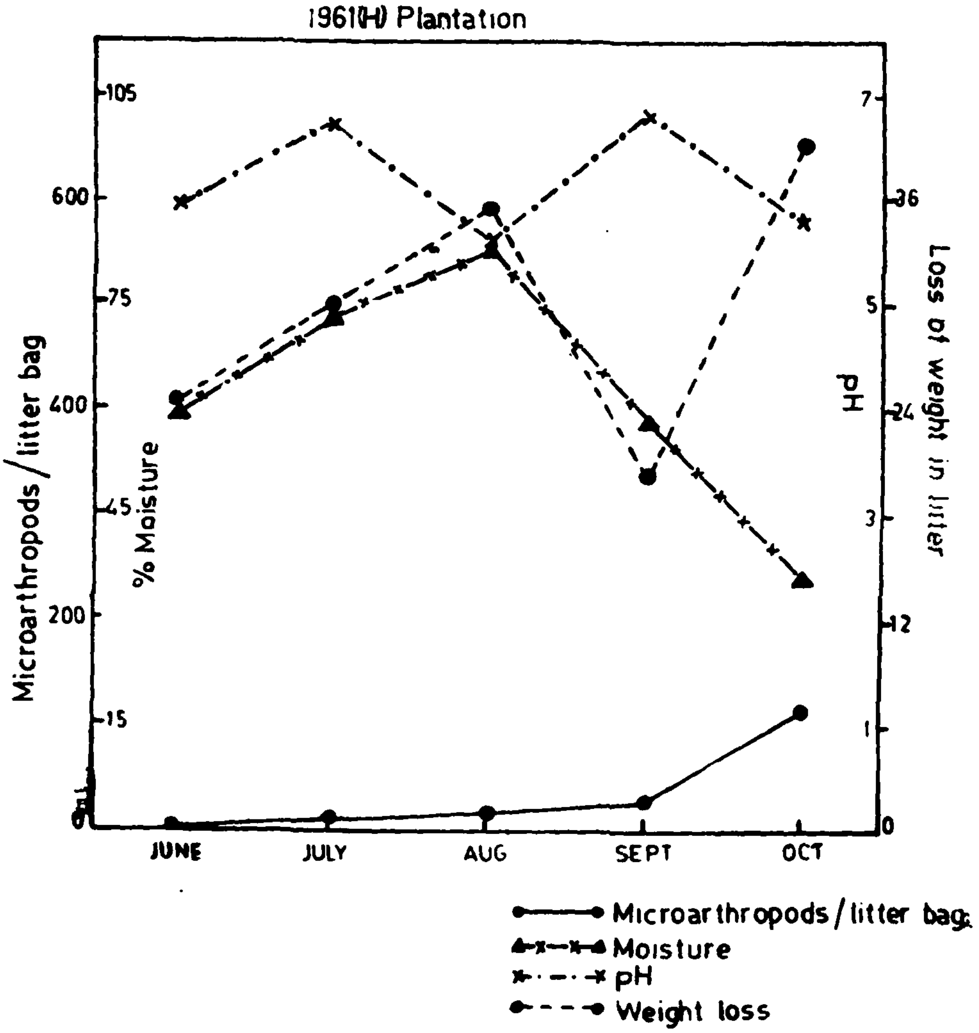

Fig. 4

Moisture contents of the bags ranged from 40 to 82 per cent (Table II). These low and high levels correspond to the dry (October) and rainy months (July and August) respectively. The pH was always on the acidic side (5.1 to

6.5 Table II) in all the plantations, without much variation in each. No correlation existed between microarthropod abundance and either moisture or pH.

TABLE I

Total mean number of different groups of microarthropods seen in the litter bags

Year of plantation	June				July				August				September				October			
	C.	A.	Misc.	Total	C.	A.	Misc.	Total	C.	A.	Misc.	Total	C.	A.	Misc.	Total	C.	A.	Misc.	Total
1970	0	0	0	0	2	6	2	10	4	7	3	14	3	18	2	24	186	204	3	393
1965	70	3	2	75	226	8	3	237	94	5	3	102	146	47	4	196	525	170	17	712
1955	2	173	1	176	4	7	2	13	2	4	2	8	4	16	2	24	22	15	3	40
1961 High altitude	0	3	0	3	2	7	1	10	5	8	3	16	7	17	3	27	34	81	2	117
1961 Low altitude	4	5	2	11	6	8	3	17	9	7	4	20	22	16	4	41	131	145	25	301

