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Insect species diversity in the tropics : Sampling methods and a case study

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SUMMARY

The tropical regions of the world generally have a richer store of biological diversity than other regions of the globe. But most tropical habitats face a significant threat of destruction. Yet, little is known about tropical biotic communities. Suspecting that at least part of the reason for the poor documentation of tropical insect communities is the lack of appropriate research methodology, we have endeavoured to standardise a package of methods for quantitative and reproducable sampling of insects, suitable for tropical ecologists with modest research budgets. This methodology includes the use of a small light trap as well as net sweeps, pit fall traps and scented traps. The methods have been used to sample insect species diversity patterns in 3 replicate 1 ha plots each in twelve selected localities in the uttara kannada district of Karnataka. During this case study we have encountered 16,852 individuals belonging 1,789 species from 224 families and 19 orders of insects. In this report we provide evidence that this methodology is adequate for sampling insects and differentiating habitats on the basis of the distribution of insect species. Several interesting biological questions that tropical ecologists can study with the data generated from the application of these methods are also illustrated.

INTRODUCTION

One of the few relatively undisputed generalisation in community ecology is a latitudinal gradient of increase in biological species richness and diversity from the temperate regions to the tropics (see Krebs 1985; Colinvaux, 1986). Apart from being something of a rule in community ecology this means that those of us who live in the tropics enjoy a biologically rich environment. It is equally undisputed however that most tropical organisms are poorly studied and the little that we do know about any group of organisms comes largely from studies of temperate species. This is expressed most dramatically in the statement that the number of biologists is negetively correlated with the number of biological species in different regions of the globe. The poor state of our understanding of tropical biology may be partly attributed to the relative economic backwardness of tropical countries, the lack of facilities for research and sometimes to the lack of the tradition of modern scientific work.

We suggest however that at least sometimes this is due to the lack of appropriate research methodology suitable for tropical conditions. Studies on insect species diversity and the long term monitoring of insect species and populations in different habitats are an example. Almost all the major long term insect monitoring programs are based on light trap catches, a method that requires uninterrupted supply of electricity, often in the middle of a forest (Holloway, 1980, 1987; Taylor 1978; Wolda 1983, Wolda and Roubik 1986). Sometimes the light traps are operated for years together without intrruption. In most tropical situations uninterrupted supply of electricity is nearly impossible even in cities and towns, let alone in the middle of a forest. The establishment and long term maintainence of electricity generating devices is prohibitively expensive for most ecologists working in tropical countries.

Suspecting that this has prevented many tropical ecologists from undertaking insect species diversity studies (see Wolda 1981), we have attempted to standardise a package of methods for quantitative and reproducible sampling of insects, suitable for tropical ecologists with modest research budgets. Our methodology is based on the use of a small light trap based on routinely available dry batteries but significantly supplemented by other methods such as net sweeps, pit fall traps and scented traps. We show here that such a methodology is adequate for sampling insects and differentiating habitats on the basis of insect species distribution. We also briefly illustrate some interesting biological questions that ecologists in tropical countires can begin to ask with the data generated from such methodology.

METHODS

A. Study sites

All our study sites were located in the Uttara Kannada district of the state of Karnataka. The study sites fall broadly into two categories reflecting different levels of disturbance namely the Reserve forest (R.F.) (relatively less disturbed) and the Minor forest (M.F.) (relatively more disturbed). Sites representing both these categories were chosen in the coastal plains as well as at higher elevations approximate altitude 600m). Selection of study sites in this manner ensured that these sites represent habitats under different environmental conditions and levels of disturbance. In addition to these forested habitats three monoculture plantations and a leaf mannure forest (Betta land) were also chosen for the study. At each of these sites sampling was carried out in three one hectare plots. Thus a total of 36 one hectare plots from 12 habitat types were sampled (Fig 1, Table 1). A brief description of each study site is given in table 2.

B. Sampling methods

To develop a package of methods for quantitative and reproducible sampling of insect species, collections were made using four different methods which were standardized after extensive field trials.

1. Light trap: A portable light trap which can be easily dismantled was fabricated using locally available inexpensive material. The light trap uses a flourescent light source (Eveready Flourolite) powered by routinely available battery cells. The main framework of the trap consists of four iron legs, an aluminium roof and two aluminium baffles, between which the light source is placed. Insects attracted to the light were collected through a funnel in a cyanide jar, below the light. One light trap was placed in the centre of the plot. The light was

FIGURE 1

A map of uttara kannada district showing the 12 sites used in the study. 1 = Santagal R.F., 2 = Nagur R.F., 3 = Mirjan M.F., 4 = Chandavar M.F., 5 = Bengle M.F., 6 = Bidralli R.F., 7 = Sonda R.F., 8 = Bhairumbe M.F., 9 = Betta land, 10 = Eucalyptus plantation, 11 = Teak plantation and 12 = Areca plantation.

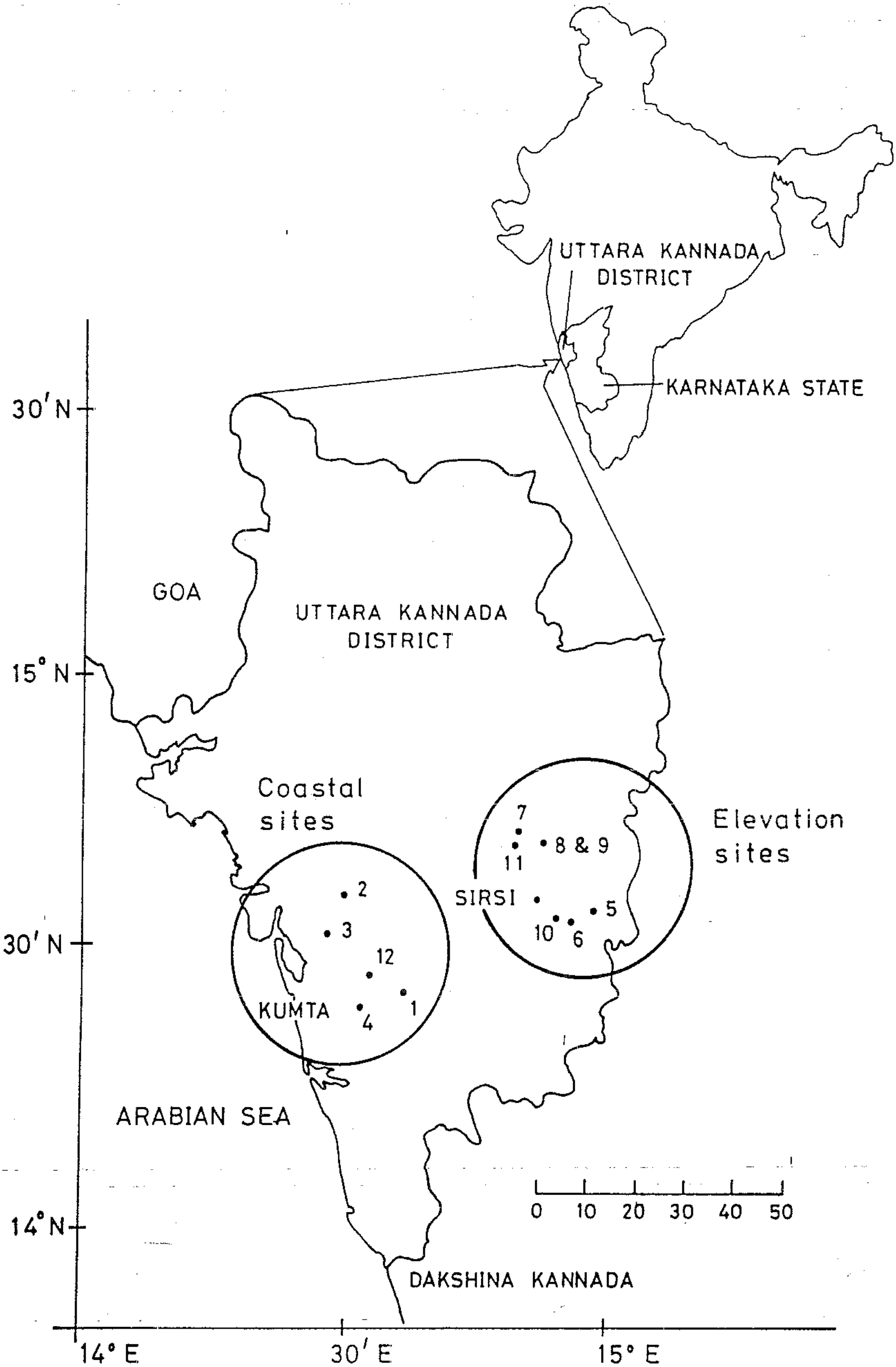

UTTARA KANNADA
DISTRICT
KARNATAKA STATE
30′N
15° N
30′N
14° N
GOA
UTTARA KANNADA
DISTRICT
Coastal
sites
Elevation
sites
SIRSI
KUMTA
1
2
3
4
5
6
7
8 & 9
10
11
12
ARABIAN SEA
0 10 20 30 40 50
DAKSHINA KANNADA
14° E
30′ E
15° E

TABLE 1: STUDY SITES AND PLOTS

	Reserve forest	Minor forest	Plantation	Leaf manure forest
Coastal sites	Santgal R.F (Plot Nos. 1-3)	Chandavar M.F (Plot Nos. 10-12)	Areca Plantation (Plot Nos. 34-36)	
	Nagur R.F (Plot Nos. 4-6)	Mirjan M.F (Plot Nos. 7-9)		
Elevation sites	Bidralli R.F (Plot Nos. 16-18)	Bengle M.F (Plot Nos. 13-15)	Teak Plantation (Plot Nos. 31-33)	Betta Land (Plot Nos. 28-30)
	Sonda R.F (Plot Nos. 19-21)	Bhairumbe M.F (Plot Nos. 22-24)	Eucalyptus Plantation (Plot Nos. 28-30)	

TABLE 2: A BRIEF DESCRIPTION OF STUDY SITES

LOCALITIES (1)	VEGETATION TYPE (2)	DOMINANT TREE SPECIES (3)	REMARKS (4)
SANTAGAL R.F.	Evergreen	*Cinnamomum*, *Bischofia* and *Diospyros* spp.	Thick tree canopy, understorey of Cane breaks.
NAGUR R.F.	Evergreen	*Holigarna* and *Hopea* spp.	Thick tree canopy, understorey of saplings.
MIRJAN M.F.	Scrub	*Ixora*, *Buchnania* and *Terminalia*	Highly degraded semi-evergreen.
CHANDAVAR M.F.	Semi-evergreen	*Ixora*, *Aporosa* and *Hopea* spp.	Degraded, understorey of frequently lopped saplings.
BENGLE M.F.	Moist deciduous	*Terminalia* spp.	Degraded, thick under-growth of grass and annual herbs.
BIDRALLI R.F.	Moist deciduous	*Terminalia*, *Xylia* and *Lagerstromia* spp.	Undergrowth of herbs and shrubs, mainly *Clerodendrum*.

TABLE 2 Contd....

(1)	(2)	(3)	(4)
SONDA R.F.	Moist deciduous	*Terminalia, Xylia* and *Aporosa*	Understorey mainly of *Psychotria* spp.
BHAIRUMBE M.F.	Moist deciduous	*Caryea, Ziziphus* and *Randia*	Degraded, undergrowth of *Chromelina*.
BETTA LAND	Moist deciduous	*Terminalia* and *Lagerstromia*	Cleared of all under-growth, maintained for leaf manure.
EUCALYPTUS PLANTATION	Monocultre	*Eucalyptus* spp.	Thick undergrowth of grass and herbs, surrounded by extensive moist deciduous forest.
TEAK PLANTATION	Monoculture	*Tectona grandis*	Little or no undergrowth except *Lantana* and *Chromelina*.
ARECA PLANTATION	Monoculture	*Areca catechu*	Plantations in valleys, surrounded by evergreen forest on hills.

switched on at dusk and allowed to burn itself out as the batteries drained after about six hours. The insects trapped in the jar were collected the next morning and preserved in 70% alcohol.

2. Net Sweeps: Net sweeps were carried out to collect insects off the vegetation. The nets used in systematic sweeping of the ground level vegetation were made of thick cotton cloth with a diameter at the mouth of 30 cm and a bag length of 60 cm. For carrying out net sweeps the plot was divided into 100 quadrats, measuring 10m x 10m each. Six such quadrates were chosen at random and the entire ground level vegetation in the chosen quadrat was covered during the sweeping. Net sweeps were always done between 10.00 a.m - 12.00 noon. The insects collected from each quadrat were transferred into polythene bags containing a cotton wad dipped in chloroform. Insects were later separated from litter and preserved in vials containing 70% alcohol.

3. Pit-fall traps: The pit-fall traps consisted of a 2.5 litre plastic jar buried at ground level and protected from rain by a tripod stand carrying a plastic plate of about 30 cm. One pit fall trap was placed in each of five randomly chosen 10m x 10m quadrats. Each jar carried 25 ml of 0.05% methyl parathion. The traps were set up between 3.00 and 5.00 p.m. and were collected the next morning. Insects trapped in the jars were preserved in 70% alcohol.

4. Scented traps: A plastic jar of 2.5 litre capacity was used to fabricate a scented trap. The mouth of the jar was shielded from

rain water using a plastic plate allowing a gap of 6 cm between the mouth of the jar and the plastic plate so that insects could freely move into the jar. The trap was baited with 200 ml of saturated jaggery (unrefined cane sugar) solution with two tablets of baker's yeast, 0.05% (final concentration) methyl parathion and 0.5 ml of pineapple essence. The traps were hung at about 1 m from the ground on a wooden peg. Five such traps were used, one each in the centre fo a randomly chosen 10m X 10m quadrat. The scented traps were also set between 3.00 - 5.00 p.m. and collected the following morning. Insects trapped in the jaggery solution were filtered, washed and preserved in 70% alcohol.

Thus one light trap placed in the middle of a one hectare plot working for about 7 hrs (7.00 pm to 2.00 am), net sweeps in 6 randomly chosen 10m X 10m quadrats, 5 randomly placed pit fall traps and 5 randomly placed scented traps, both working for about 18 hrs each constituted one sampling unit.

C. Preservation of specimens and data recording

All insects (except large moths) were stored in alcohol for future sorting. The insects were identified upto the family level and within each family, recognisable taxonomic units (RTU) were seperated based on morphological differences. For convenience, the RTUs will be referred to as species throughout this report. Each such specimen was given a serial number within that family. The same number was given to a species collected from any locality in the study area. For each locality, plot and quadrat, information on the order, family, serial number, number of nymphs or larvae and the number of adults was recorded. Only data on the adult insects are presented here.

D. Canopy Cover Index

It was obvious from our preliminary results that a subjective classification of habitats into more disturbed and less disturbed categories is insufficient to discern any relationship between patterns of diversity and levels of disturbance. An attempt was therefore made to develop an index to quantify levels of disturbance. One of the major causes of disturbance in tropical forests is a tree fall, either man made and natural, which leads to large scale changes in the understory vegetation. The extent of canopy cover could thus be one good measure of disturbance.

A relative estimate of the extent of canopy cover was obtained by the presence or absence of canopy at randomly chosen points in the study plots. Fifty such points at the corners of 10m X 10m quadrats were chosen to make observations on the canopy cover. At each of these points the observer counted the number of trees whose canopy intersected his line of sight immediately above his head. Shrubs, tree branches and leaves obstructing the line of sight at less than about 3 m from the ground were not counted. The number of trees which formed a canopy over these fifty points was used to obtain a mean value for the plot, which we call the Canopy Cover Index.

E. Data Analysis

1. α Diversity : The following indices of α (within site) diversity were computed.

(i) Simpson's diversity index,

$$D = 1 - \sum_{i=1}^{S} p_i^2$$

where p_i is the proportion of the ith species and S is the total number of species in the sample. (Simpson 1949: actually $\sum_{i=1}^{S} p_i^2$ in his paper)

(ii) Shannon Weiner diversity index (Margalef 1958) given by

$$H' = -\sum_{i=1}^{S} p_i \,(\ln p_i)$$

(iii) α of the log series (Fischer et al 1943) given by the equation,

$$S = \alpha \log_e (1 + N/\alpha)$$

where S is the number of species in sample, N is the number of individuals in sample, and α is the index of diversity. α was computed by an iterative procedure. The standard deviation of α was estimated as $\alpha / \{-\log(1-X)\}$ where $X = N/(N + \alpha)$

(iv) Hill's diversity indices (Hill,1973; Gadagkar 1989),

$$N_1 = \exp(H') \quad \text{and}$$

(v) $$N_2 = 1 / \sum_{i=1}^{S} p_i^2$$

(vi) $$S_m = \Sigma \{ 1 - (1-n_i)^m \}$$

S_m is the expected number of species in a sample of m individuals chosen randomly from a community of n individuals, where n_i is the proportion of the ith species in the universe (Hurlbert, 1971). Chosing a value of 20 for m (after Wolda 1983) we estimated this diversity index using its unbiased estimater namely,

$$\sum_{i=1}^{S} 1-C(n-n_i, m)/C(n/m)$$

where n_i is the proportion of the ith species in the sample.

2. β diversity : β (between site or between method) diversity was estimated as coefficients of similarity given by the Morishita-Horn Index (Wolda, 1981) with logarithmic transformation of the data

$$C_\lambda = \frac{2\Sigma(n_{1i} \cdot n_{2i})}{(\lambda_1 + \lambda_2) \cdot N_1 N_2)}$$

where,

$$\lambda_j = \frac{\Sigma n^2_{ji}}{N_j^2}$$

where n_{ji} is the number of individuals of species i in sample j and N_j is the number of individuals in sample j. Log transformation was performed as $ln(n_{ji}+1)$.

Results:

1.Summary of catch data:

A summary of the insect catch data in the form of the number of orders, families, species and individuals and α of the log series as an index of diversity for each of the 36 plots are shown in table 3. In any given plot we encountered from 4-12 orders, 24-77 families, 43-239 species and 86-1331 individuals. In all the 36 plots put together we encountered 19 orders, 219 families, 1789 species and 16,852 individuals. Some patterns in this data are immediately apparent. The highest number of individuals, species and the highest diversity were seen in one or more of the *Eucalyptus* plantation plots, while the lowest number of individuals, species and the lowest diversity were seen in one or more of the teak plantation plots. Natural forest plots including relatively less as well as the relatively more disturbed ones were in between these two extremes shown by the monoculture plantations.

2.Comparison of methods of collection:

Net sweeps yielded the maximum numbers of orders, families, species, individuals and also the highest diversity of insects. But the remaining three methods namely, the light trap, pitfall traps and scented traps together accounted for atleast 50% of

TABLE 3 : SUMMARY OF CATCH DATA

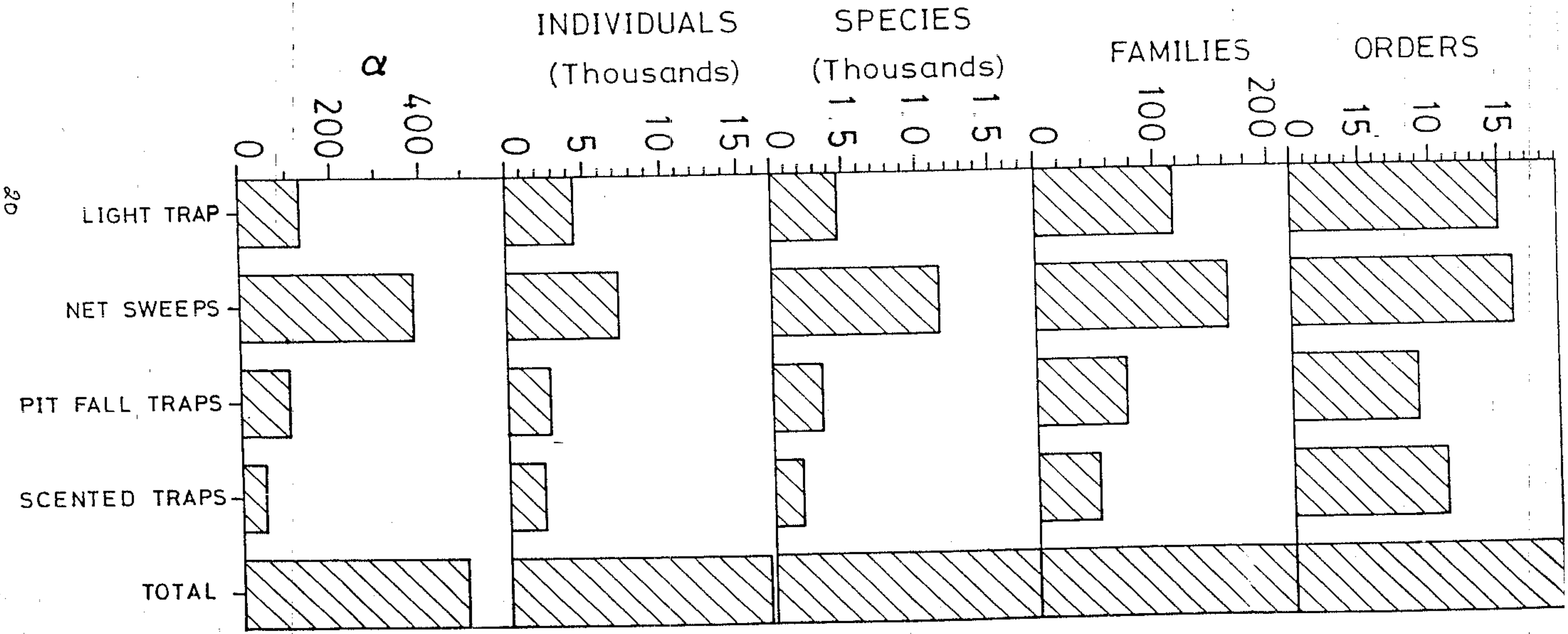
LOCALITY	PLOT NUMBER	NO.OF ORDERS	NO.OF FAMLIES	NO.OF SPECIES	NO.OF INDIVI--DUALS	ALPHA OF LOG SERIES
SANTGAL R.F	1	7	36	77	144	67.31
SANTGAL R.F	2	8	33	73	231	36.77
SANTGAL R.F	3	9	36	88	199	60.36
NAGUR R.F	4	10	33	59	247	24.55
NAGUR R.F	5	5	28	64	265	26.81
NAGUR R.F	6	8	30	65	213	31.88
MIRJAN M.F	7	8	40	87	950	23.31
MIRJAN M.F	8	9	48	102	874	29.93
MIRJAN M.F	9	10	44	88	1085	22.61
CHANDAVAR M.F	10	9	52	99	529	35.93
CHANDAVAR M.F	11	8	37	79	757	22.20
CHANDAVAR M.F	12	10	45	103	407	44.42
BENGLE M.F	13	12	77	164	496	85.58
BENGLE M.F	14	5	46	110	445	46.74
BENGLE M.F	15	10	68	171	590	80.79
BIDRALLI R.F	16	10	71	144	322	100.02
BIDRALLI R.F	17	12	67	157	539	74.44
BIDRALLI R.F	18	12	53	111	445	47.44
SONDA R.F	19	8	35	78	204	46.15
SONDA R.F	20	6	30	73	173	47.61
SONDA R.F	21	4	35	67	256	29.53
BHAIRUMBE M.F	22	10	30	67	175	39.69
BHAIRUMBE M.F	23	9	29	58	177	30.05
BHAIRUMBE M.F	24	7	43	77	301	33.44
BETTA LAND	25	7	46	122	539	49.15
BETTA LAND	26	10	40	100	304	51.97
BETTA LAND	27	7	33	87	262	45.56
EUCALYPTUS PLANTATION	28	12	66	204	659	101.14
EUCALYPTUS PLANTATION	29	12	68	239	1331	84.95
EUCALYPTUS PLANTATION	30	8	52	176	1191	57.04
TEAK PLANTATION	31	7	29	55	145	32.30
TEAK PLANTATION	32	9	24	43	128	22.73
TEAK PLANTATION	33	7	29	46	86	40.22
ARECA PLANTATION	34	7	45	99	862	28.87
ARECA PLANTATION	35	7	36	102	721	32.42
ARECA PLANTATION	36	7	42	106	600	37.37
TOTAL		19	219	1789	16852	506.06

the catch. (Fig.2) The light trap yielded more Coleopterans than any other method. Most of the Hemipterans caught were from the net sweeps although the net sweeps yielded an equally rich collection of Hymenopterans and Dipterans. Pitfall traps yielded more Hymenopterans than any other order while scented traps caught more Dipterans than any other order (Fig.3). Comparison of different species and their abundances among catches by different methods using the Morishita-Horn Diversity Index shows that each method yielded quite a different sample of insects. The similarity coeffficent between any two methods ranged between 0.13 and 0.28. The consequent large distance (defined as 1 - coefficient of similarity) between insect samples obtained by different methods are shown in Fig.4.

Since one light trap, 6 net sweeps, 5 pitfall traps and 5 scented traps were employed in each plot we can compare the catches between different replicates of the same method. Employing the Morishita-Horn Similarity Index once again, we find that catches from different replicates of the same methods were by and large more similar than catches by different methods. It is important to note however that there are occassional exceptions. This is illustrated in an example of comparison of the 17 traps employed in plot number 1 (Fig.5). The catches from pitfall traps 1 and 3 have a greater similarity to catches from scented traps than to catches from the remaining pitfall traps. Similarly the catch from netsweep 3 stands out as being different from everything else. These anomalies may be on account of random fluctuations in the small samples of insects caught in

FIGURE 2

Numbers of orders, families, species, individuals and diversity of insects trapped by different methods.



α
INDIVIDUALS (Thousands)
SPECIES (Thousands)
FAMILIES
ORDERS
LIGHT TRAP
NET SWEEPS
PIT FALL TRAPS
SCENTED TRAPS
TOTAL

FIGURE 3

Taxonomic break up of insects trapped by different methods.