C=Collembola
A=Acarina

TABLE II

Microarthropod frequency in relation to pH, moisture and weight loss in litter

Year of plantation		June	July	August	September	October
1970	A	0	10	14	23	39.3
	B	16%	30.5%	27%	18%	32%
	C	5.75	5.85	6.15	6.45	5.75
	D	65%	79.3%	76.2%	63.9%	40.3%
1965	A	75	237	102	196	712
	B	21%	39.5%	27.5%	23°/o	35°/o
	C	5.4	5.7	5.6	6.1	4.9
	D	65	76°/o	78°/o	75.4°/o	64.1°/o
1955	A	176	13	8	24	40
	B	10.5%	35.3°/o	36.5°/o	25°/o	36°/o
	C	6	5.4	5.6	6.5	6
	D	69	73	74.3°/o	61.7	48°/o
1961 (High altitude)	A	3	10	16	27	117
	B	24.2°/o	30°/o	35.4°/o	20°/o	39°/o
	C	5.9	6.7	5.6	6.8	5.8
	D	59	73.2°/o	82.8°/o	57°/o	34.7°/o
1961 (Low altitude)	A	11	17	20	41	301
	B	20.5 °/o	37°/o	33.8°/o	21.5°/o	33°/o
	C	5.3	5.5	6.8	5.8	5.1
	D	65°/o	74.5°/o	76.6°/o	62.8°/o	41.1%

A=Total microarthropods.
B=Per cent of weight loss in the litter (in the bags)
C=pH
D=Per cent of moisture content of the litter.

A strong positive correlation between moisture content and the densities of microarthropods per litter bag has been established by Weigert (1974) in his work in South Carolina old fields in U.S.A. Anderson (1975) in his work in Blean Woods National Nature Reserve, U.K., could not establish any correlation between weight loss in litter bags and microarthropod abundance and recorded a low correlation between moisture and microarthropod adundance. In the