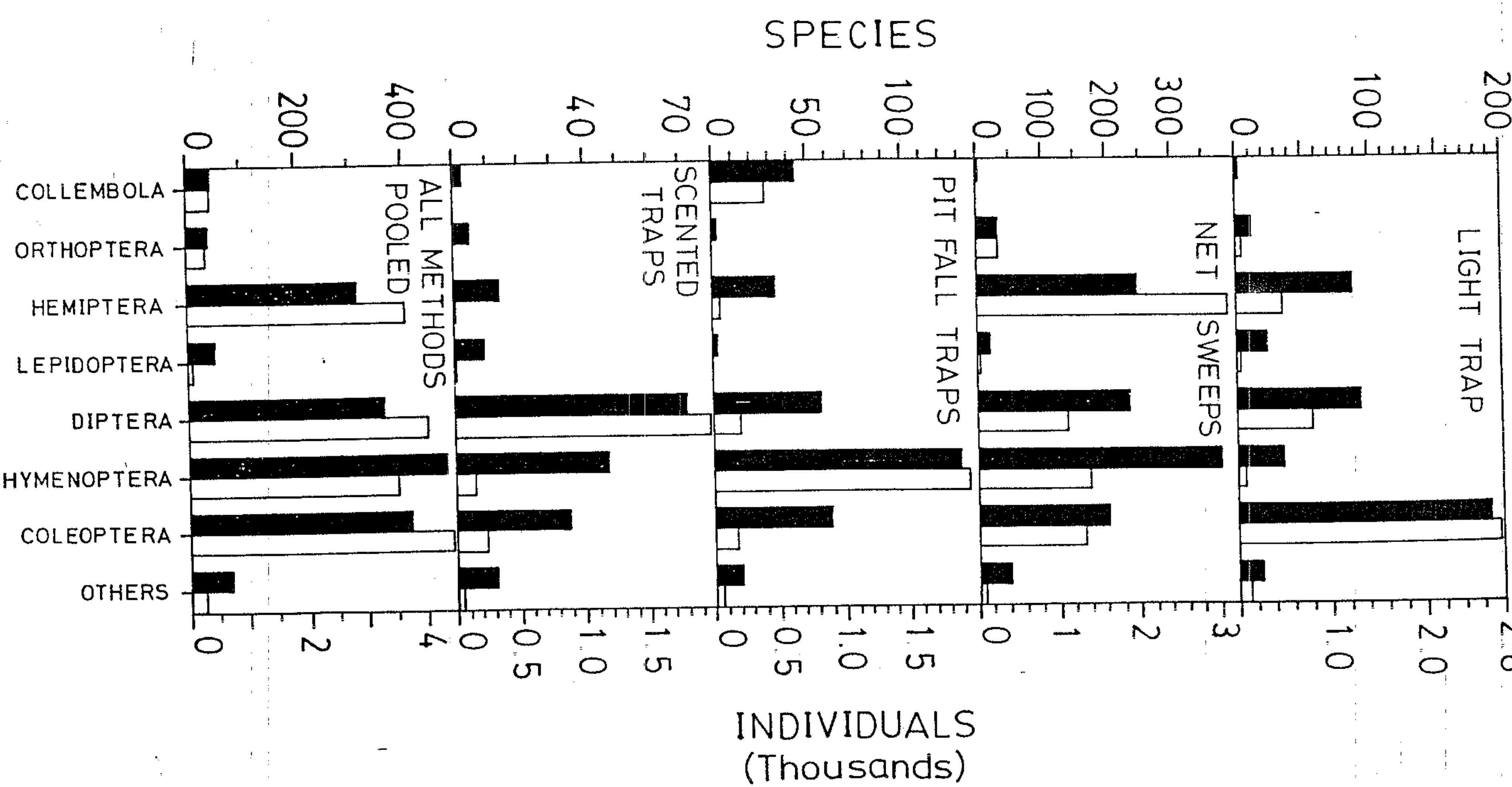

SPECIES
ALL METHODS POOLED
SCENTED TRAPS
PIT FALL TRAPS
NET SWEEPS
LIGHT TRAP
COLLEMBOLA
ORTHOPTERA
HEMIPTERA
LEPIDOPTERA
DIPTERA
HYMENOPTERA
COLEOPTERA
OTHERS
INDIVIDUALS
(Thousands)

FIGURE 4

Dendrogram comparing insects caught by different methods (Distance = 1 - Morishita Horn Index of Similarity). Data pooled from 36 plots.

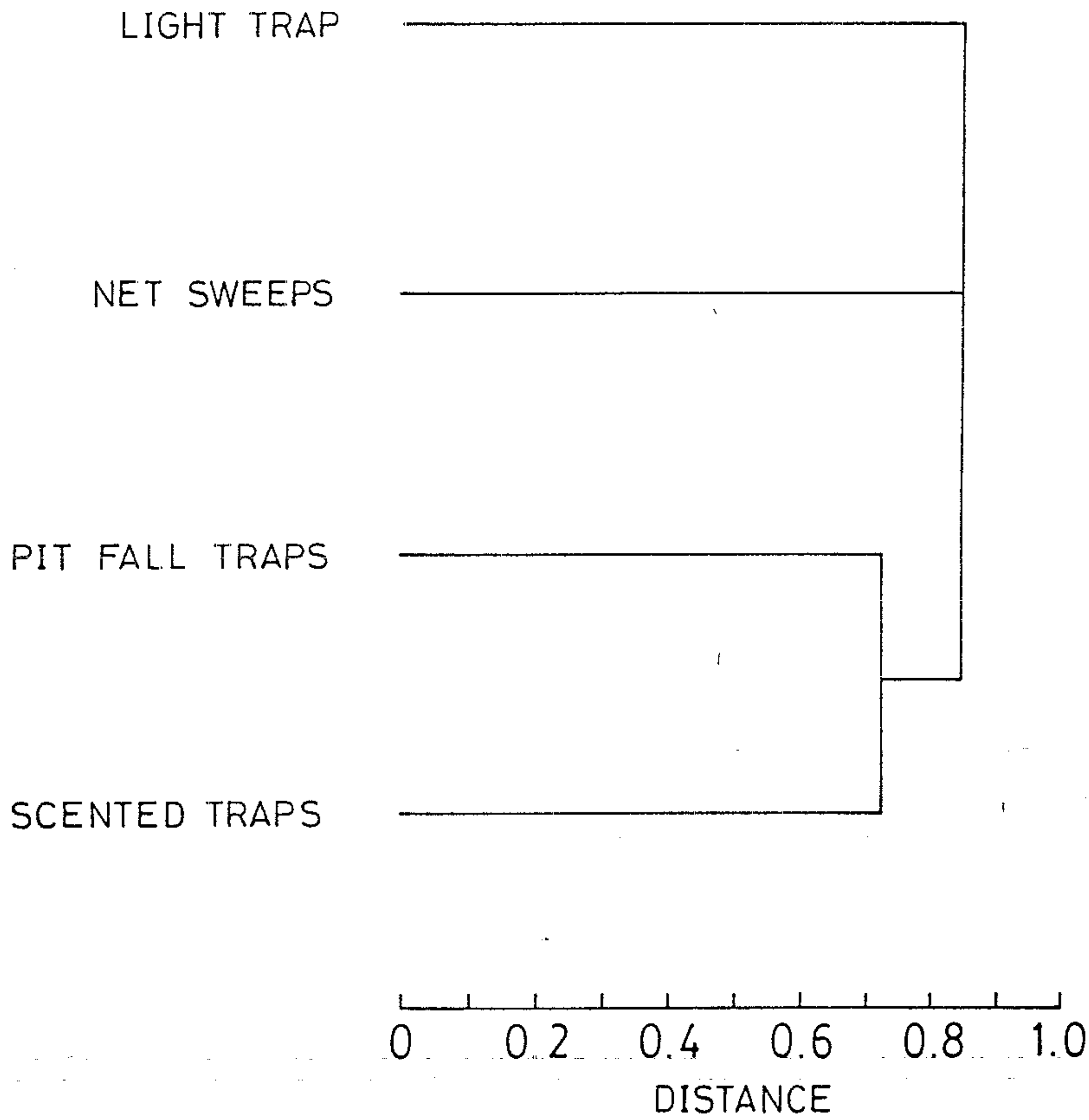
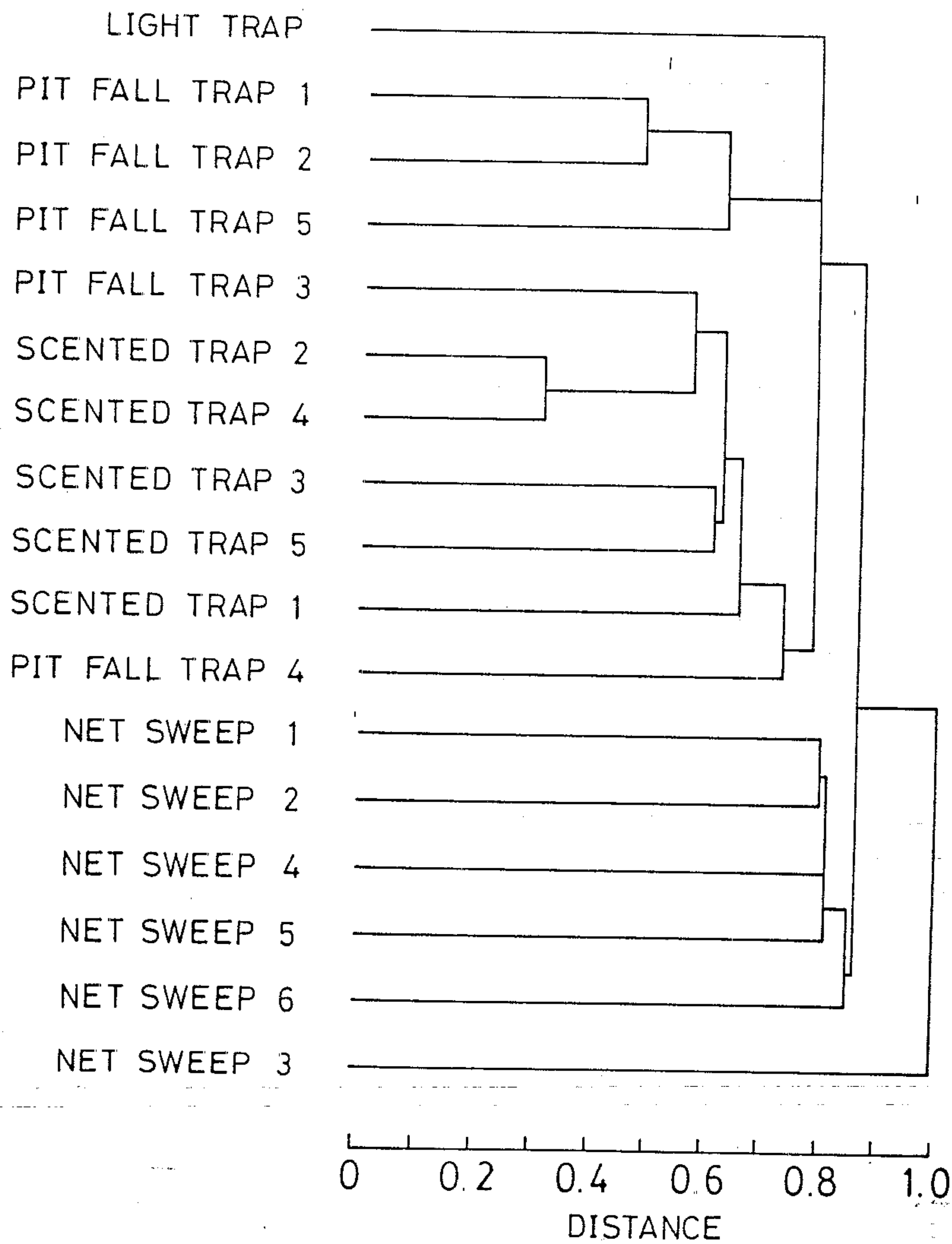

LIGHT TRAP
NET SWEEPS
PIT FALL TRAPS
SCENTED TRAPS
0
0.2
0.4
0.6
0.8
1.0
DISTANCE

FIGURE 5

Dendrogram comparing insects caught by similar and different traps within a plot. In general insects caught by the same method has greater similarity among themselves than insects caught by different methods. But notice that insects caught in pitfall trap number 3 were similar to those caught in the scented traps rather than those caught in other pitfall traps and that insects caught in netsweeps 3 were very different from all other insects caught in this plot. Data from plot 1.


LIGHT TRAP
PIT FALL TRAP 1
PIT FALL TRAP 2
PIT FALL TRAP 5
PIT FALL TRAP 3
SCENTED TRAP 2
SCENTED TRAP 4
SCENTED TRAP 3
SCENTED TRAP 5
SCENTED TRAP 1
PIT FALL TRAP 4
NET SWEEP 1
NET SWEEP 2
NET SWEEP 4
NET SWEEP 5
NET SWEEP 6
NET SWEEP 3
0
0.2
0.4
0.6
0.8
1.0
DISTANCE

each individual trap. Pooling the insects from each replicate of the same method leads to fewer exceptions. This is illustrated by comparing such pooled data from each method across the three replicate plots within a study site. For most sites the pattern is as distinct as in the example shown in Fig.6 for plots 7,8 and 9 in Mirjan M.F. It is thus clear that relatively similar insects are caught by repeating the same method in different replicate plots while relatively different insects are caught by different methods. This is by and large the pattern we find in all localities but once again there are some minor exceptions. In plots 19, 20 and 21 from the site in Sonda R.F. the catches from pitfall trap 21 and scented trap 21 have greater similarity to each other than either of them have to catches from other pit fall traps or scented traps. Besides the catch from light trap 19 is different from everything else (fig.7).

3. Comparison of plots and sites:

Pooling catch data from all the 17 traps in each plot the 36 plots may be compared using the Morishita-Horn Similarity Index. By and large, the 3 replicate plots in each locality are similar to each other and form a cluster before they 'join' other clusters. This pattern was seen in 9 out of 12 sites namely, Santagal R.F., Nagur R.F., Mirjan M.F., Areca Plantation, Eucalyptus Plantation, Sonda R.F., Bhairumbe R.F., Betta land and Teak Plantation. But there are some exceptions such as Chandavar M.F., Bengle M.F. and Bidralli R.F. where at least one plot had greater similarity to plots from some other site than to other

FIGURE 6

Dendrogram comparing insects caught by different methods in different replicate plots of the same locality. Notice that the insects fall into four neat clusters depending on the method of trapping. Data from plots 7,8 and 9 in Mirjan M.F.

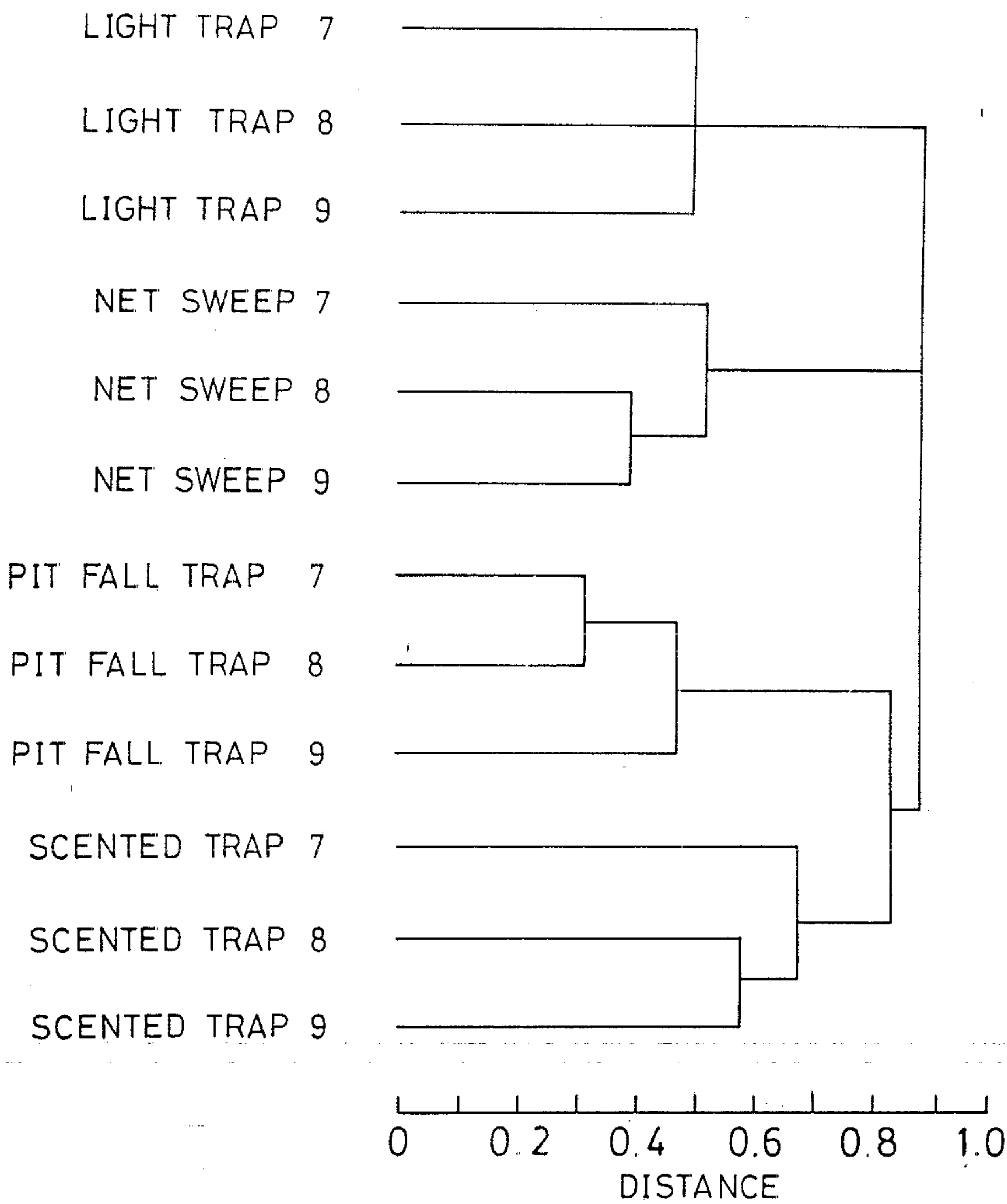
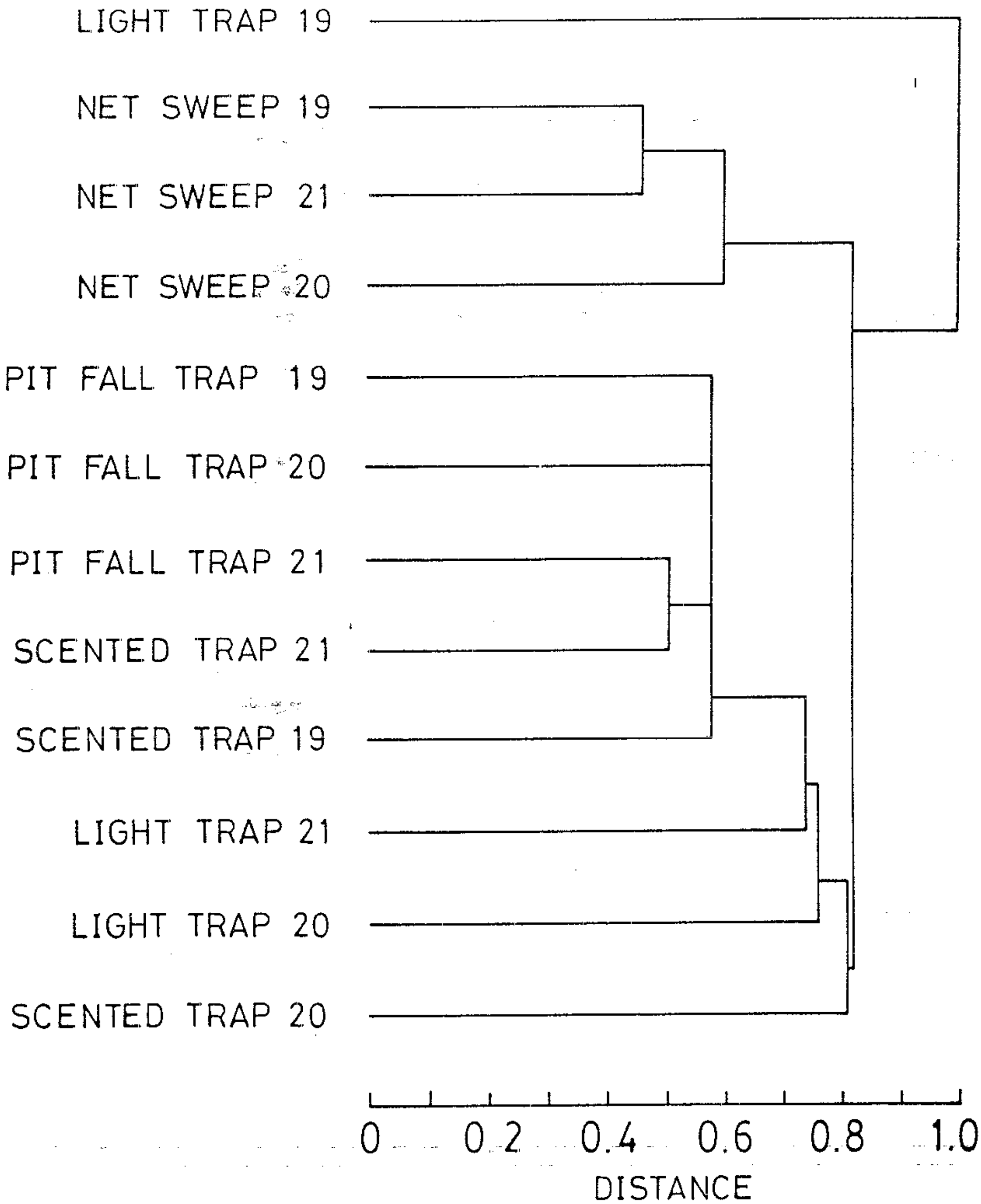

LIGHT TRAP 7
LIGHT TRAP 8
LIGHT TRAP 9
NET SWEEP 7
NET SWEEP 8
NET SWEEP 9
PIT FALL TRAP 7
PIT FALL TRAP 8
PIT FALL TRAP 9
SCENTED TRAP 7
SCENTED TRAP 8
SCENTED TRAP 9
0
0.2
0.4
0.6
0.8
1.0
DISTANCE

FIGURE 7

Comparison of insects caught by different methods as in figure 6 showing that sometimes insects caught by the same methods in different replicate plots can be relatively dissimilar. Data from plots 19, 20 and 21 in Sonda R.F.


LIGHT TRAP 19
NET SWEEP 19
NET SWEEP 21
NET SWEEP 20
PIT FALL TRAP 19
PIT FALL TRAP 20
PIT FALL TRAP 21
SCENTED TRAP 21
SCENTED TRAP 19
LIGHT TRAP 21
LIGHT TRAP 20
SCENTED TRAP 20
0
0.2
0.4
0.6
0.8
1.0
DISTANCE

plots from the same site. (Fig. 8).

Insect catches pooled from all methods and from the three replicate plots constitute a combined sample for a site. Such combined samples permit comparison between the different habitats represented by different sites. In Fig. 9 all the 12 sites are ordered in decreasing levels of diversity as computed by α of the log series. Because the variance of α can be easily computed, we can make statements such as the insects caught in Bidralli R.F. are significantly more diverse than those caught from Santagal R.F. which in turn are significantly more diverse than those caught from Chandavar M.F. and so on. Arranging the 12 sites in decreasing order of diversity, Fig.9 indicates for each site, its nearest neighbour (in terms of diversity) compared to which it is significantly more diverse.

Similarly, using pooled catch data for each site we compare them using the Morishita-Horn Index. This leads to the remarkable result that with the exception of teak plantation, all down-ghat sites form one cluster and all up-ghat localities form a different cluster (Fig. 10)

4. Relative abundance of different species:

Natural communites are expected to have a highly skewed distribution of relative abundances such that most species are represented by small numbers of individuals and fewer and fewer species represented by larger and larger number of individuals. All our trapping methods clearly reproduce such a pattern thus suggesting that the insects trapped are a reasonably random

FIGURE 8

Dendrogram showing similarity of insects caught in each of the 36 plots. With the exception of Chandavar, Bengle and Bidralli similarity between replicate plots of a site is greater than that between plots of different sites.