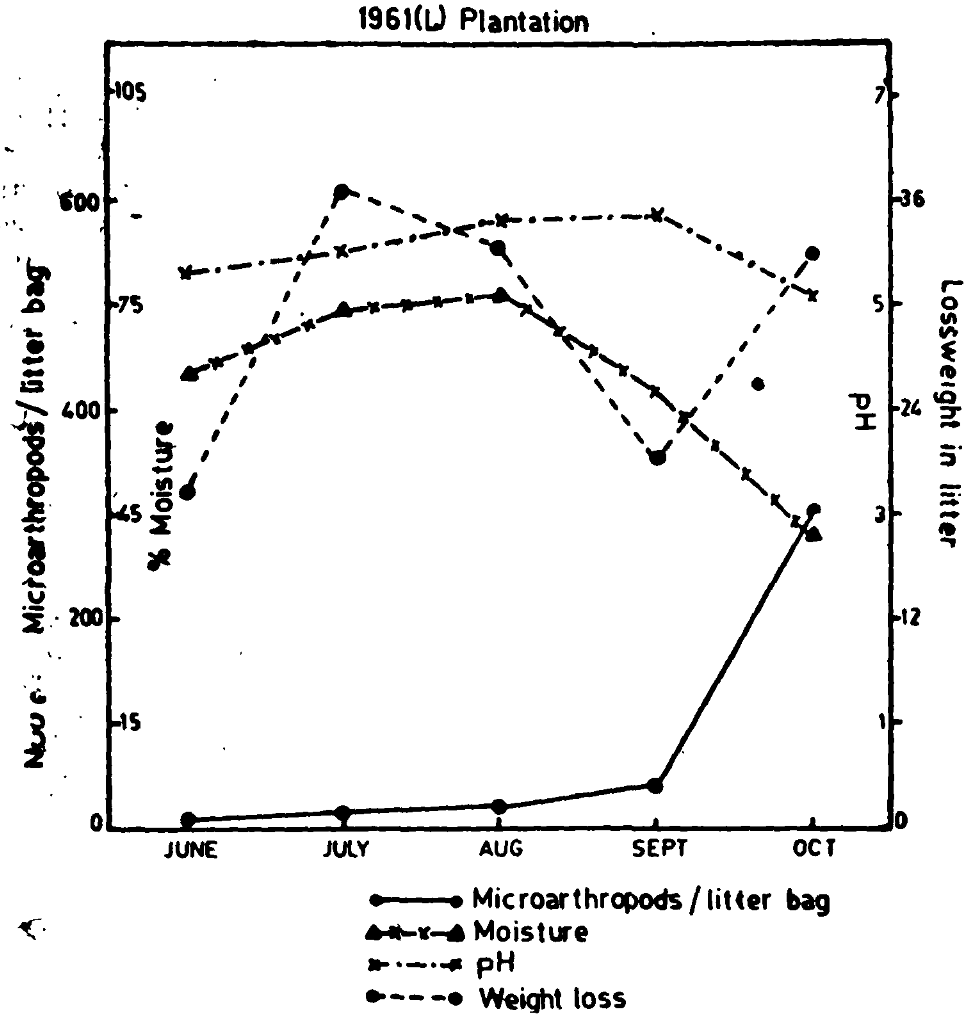

Fig. 5

present study, although the increased in weight loss observed in the litter bags corresponds to the increased abundance of microarthropods, no significant statistical correlation could be established between these two. This is explained by reports on oribatid mites Wallwork (1958) and Wooley (1960) who showed that not all mites are capable of feeding on fresh or coarse litter and that many species require greatly decayed material. Litter decomposed by a sucession of arthropods species. (Anderson 1975).

The species invading the litter bags are determined by the mesh size of the bags used. The changeover in mites from fungal-feeding to litter-feeding occurs when polyphenols are reduced to low concentrations (Anderson 1973).

The slow rate of breakdown of litter confined in the litter bags can be attributed to the exclusion of earthworms and other larger meso-and macro fauna of the soil which fragment the litter make it palatable to most species of litter-inhabiting microarthropods. The microarthropods which occupy the various soil horizons act upon the decayed litter in succession as the litter becomes incorporated into the deeper layers of soil with progressing decay. Litter bags present such incorporation and this again slows down the rate of decomposition.

The authors wish to express their thanks to Prof. R. G. Michael and Prof. P. S. Rama krishnan, Head of the departments of Zoology and Botany respectively for providing necessary facilities. They are also grateful to Dr. J. M. Anderson, Hatherly Laboratories, UK, for his constant encouragement and helpful suggestions. Our thanks are due to North-Eastern Hile University and University Grants Commission for financial assistance.

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factories in Japan utilise earthworms as decomposer organisms for their waste discharge (Watanabe and Tsukamoto 1976). Studies on density, biomass, and energy budget of Indian earthworms indicate that they not only process some 14 percent of the total energy input into the ecosystem but produce some 31 tonnes/Acre/year of wormcast and 72 kg/acre year of nitrogen (Dash and Patra, 1977). Scientists have suggested to utilize these organisms along with organic manures as an alternative to the extensive use of chemical fertilizers.

Fertilizers and insecticides when mixed with the soil by cultivation or leaching, reach the soil biota. Chlorinated hydrocarbous and organophosphate insecticides seriously decrease population of earthworms (Edwards, 1967). Aldrin and Dildrin two extensively used insecticides have been found in earthworm tissue. These pesticides not only cause damage to the beneficial biota in soil but ultimately get incorporated into the food chain and accumulate in alarming amount in animal and human tissue and create health hazards. Fertilizers sometimes destroy the nitrogen fixing ability of the soil. Therefore understanding of ecosystem functioning is a must if we wish to enjoy a rich, clean and healthy environment.

7. Insect Heterothophs and Nutrient Cycling in Terrestrial Ecosystems

M. Vikram Reddy and J. R. B. Alfred, Meghalay

Plant nutrients are one of the most important groups of limiting factors in the dynamics of an ecosystem. A lack of these cuts short its primary production. Insect consumers, as one of the components of the ecosystem play a significant role in nutrient cycling. Very little is known about the role played by these insect heterotrophs i.e. consumers and decomposers on nutrient cycling and vice versa. Hence, these aspects are worth considering to understand the holistic functioning of the ecosystem.