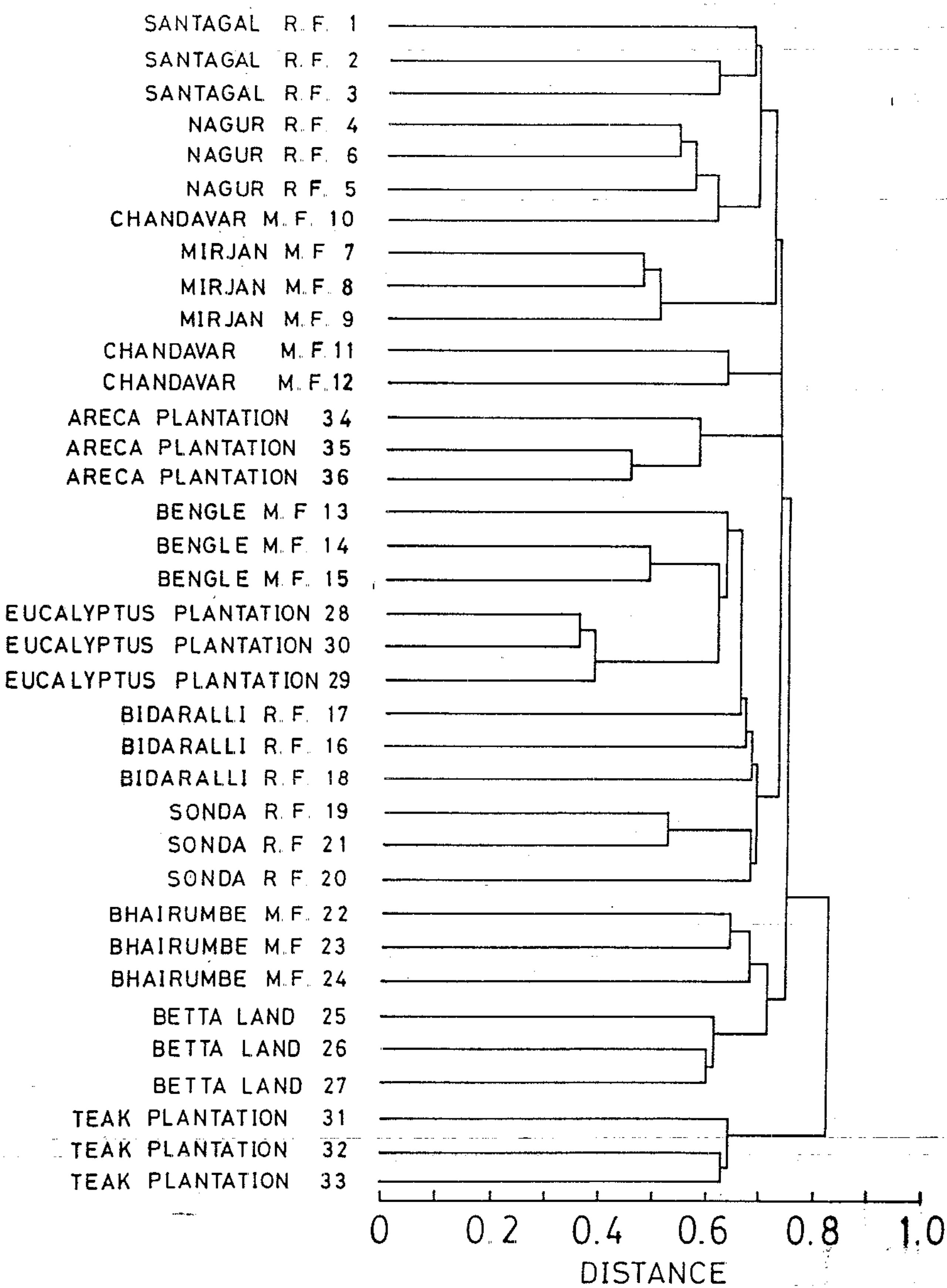
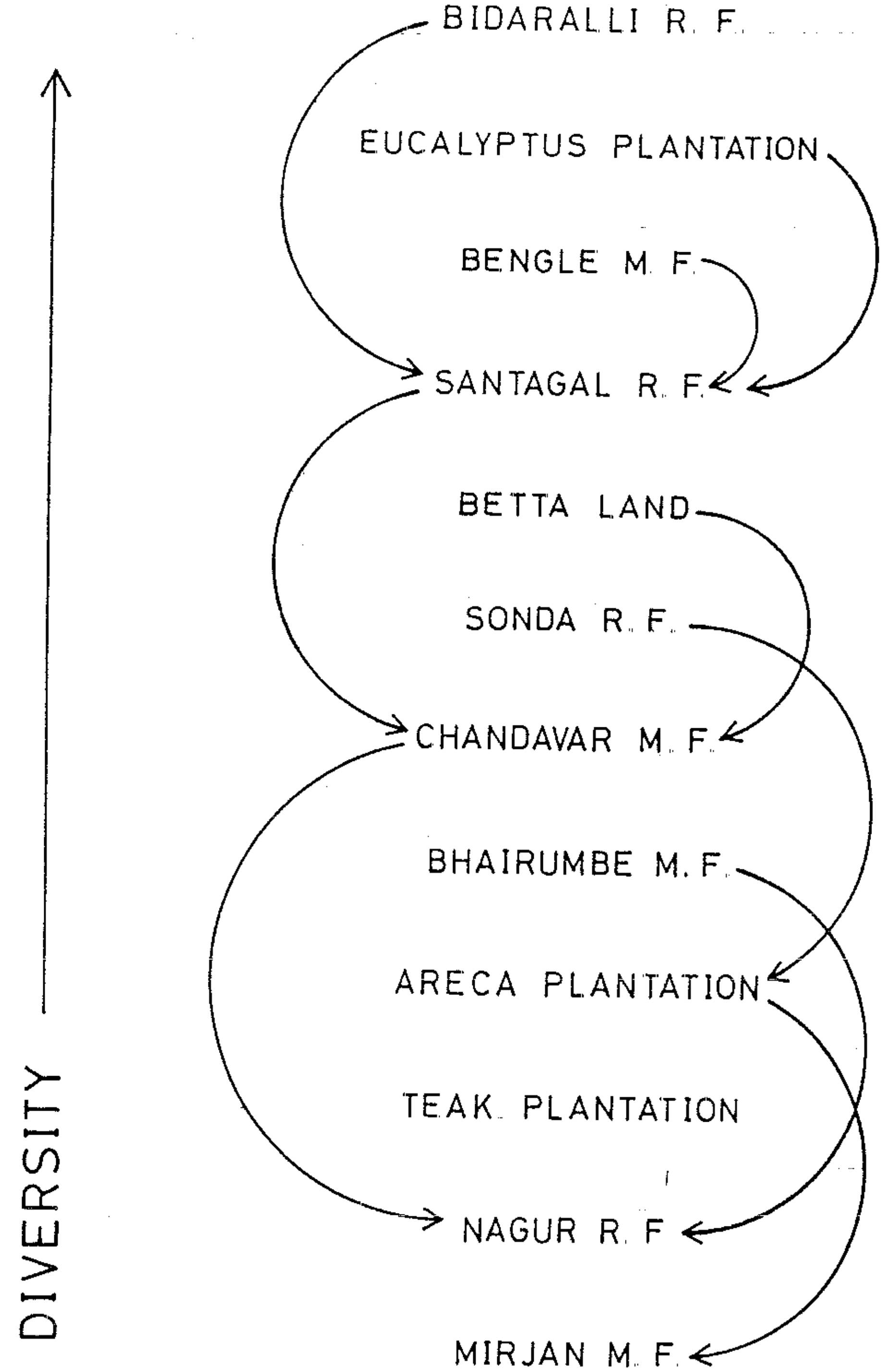

SANTAGAL R.F. 1
SANTAGAL R.F. 2
SANTAGAL R.F. 3
NAGUR R.F. 4
NAGUR R.F. 6
NAGUR R.F. 5
CHANDAVAR M.F. 10
MIRJAN M.F 7
MIRJAN M.F. 8
MIRJAN M.F. 9
CHANDAVAR M.F. 11
CHANDAVAR M.F. 12
ARECA PLANTATION 34
ARECA PLANTATION 35
ARECA PLANTATION 36
BENGLE M.F 13
BENGLE M.F. 14
BENGLE M.F. 15
EUCALYPTUS PLANTATION 28
EUCALYPTUS PLANTATION 30
EUCALYPTUS PLANTATION 29
BIDARALLI R.F. 17
BIDARALLI R.F. 16
BIDARALLI R.F. 18
SONDA R.F. 19
SONDA R.F 21
SONDA R.F. 20
BHAIRUMBE M.F. 22
BHAIRUMBE M.F 23
BHAIRUMBE M.F. 24
BETTA LAND 25
BETTA LAND 26
BETTA LAND 27
TEAK PLANTATION 31
TEAK PLANTATION 32
TEAK PLANTATION 33
0
0.2
0.4
0.6
0.8
1.0
DISTANCE

FIGURE 9

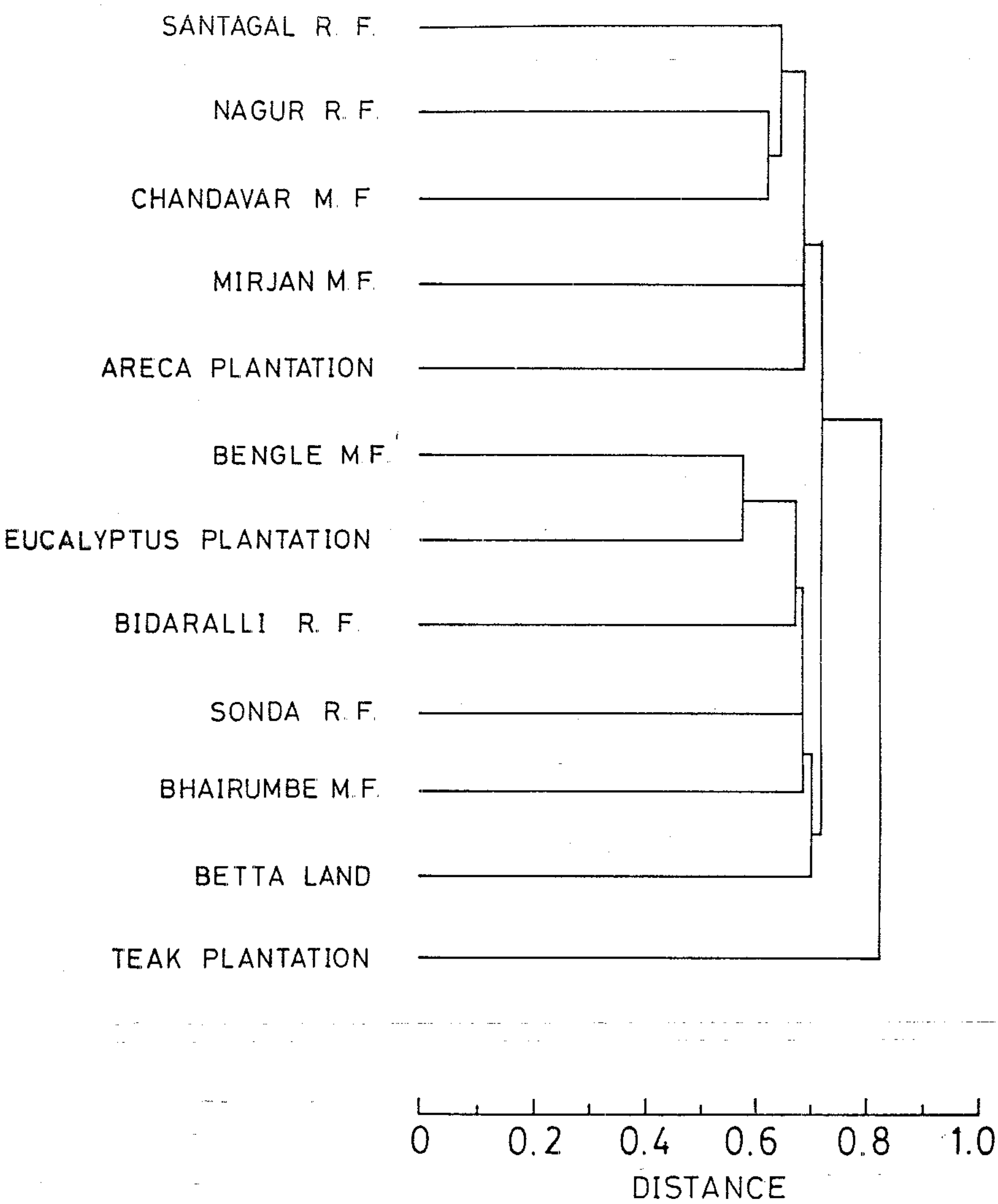
Ordering of sites with the most diverse Bidralli R.F. on top and the least diverse Mirjan M.F. at the bottom. Arrows indicate the nearest neighbour (in terms of diversity) compared to which each site is significantly more diverse ($p < 0.05$). Data pooled from 3 replicate plots each.



DIVERSITY
BIDARALLI R. F.
EUCALYPTUS PLANTATION
BENGLE M. F.
SANTAGAL R. F.
BETTA LAND
SONDA R. F.
CHANDAVAR M. F.
BHAIRUMBE M. F.
ARECA PLANTATION
TEAK PLANTATION
NAGUR R. F
MIRJAN M. F.

FIGURE 10

Dendrogram showing similarity between different sites. Notice that with the exception of the teak plantation all the down-ghat sites form one cluster and the up-ghat sites a different cluster. Data pooled from three replicate plots for each site.


SANTAGAL R. F.
NAGUR R. F.
CHANDAVAR M. F
MIRJAN M.F.
ARECA PLANTATION
BENGLE M.F.
EUCALYPTUS PLANTATION
BIDARALLI R. F.
SONDA R. F.
BHAIRUMBE M.F.
BETTA LAND
TEAK PLANTATION
0
0.2
0.4
0.6
0.8
1.0
DISTANCE

sample of at least a subset of the community (Fig.11).

5. Comparison of diversity indices:

Data from the 36 plots shows a strong correlation between the total number of species and the total number of individuals caught in each plot (table 3 and fig. 12; $p < 0.00001$). A similarly strong correlation exists between the number of species and the α diversity index but we obtained relatively poor correlations between the number of species and other diversity indices tested (table 4, fig.12).

6. Comparison of sites:

Reserve forests, Minor forests and Plantations were initially chosen because they were expected to represent different levels of disturbance. To obtain a more objective and continuous index of disturbance however, we have measured the extent of canopy cover in each plot. This was achieved through the canopy cover index which is the mean number of trees whose canopies overlap with each other at any given point in the plot (see methods). Clearly canopy cover is only one of the many factors that must affect the distribution and abundance of insects on the floor of the forests. This is reflected by the considerable scatter in points when we plot the number of species, diversity or number of individuals as a function of the canopy cover index (fig.13.). Nevertheless there is a statistically significant inverse correlation between the canopy cover index and the number of individuals ($p < 0.02$). There is also a suggestion that both the number of species and diversity

FIGURE 11

Species abundance curves for insects caught by different methods.

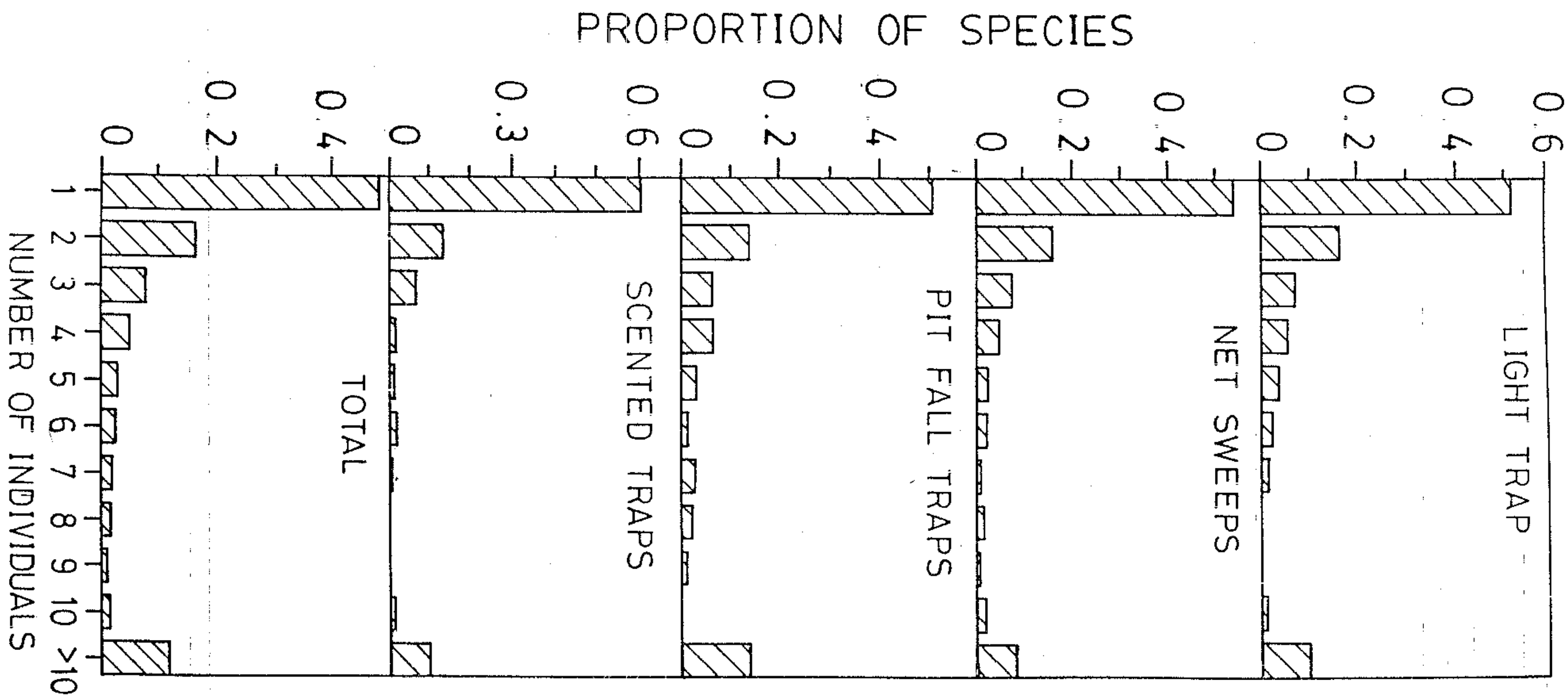

PROPORTION OF SPECIES
0
0.2
0.4
0.3
0.6
TOTAL
SCENTED TRAPS
PIT FALL TRAPS
NET SWEEPS
LIGHT TRAP
1 2 3 4 5 6 7 8 9 10 >10
NUMBER OF INDIVIDUALS

TABLE : 4 KENDALLS COEFFICIENT OF RANK CORRELATION BETWEEN NUMBER OF SPECIES AND NUMBER OF INDIVIDUALS AND DIVERSITY INDICES

VARIABLE	TAU	SD	Z
1. No. of individuals	0.5436	0.1165	4.6645
2. Simpson's index of Diversity (D) (or Hill's diversity index N_2)	0.2267	0.1165	1.9450
3. Shannon Weiner diversity index (H) or (Hill's diversity index N_1)	0.3703	0.1165	3.1778
4. α of log series	0.4916	0.1165	4.2187
5. S_{20}	0.1756	0.1165	1.5067

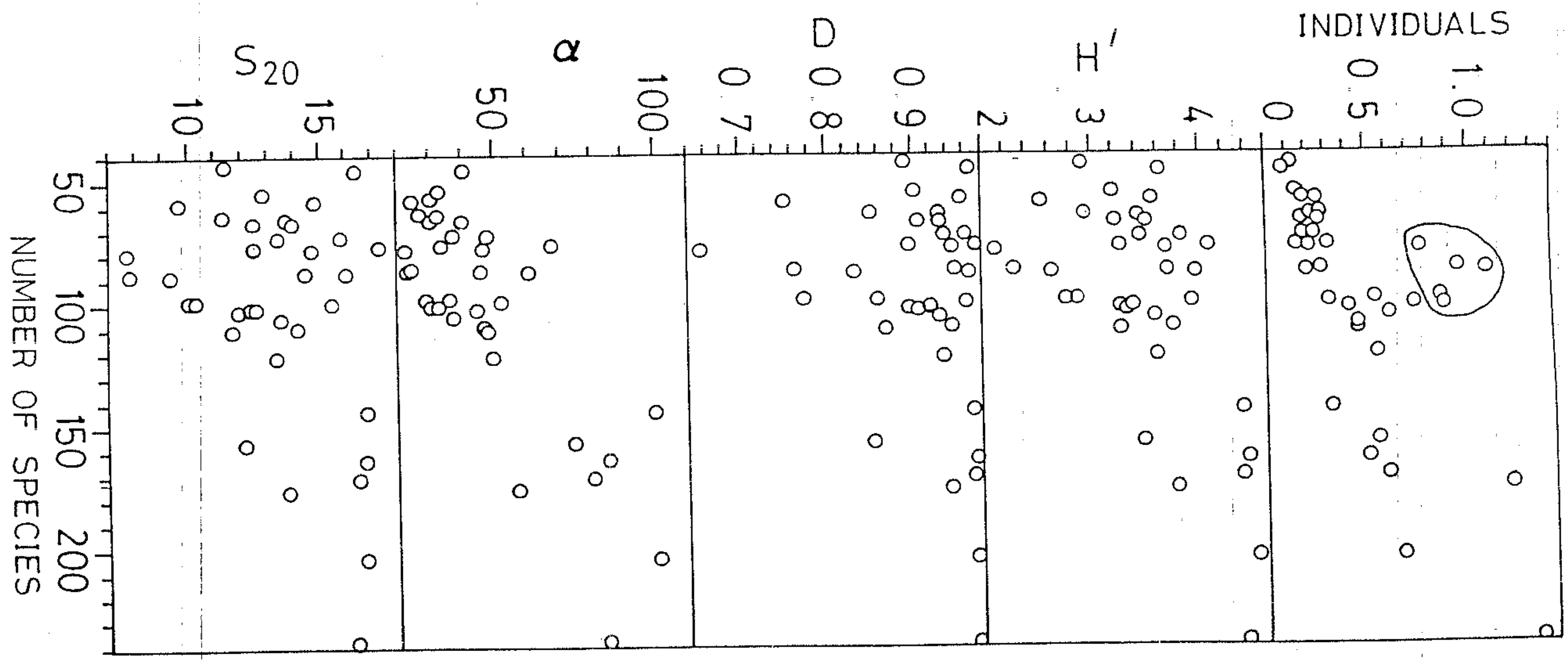
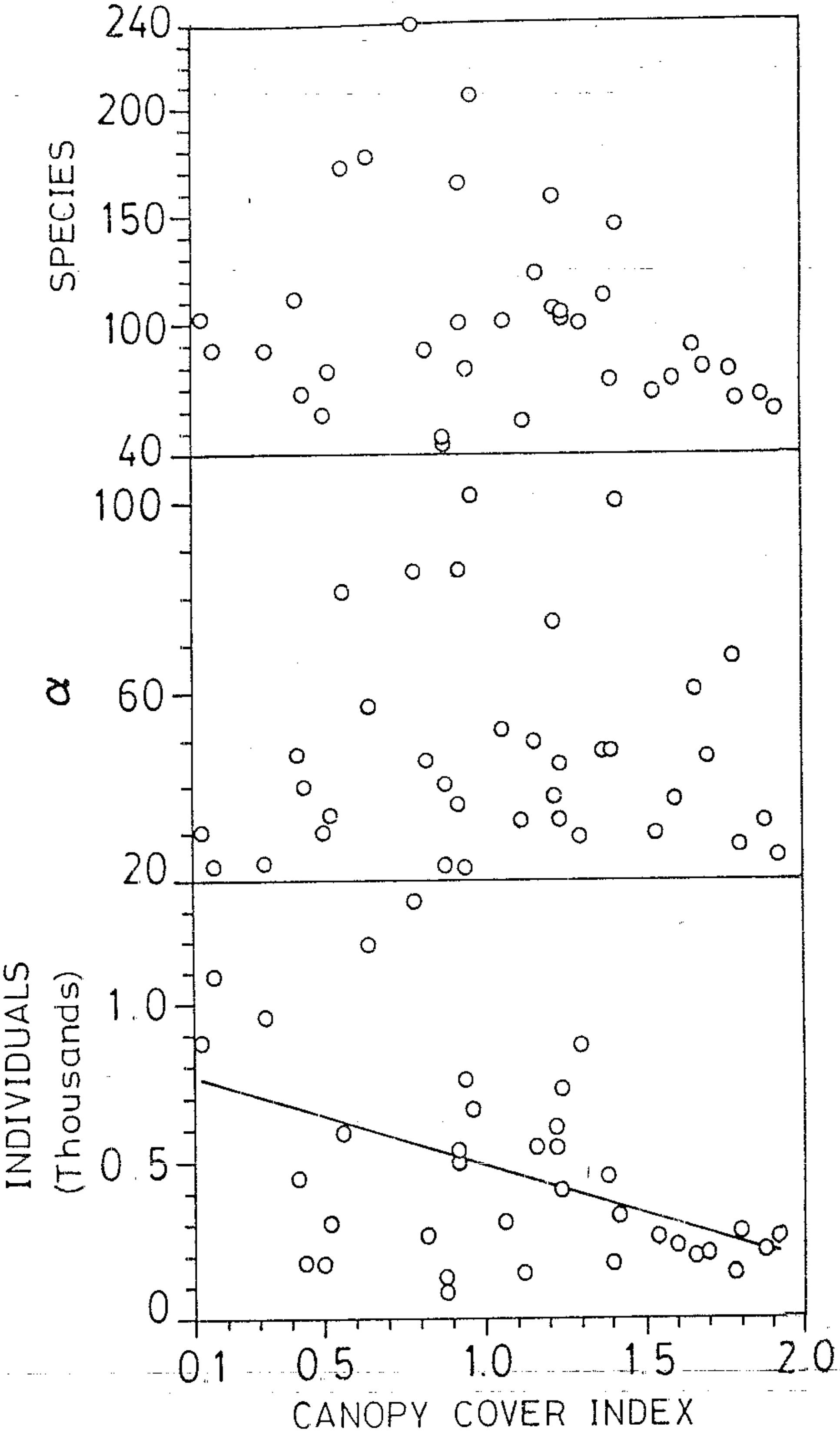

S20
α
D
H'
INDIVIDUALS
10
15
50
100
0.7
0.8
0.9
2
3
4
0
0.5
1.0
50
100
150
200
NUMBER OF SPECIES

FIGURE 13

Relationship between canopy cover index and number of species, α diversity index and number of individuals. There is a significant negative correlation between canopy cover index and number of individuals (Bottom panel). (Kendalls Rank Correlation Coefficient Tau = −0.2711; $p < 0.05$; the straight line is given by $Y = -311.68 X + 800.74$; $p < 0.01$). Each point represents one of the 36 plots.



SPECIES
240
200
150
100
40
α
100
60
20
INDIVIDUALS (Thousands)
1.0
0.5
0
0.1
0.5
1.0
1.5
2.0
CANOPY COVER INDEX

are more variable and can reach very high levels at intermediate levels of canopy cover while relatively fewer species and lower diversity are obtained at very high or very low value of canopy cover index.