Normal insect grazing on the foliage never impairs the annual primary production. However, it accelerates the plant growth. These insects return a considerable amount of nutrients to the forest floor in the form of dead insect bodies, insect excreta and waste food parts. Reichle (1971) stated that about 2 per cent of calcium and 7 per cent of potassium is returned to the forest floor annually by the insect grazers. It has also been reported that moderate to severe defoliation can increase normal nitrogen, phosphorus in the litter fall by 20 to 200 per cent. Besides the grazers, the decomposer fauna degrade a major amount of dead plant material into smaller and simpler fractions and enhance the circulation of nutrients essential for plant growth. Microarthropods such as collembola and mites, play an important role in nutrient cycling by taking active part in litter break-down processes.

Forest fertilization which is a common practice to increase the wood production, changes the nutrient balance of the ecosystem. This imbalance affects the physiological condition of the green plant and in turn on the animals grazing them. The effect of these nutrients on forest insects depends on the type of the tree, fertilizer used and the insect species. Generally the fertilizers limit the defoliator population development. This is due to the nutritional imbalance in their diet (House, 1965). On the other hand, the addition of mineral fertilizers increase the population of certain sap-sucking insect such as aphids and mites. This is due to increase in the soluble nitrogen levels of the leaves. Besides this, the addition of nutrients increase the availability of soft tissue in the tree, thus increasing the population of twin and shoot-boring insects. Very little is known about the effect of fertilization on soil decomposer fauna. In fact, the addition of fertilizers increasees the abundance of soil fauna, the real cause of which is yet to be known

Although little is known about the effect of less-amout of nutrients on insect consumers, there are reports that certain insect outbreaks occur in forests growing on nutrient poor-soils. For example, occurrence of outbreaks of several species of pine defoliators were reported in stands growing on nitrogen deficient soils (Gremal'skii, 1961).

These interrelationships show that the insect hetertrophs particularly consumers and decomposers undoubtedly play a significant role in the functioning of a terrestrinl ecosystem,

8. Use of Plant Materials as Nematicides

N. C. Sukul and A. Chatterjee, SANTINIKETAN

The use of chemical pesticides for the control of plant-parasitic nematodes involves some problems. They are mostly phytotoxic, pollutants of soil and also very costly. For this reason the use of non-persistant pesti cides which are less dangerous ecologically, are increasingly recommended.

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A CASE-STUDY ON STRUCTURE OF CONSUMER AND DECOMPOSER ENTOMOFAUNA OF PINE (PINUS KESIYA ROYLE) FOREST ECOSYSTEMS OF NORTH-EASTERN (INDIA).

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ABSTRACT

In a case-study of ecosystem structure of consumers and decomposer entomofauna of pine forests of North Eastern India, it has been seen that the pine, Pinus kesiya Royle was the dominant primary producer. Insect consumers are rel related to the primary producers by regulating the primary production. Among insect consumers, aphids were one of the important sap-sucking consumer groups. Three different species of aphids, such as Cinara attrotibialis David and Rajasingh, Eulachnus thunbergii Wilson and Neomyzus Circumflexus (Buckton) have been recorded, each occupying different ecological niches. These were the only sap-suckers seen throughout the year. Among chewing consumers, Lepidoptera was the most dominant followed by Diptera, Heteroptera and so on. Collembola was the most dominant group followed by Acarina on the forest litter-soil subsystem. The population density of total edaphic arthropods was recorded 145,200 per m^2. Both chewing consumers, and decomposer arthropods were maximum in the wet season and minimum in dry season. This case-study presents the existence of a variety of arthropod fauna in the pine forest ecosystems which clearly indicates their complexity.

Every ecosystem regardless its size and shape is characterised by different components such as soil, primary producers, consumers, decomposers and microclimate etc. These components parts are directly or indirectly dynamically interrelated with each other in the form of food chains and nutrient cycles. To understand the ecosystem as a whole, it is essential to know its different components and their relationships. There is very little literature on the holistic investigation of the Indian ecosystems. A case-study of the structure of consumer and decomposer entomo entomofauna in pine forest ecosystems was undertaken in cultiva cultivated forests of Govt. of Meghalaya situated on both sides of the old Gauhati-Shillong Road near Shillong. The dominant primary producer tree species in the ecosystem is the local pine, Pinus kesiya Royle., Eupatorium, Artimesia and Lantana being the dominant undergrowths. The altitude of different canopies ranges from 950 to 1250 meters. The latitude is N 25^{o} 34' and longitude E 91^{o}56'.