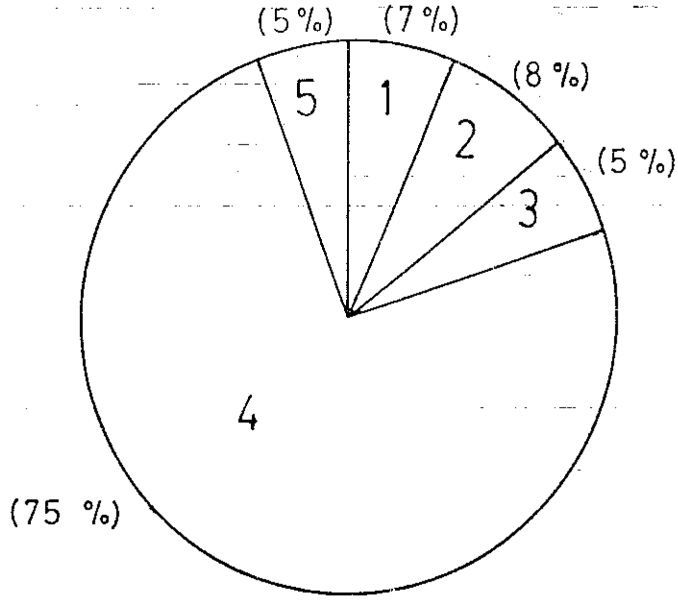
7. Habitat "Specialisations":

Comparing the relative contributions of different insect orders both in terms of number of species and in terms of number of individuals we find that in some localities a very large proportion of the species or individuals belong to one insect order and the dominant order varies from locality to locality. While some localities are so "specialised" others appear to be more "generalised" with a fairly even distribution of species and individuals across 4 or more orders. A few of the relatively clearer examples of this phenomenon are shown in Figs. 14 and 15. 75% of all insects caught in Mirjan M.F belonged to Coleoptera, 58% of all insects caught in Chandavar M.F. belonged to Diptera whereas in Bhairumbe M.F. 28% of the insects belonged to Hemiptera, 25% to Coleoptera, 22% to Hymenoptera and 17% to Diptera. Similarly 40% of all species caught from Mirjan M.F. belong to Coleoptera, 38% of all species caught in the *Eucalyptus* plantations belonged to Hymenoptera but in Bengle M.F. 25% of the species belonged to Hymenoptera, 25% to Diptera, 22% to Hemiptera and 19% to Coleoptera. A list of the orders and families encountered along with the numbers of species and individuals caught from each family are in Appendix 1.

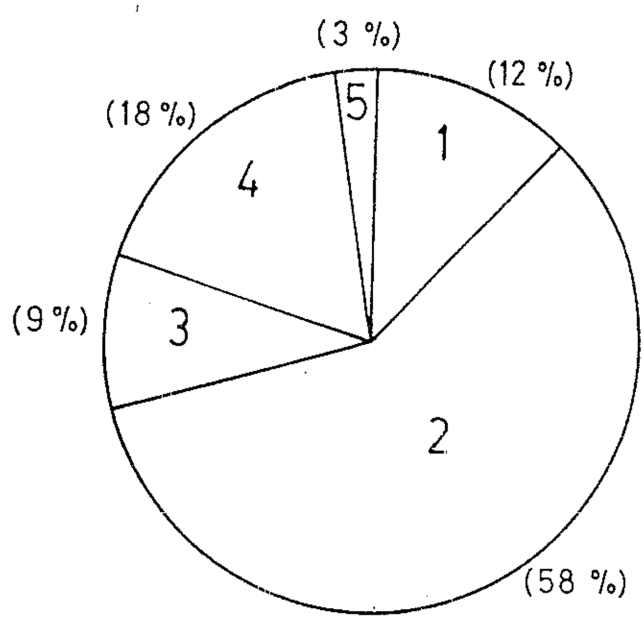
FIGURE 14

Pie Charts showing the proportion of individuals belonging to different orders. 1 = Hemiptera, 2 = Diptera, 3 = Hymenoptera, 4 = Coleoptera and 5 = rest of the orders. A = Mirjan M.F., B = Chandavar R.F. and C = Bhairumbe M.F. Data pooled from 3 replicate plots of each sites.

A



B



C

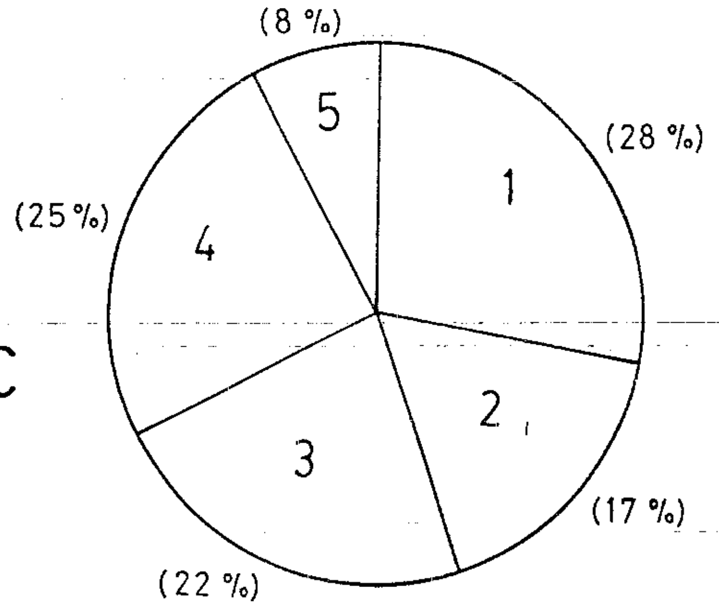
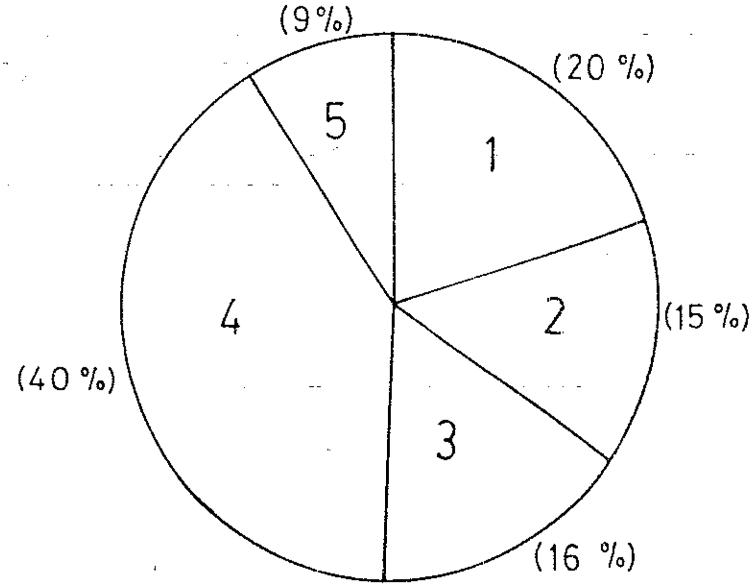


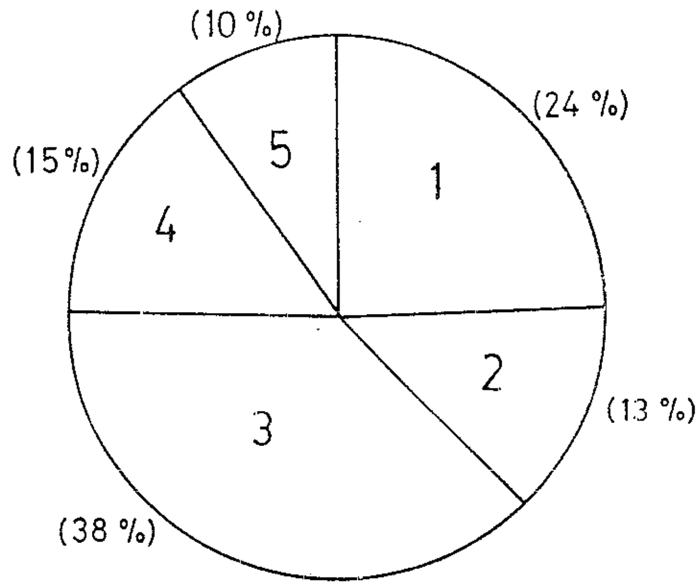
FIGURE 15

Pie Charts showing the proportion of species belonging to different orders. Order numbers as in figure 14. A = Mirjan M.F., B = Eucalyptus Plantation and C = Bengle M.F. Data pooled from three replicate plots of each site.

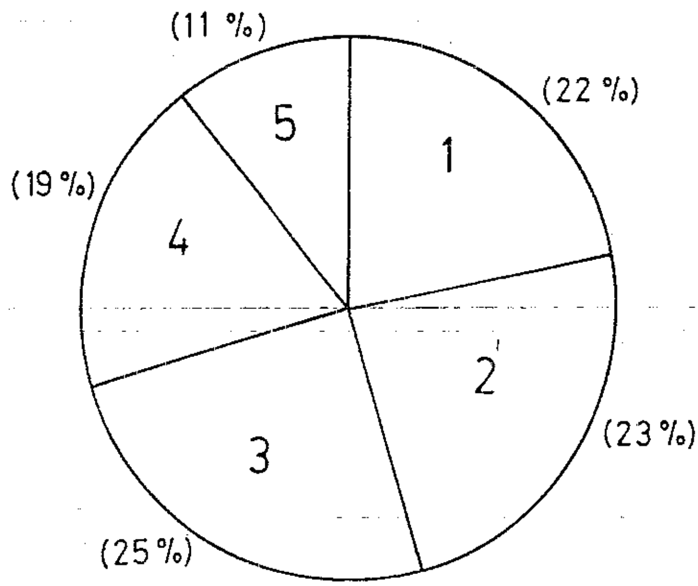
A



B



C



DISCUSSION

We have outlined here a strategy for quantitative and reproducible sampling of insects in forested habitats that is likely to be useful to tropical ecologists with modest research budgets and minimal facilities. We have argued that methods requiring the operation of a light trap continuously for months or years and especially in forested sites are inaccessible to most ecologists living and working in the tropical countries of the world. On the other hand it is studies of tropical communities that are most urgently needed and most likely to provide adequate field data required for understanding the principles of community ecology. We have therefore standardised a package of methods involving a small, portable, dry battery operated light trap and supplemented with other methods such as net sweeps, pitfall traps and scented traps. In an effort to make the methods reproducible we have, by careful standardisation, attempted to hold the sampling intensity or effort constant. One sampling unit thus corresponds to one light trap operated for a fixed number of hours in the middle of a one hectare plot, 6 net sweeps performed by a standardised method in 6 randomly chosen 10m x 10m quadrats, 5 pitfall traps and 5 scented traps placed at randomly chosen positions for 18 hrs in a one hectare plot. Such a sampling exercise can be completed in 24 hrs and therefore may be repeated every day by the same people and the same equipment. We have shown that such a sampling method yields a collection of insects which may be said to broadly represent that locality. The method could thus be used to compare insect communities in different habitats or across different seasons and can also be used for long term monitoring of changes in tropical habitats.

Traditional methods based exclusively on operating powerful light traps every night represent a very intense level of sampling compared to our methods. The result is that it is impossible to use all the insects caught in these light traps. Most investigators are forced to discard the bulk of the catches and concentrate their attention on one or a small group of insect species. The methods we describe sample insects at a much lower intensity making it necessary and possible to use all the insects collected. Clearly this is a more efficient procedure and leads to minimal destruction of natural populations of insects. Undoubtedly, the traditional powerful light trap method is more convenient - little or no work is required on the part of the investigators and sorting and identifying insects belonging only to a small, selected, familiar group is relatively easy. Our method requires more work on the part of the investigators both in terms of preparation and laying out the traps and more significantly in sorting all the insects belonging to different and often unfamiliar groups. Tropical ecologists will inevitably have to pay some price for not always being able to set up well organized research stations and obtain large budgets. We believe that the price in terms of man-power required by the methods we describe is small and a requirement of man-power is one price that tropical countries can pay relatively easily. Besides, the methods we have used will also help detect community land changes in the insect fauna which is difficult when only a selected group of species are monitored.

Because of the low intensity of sampling and the consequent need to include all insects collected in any analysis, we thought it best to use a variety of different trapping methods so as to attract different kinds of insects. Our finding that the catches for each of the 4 methods are quite different from each other justifies this. Because of the low intensity of sampling and the consequent small numbers of insects caught in each trap leading to random fluctuations, we thought it necessary to include several traps of the same kind in each plot and to use atleast 3 replicate plots in each habitat site. Although the insects caught by the same method have greater similarity to each rather than to insects caught by other methods in the plot, there are a few exceptions. Similarly although the insects caught in different replicate plots of a locality have a greater similarity to each rather than to insects caught in some other locality, again there are a few exceptions. These exceptions justify the inclusion of replicate traps and replicate plots, but the relative rarity of these exceptions suggest that the extent of replication is fairly adequate.

We were also concerned about whether our methods would be sufficiently unbiased as to catch a reasonably random sample of the populations. For instance we did not want a trail of ants to fall into one of our pit fall traps or some nearby rotting fruits to fill our scented traps with hundreds of individuals of a few species. We wished to get as many different species as possible and ideally, in proportion to their natural occurence. We cannot be sure that this has been achieved but the relative abundance curves from each of our methods and from our total catch suggests no serious anomaly of the "trail of ants" or "rotting fruits" kind.

In the process of standardizing these methods, we applied them to 12 carefully selected sites representing diverse habitat types so that, if the methods were successful, we might have something to say about the habitat types. We believe that the methods are successful and are therefore in a position to rank the chosen localities in their order of diversity values. The range of diversity values obtained are sufficient to permit us to make these comparisons with statistical significance. Another interesting result we have is that with the exception of the teak plantation, the coastal and the elevation sites form 2 different clusters suggesting that geographical seperation and altitudinal variation override even extreme differences in levels of disturbance. We obtained this result inspite of including relatively undisturbed reserve forests, relatively disturbed minor forests as well as monoculture plantations both among the coastal as well as elevation sites. This is not to say that there was no difference among the various sites in one region. Several statistically significant differences in levels of diversity between sites in the same geographical region and altitude were obtained. And yet similarity between sites within one geographical and altitudinal region was greater than similarity across geographical or altitudinal regions.

In addition to providing a method of understanding and comparing tropical habitats we believe that such a method, if applied on a large scale, will permit tropical ecologists to generate substantial field data relevant to current ecological theory. For instance we have made a preliminary attempt to evaluate the utility of different diversity indices in describing these insect communities. Because the number of species is well correlated with the number of individuals a useful diversity index would be one which is also well correlated with the number of species. Of several diversity indices tested, we find that α of log series is relatively most satisfactory in this regard. Taylor *et al* (1986) and Wolda (1983) have also advocated α as a relatively more useful index of diversity.

Similarly we have made an attempt to understand the factors affecting the distribution of diversity and abundance of insects. Using the canopy cover index as an objective and continuous measure of levels of disturbance we have shown that the number of individuals is inversely correlated with the canopy cover index. As the canopy is opened up, we find many more insects in the forests understorey. This result is further evidence that the insects we trap are atleast loosely associated and therefore characteristic of a given region. Canopy cover is clearly only one of the many factors that must affect distribution of insects. Despite the resultant scatter in the data, we have an indication that insect diversity can reach high levels at intermediate levels of canopy cover. When the canopy is closed there is little understorey vegetation and little hence insect activity.

When the canopy is completely opened up it results in nearly dry and barren land. It is at intermediate levels of canopy cover that a rich mosaic of habitat types can form in the forest understorey and lead to high levels of insect diversity.

The localities we have studied are different from each other in many ways. One of the more interesting differences lies in the proportional representation of species or individuals belonging to different insect orders. While some localities are "generalised" in that they have a fairly uniform distribution across 4 or more orders, others are more "specialized". For instance, Mirjan M.F. is a Hymenoptera "specialist", Chandavar M.F. is a Diptera "specialist". Why is there such a pattern in the distribution of insects ? Data of this kind will help formulate specific studies intended to understand the factors governing insect distribution. We believe that these methods will be equally useful for monitoring seasonal and long term changes in tropical habitats. Work is in progress to apply these methods in that direction.

It is now widely recognised that tropical habitats face a much greater threat of destruction than other regions of the globe. This makes the study of tropical insect communities both urgent and challenging. It is also true that the economic conditions of most tropical countries make a certain amount of developmental activity inevitable. For this reason ecologists are being increasingly called upon to make assessments of the impact of such developmental projects on tropical biotic communities. We hope that the methods described here will contribute towards meeting these challenges.

ACKNOWLEDGEMENTS

We thank Mr.R.J.Ranjit Daniels for assistance in the field, Mrs.Vijayalakshmi Kandula for assistance in sorting the insects and Prof.Madhav Gadgil for many helpful discussions. Supported in part by a grant from the Department of Environment, Government of India.

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APPENDIX 1. LIST OF ORDERS, FAMILIES AND THE NUMBERS OF SPECIES AND INDIVIDUALS ENCOUNTERED IN EACH FAMILY.

ORDER	FAMILY	NUMBER OF SPECIES	NUMBER OF INDIVIDUALS
COLLEMBOLA	ENTOMOBRYIDAE	33	338
	ISOTOMIDAE	5	34
	SMINTHURIDAE	4	8
	PODURIDAE	5	39
TOTAL	**04**	**47**	**419**
EPHEMEROPTERA	CAENIDAE	1	61
	EPHEMERIDAE	1	1
	BAETIDAE	1	1
TOTAL	**03**	**3**	**63**
ODONATA	LIBELLULIDAE	2	2
	COENAGRIONIDAE	4	10
TOTAL	**02**	**6**	**12**
ORTHOPTERA	ACRIDIDAE	11	117
	GRYLLIDAE	10	158
	TRIDACTYLIDAE	4	16
	TETRIGIDAE	6	23
	TETTIGONIIDAE	8	17
	GRYLLACRIDIDAE	2	2
TOTAL	**06**	**41**	**333**
PHASMIDA	PHASMATIDAE	4	6
TOTAL	**01**	**4**	**6**
DERMAPTERA	FORFICULIDAE	1	1
TOTAL	**01**	**1**	**1**
EMBIOPTERA	OLIGOTOMIDAE	3	4
TOTAL	**01**	**3**	**4**
DICTYOPTERA	BLATTIDAE	5	10
	MANTIDAE	3	3
	BLATELLIDAE	6	27
TOTAL	**03**	**14**	**40**
ISOPTERA	TERMITIDAE	5	79
TOTAL	**01**	**5**	**79**

APPENDIX 1 Contd.....

1	2	3	4
PSOCOPTERA	ARCHIPSOCIDAE	3	6
	PSOCIDAE	6	14
	PSEUDOCAECILIIDAE	7	11
	PSYLLIPSOCIDAE	1	1
	LEPIDOPSOCIDAE	1	1
TOTAL	05	18	33
HEMIPTERA	APHIDIDAE	5	45
	CERCOPIDAE	20	262
	CICADELLIDAE	112	2196
	COREIDAE	16	134
	FLATIDAE	7	14
	LYGAEIDAE	23	130
	MEMBRACIDAE	13	89
	MIRIDAE	21	188
	PENTATOMIDAE	17	47
	PHYMATIDAE	1	1
	PYRRHOCORIDAE	2	3
	REDUVIIDAE	7	8
	SCUTELLERIDAE	2	14
	TINGIDAE	8	43
	MESOVELIIDAE	3	9
	LOPHOPIDAE	1	6
	DELPHACIDAE	16	145
	NABIDAE	5	19
	MONOPHLEBIIDAE	1	7
	CORIXIDAE	3	131
	ARADIDAE	2	2
	HYDROMETRIDAE	1	43
	DIPSOCORIDAE	3	16
	PSYLLIDAE	3	6
	FULGORIDAE	1	1
	CIXIIDAE	3	7
	DERBIDAE	1	1
	TROPIDUCHIDAE	1	1
	VELIIDAE	2	59
	ISSIDAE	1	6
	ANTHOCORIDAE	2	8
	ERISOMATIDAE	1	1
	DICTYOPHARIDAE	2	5
	CYDNIDAE	2	5
	SALDIDAE	2	9
	ENICOCEPHALIDAE	1	1
	AETALIONIDAE	1	1
	UNIDENTIFIED	4	5
TOTAL	37	316	3668

APPENDIX 1 Contd....

1	2	3	4
THYSANOPTERA	PHLAEOTHRIPIDAE	10	19
	THRIPIDAE	1	3
TOTAL	02	11	22
NEUROPTERA	MYRMELIONTIDAE	3	3
	SISYRIDAE	1	1
	HEMEROBIIDAE	3	5
	MANTISPIDAE	1	4
	CHRYSOPIDAE	1	1
TOTAL	05	9	14
LEPIDOPTERA	NOCTUIDAE	12	20
	PIERIDAE	1	2
	PYRALIDAE	6	26
	LYONETIDAE	1	5
	TINEIDAE	1	2
	GRACILLARIIDAE	1	2
	GELECHIIDAE	3	5
	GALLERIIDAE	1	1
	SATYRIDAE	2	3
	LIMACODIDAE	1	1
	HESPERIIDAE	1	1
	MICROLEPIDOPTERA	9	10
	UNIDENTIFIED	11	13
TOTAL	12	50	91
TRICHOPTERA	HYDROPSYCHIDAE	1	1
TOTAL	01	1	1
DIPTERA	AGROMYZIDAE	9	22
	ANTHOMYIIDAE	13	36
	ASILIDAE	6	34
	BIBIONIDAE	2	5
	BOMBYLIIDAE	5	7
	CECIDOMYIIDAE	21	1379
	CHAMAEMYIIDAE	3	25
	CHIRONOMIDAE	29	369
	CONOPIDAE	1	1
	CULICIDAE	20	52
	DROSOPHILIDAE	24	955
	EPHYDRIDAE	2	3
	MILICHIIDAE	3	3
	MUSCIDAE	19	27
	MYCETOPHILIDAE	3	3
	PHORIDAE	23	143
	PIPUNCULIDAE	2	6
	PSYCHODIDAE	10	52

APPENDIX 1 Contd....

1	2	3	4
	SEPSIDAE	6	35
	SPHAEROCERIDAE	10	33
	SYRPHIDAE	5	17
	TACHINIDAE	5	6
	TIPULIDAE	6	9
	PLATISTOMATIDAE	1	1
	CERATOPOGONIDAE	12	61
	DOLICHOPODIDAE	11	61
	CELYPHIDAE	2	13
	CHLOROPIDAE	28	218
	OTITIDAE	7	124
	TEPHRITIDAE	4	10
	SCIARIDAE	30	295
	ITONIDIDAE	1	1
	TABANIDAE	1	1
	SCIOMYZIDAE	1	1
	CURTONOTIDAE	1	1
	DRYOMYZIDAE	1	1
	LAUXANIIDAE	1	1
	EMPIDIDAE	1	1
	RHAGIONIDAE	1	2
	LEPTOGASTRIDAE	1	1
	UNIDENTIFIED	32	41
TOTAL	40	363	4056
SIPHONAPTERA	HYSTRICHOPSYLLIDAE	1	1
TOTAL	01	1	1
HYMENOPTERA	ANTHOPHORIDAE	1	1
	APHELINIDAE	1	1
	APIDAE	2	2
	EVANIDAE	3	5
	BRACONIDAE	59	125
	CHALCIDIDAE	22	60
	ENCYRTIDAE	11	27
	EULOPHIDAE	29	45
	FORMICIDAE	129	2762
	ICHNEUMONIDAE	59	190
	MYMARIDAE	4	6
	POMPILIDAE	4	4
	SCOLIIDAE	1	1
	SPHECIDAE	3	3
	TIPHIIDAE	2	2
	TRICHOGRAMMATIDAE	1	1
	VESPIDAE	2	2
	ELASMIDAE	3	3
	TETRASTYCHIDAE	4	4
	PTEROMALIDAE	25	35
	EUMENIDAE	1	1

APPENDIX 1 Contd....

1	2	3	4
	CYNIPIDAE	6	23
	GONATOCERIDAE	2	2
	COLLETIDAE	3	9
	EUPELMIDAE	9	42
	BETHYLIDAE	15	43
	PERILAMPIDAE	7	18
	HALICTIDAE	4	7
	SCELIONIDAE	13	24
	TORYMIDAE	11	20
	CERAPHRONIDAE	2	3
	DIAPRIIDAE	7	16
	PLATYGASTERIDAE	7	9
	DRYINIDAE	3	8
	UNIDENTIFIED	28	32
TOTAL	34	483	3536
COLEOPTERA	ALTICIDAE	2	2
	BRUCHIDE	5	7
	BUPRESTIDAE	7	18
	CARABIDAE	26	912
	CASSIDAE	1	1
	CERAMBYCIDAE	1	1
	CETONIDAE	3	18
	CHRYSOMELIDAE	50	448
	COCCINELLIDAE	20	147
	CURCULIONIDAE	49	594
	DYNASTIDAE	3	29
	HISPIDAE	4	12
	LAMPYRIDAE	2	15
	MELOIDAE	3	7
	MELONTHIDAE	1	11
	PAUSSIDAE	1	1
	SCARABEIDAE	13	52
	STAPHYLINIDAE	47	1481
	ELATERIDAE	8	25
	GEORYSSIDAE	2	9
	MELANDRYIDAE	2	3
	ALLECULIDAE	5	9
	ANTHRIBIDAE	3	3
	BYRRHIDAE	9	98
	SCOLYTIDAE	12	18
	NITIDULIDAE	13	175
	TENEBRIONIDAE	36	97
	ANOBIIDAE	6	17
	DYTISCIDAE	3	9
	HYDRAENIDAE	1	1
	RHIPIPHORIDAE	2	2
	SYLVANIDAE	3	4
	CUCUJIDAE	5	10
	MYCTERIDAE	1	1

APPENDIX 1 Contd....

1	2	3	4
	HYDROPHILIDAE	5	12
	PSELAPHIDAE	5	129
	PHENGODIDAE	1	2
	AMPHIZOIDAE	1	1
	OTHNIIDAE	1	1
	MORDELLIDAE	3	6
	CLERIDAE	4	5
	CRYPTOPHAGIDAE	2	5
	CANTHARIDAE	1	1
	MYCETOPHAGIDAE	2	2
	CORYLOPHIDAE	2	3
	ANTHICIDAE	4	15
	HALIPLIDAE	1	1
	THROSCIDAE	1	1
	PHALACRIDAE	2	9
	PEDILIDAE	1	1
	MELYRIDAE	1	1
	HISTERIDAE	1	2
	PLATYPODIDAE	1	2
	SCYDMAENIDAE	1	4
	LATHRIDIIDAE	2	2
	BOSTRICHIDAE	1	1
	HETEROCERIDAE	1	1
	PTINIDAE	2	3
	RHYSODIDAE	2	5
	BYTURIDAE	1	2
	UNIDENTIFIED	15	19
TOTAL	60	413	4473
GRANDTOTAL 19	219	1789	16852