CONSUMER ENTOMOFAUNA:

Forest ecosystems support myriads of phytophagous insects. These insect consumers are related to primary producers by regulating the primary production (Mattson and Addy, 1975). Insect consumers can be broadly grouped into two categories based on their mode of feeding: (1) Sap-sucking consumers and (2) Chewing consumers. Aphids are represented as one of the important group of the sap-sucking consumers. Aphid as pests to coniferous forests has been reported by many workers, especially in Canada and U.S.A. But in India, their pest nature on forest trees is yet to be determined. During the present investigation the aphids were sampled following the method of Gray and Schuh (1941). Three different aphids have been recorded viz. Cinara attrotibialis David and Rajasingh, Eulachnus thunbergii Wilson, Neomyzus circumflexus (Buckton). The last one was recorded for the first time feeding on the young pine seedling (Reddy et al., 1978). C. attrotibialis and E. thunbergii were seen on seedlings from 6 months old to mature trees. But N. circumflexus was recorded on two month old seedlings and disappeared when the seedlings attained one year age. These occupied different and diffnite ecological niches. C. attrotibialis usually feed on the soft apical stem of the pine whereas E. thunbergii was recorded on the needles and N. circumflexus was on the youngest needles. C. attrotibialis in their peak and minimum periods were about 10 and 2 per stem respectively. E. thunbergii and N. circumflexus, each were recorded about 5 and 1 per stem. Parry (1969, 1974) worked on population ecology of Elatobium abieti-(Walker) on Sitka spruce (Picea sitchenssis (Bong). Carr.) trees and shown that the population of E.abietinum reaches a population peak in late June followed by a sudden collapse in aphid numbers. Besides these aphids, other sapsucking insects such as phytophagous mites, spittle bugs, mantids, coccine-

-llid beetles were also recorded which showed their peaks in rainy season and recorded minimums in dry season.

CHEWING-CONSUMERS:

The ecology of chewing consumers were studied with the help of a light-trap (Reddy and Alfred, 1978b). The study of the ecology of forest insects (chewing consumers) by light-trap confirms where and when the populations are active, their abundance and adult activity in relation to various environmental factors; Studies with light traps have provided useful biological data on pine insect pests (Yates, 1973; Yates and Ebel, 1972). In India very little research has been done on forest insects by lighttrapping, due to lack of proper methodology. During the present investigation light trapping of insects was conducted every new-moon night, as the effect of moonlight has been reported by many workers. All the insects collected were grouped into 15 orders (Reddy and Alfred, 1978a) viz. Lepidoptera, Diptera, Coleoptera, Hymenoptera, Heteroptera, Hemiptera, Neuroptera, Trichoptera, Orthoptera and Dictyoptera. All these insects were sampled during 1976-77. A total number of 10971 individuals were collected, Lepidoptera being most dominant (3823 inds.) followed by Diptera 3773 inds.), Heteroptera (698 inds.), Hymenoptera 592 inds.), Trichoptera 589 inds.), Coleoptera (426 indis.), Hemiptera(420 inds.), Orthoptera (273 inds.), Neoroptera 166 inds.), Dictyoptera 114 inds.), Arachnida(80 inds.), Isoptera (11 inds.), Dermaptera (3 inds.) and Odonata(2 inds.). The last three orders were recorded only during April, May and June (wet season), being absent throughout the year where as Dictyoptera was recorded only during April to August (wet season). Most of the orders were recorded maximum i.e. about more than90% of the total collection during wet season (April to October and minimum during the dry season (November to April). Similar quantitative reports were of Omen (1961) who recorded sixteen orders such as Lepidoptera, Diptera, Hymenoptera, Ephemeroptera, Neuroptera, Orthoptera, Hemiptera, Coleoptera, Trichoptera, Collembola, Isoptera, Mecoptera, Dermaptera, Psocoptera, Thysanoptera and Siphonoptera attracted to electromagnetic radiation. Milne and Milne (1944) recorded a total collection of 660 individuals of 11 orders such as Lepidoptera, Diptera, Hymenoptera, Coleoptera, Homoptera, Heteroptera, Trichoptera, Corrodentia, Neuroptera, Placoptera and Mecoptera.

These insect sap-suckers and grazers are common and ubiquitous elements of most terrestrial ecosystems. Occassionally some of these species become so abundant that they threaten the stability or out-put of the system having high ecological aesthetic or economic value (Mattson and Addy, 1975). But normal insect grazing, i.e. from 5 to 30 percent of annual foliage crops usually does not impair annual plant (primary production). In other words it may accelerate the plant growth. Either these insects are beneficial or harmful to forest ecosystems it is always worthy of knowing their structure quantitatively and qualitatively for their better management, according to the human needs.

DECOMPOSER ARTHROPOD FAUNA:

Herbivore insect fauna consume very little of the primary production of most ecosystems. The major pathway of the ecosystem is usually through feeding sequences being with saprophages (Chew, 1974). Consumer arthropod fauna of litter-soil subsystem are known as decomposers or saprophages. Chew (1974) stated that littler-soil animals are important as they physically change litter and thus facilitate the metabolism of micro-organism, prevent fungal over-growth (fungivores) and others like mites and collembola besides their other functions in the ecosystem, innoculate the litter with spores (Macfadyen, 1961). During the present investigation the litter and soil arthropod fauna were sampled following the methods described by Crossley and Hogland (1962) and Macfadyen (1962) respectively. All these arthropods collected from litter-soil subsystem are grouped into the different categories such as Coleoptera and their larvae., Dipteran larvae, Formicidae, Hemiptera, Thysanoptera, Isoptera, Myriapoda, Collembola and other apterygota, Acarina and Araneidae, Among all these groups Collembola were most dominant followed by Acarina and so on. The population density of 145,200 edaphic arthropods per m^2 (Reddy and Alfred, 1977), is comparable to estimates reported by workers investigating in other forest habitats. For example, van der Drift (1951) estimated 336,500 arthropods per m^2

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in a beech forest soil in Holland. Crossley and Bohnsack (1960) estimated 102,000 per m^2 in a pine forest soil in Tennessee and Harding (1969) reported 215,000 per m^2 in an Oakland in England. Price (1973) reported a population density of 220,739 micro-arthropods per m^2 in a California pine forest soil. The population were recorded maximum during the wet season and minimum in the dry season. The presence of these decomposer arthropods in the litter-soil sub-system throughout the year clearly indicates their activities which accelerate mineralisation leading to primary productivity.

The consumer-plant interaction is an important and essential operational character of a system as it increases the productivity complexity or homeostasis. The existence of a variety of arthropod fauna in these present ecosystems which has been observed during the present investigation clearly indicates its complexity. The total ecosystem study of its structure and function leading to modelling could be the ideal conclusion, and the present study is a beginning to such an effort.

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increase in the multiplication of tubers would ultimately lead to an increase in agricultural production of these plants.

10. Soil fauna and plant productivity

M. VIKRAM REDDY AND J. R. B. ALFRED, SHILLONG

The nutrient cycling in natural ecosystems primarily depends on the biomodification of autochthonous material in the form of shed or dead organismic remains returned to soil. Soil fauna play a significant role in these and accelerate the process of remineralisation. Soil fauna is a broad term applicable to all the groups of animals but whatever may be the soil fauna, their role in biomodification commences through the process of their feeding. This feeding is of various types, such as the mining of the parenchyma tissue ; consumption of cuticle and parenchyma from either the top or bottom of a leaf ; skeletiling ; simply eating small round holes like those produced by various orbitads or eating along the leaf edges. This comminution results in an ever-increasing surface area of the litter under process for microbial action, leaching and thus releases the minerals therefrom.

Consumption, in biological process is always followed by ejaculation. Ejaculation of faecal pellets by soil fauna is another important process leading to plant productivity through soil fertility. Besides, these faecal pellets favour the microbial growth particularly bacteria, which enhances the remineralisation process. Soil fauna is also important in downward movement of the organic minerals, in increasing soil porocity, aeration and humification which not only lead to soil fertility but to soil formation too. On the other hand, white-grubs, nematodes, collembola and symphyla act as pests and others such as mites, root aphids, nemotodic enchytraeidae, transmit various plant diseases and reduce the plant productivity. Research on complete eradiction of these economically unimportant insects without causing any ecological imbalance is also of immense importance.

11. Effect of dual culture of Azolla pinnata and yield of rice

P. K. SINGH, CUTTACK

Nitrogen is a major constraint in increasing crop yield in developing countries. Provision of enough fertilizer N being too expensive a project,