THE IMPACT OF LAND USE CHANGE ON LITTER BEETLE AND ANT COMMUNITIES IN A COFFEE - DOMINATED LANDSCAPE IN CHICKMAGALUR DISTRICT, KARNATAKA

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CERTIFICATE

This is to certify that **Smitha Badrinarayanan** of the Wildlife Institute of India has carried out an original piece of work titled "**The Impact of Land Use Change on Litter Beetle and Ant Communities in a Coffee-Dominated Landscape in Chickmagalur District, Karnataka**" in partial fulfillment of the M.Sc. (Wildlife Science) degree of Saurashtra University. These investigations were carried under my supervision at the Wildlife Institute of India from Novermber 2000 to June 2001. I also certify that this work has not been submitted for any other degree of any university.

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To the people and creatures of Koppa

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It is amazing how many people one can get to know over as short a period as the six months of my fieldwork. The task of acknowledging them is pleasant - you can put down on paper things you'd never say to people.

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SUMMARY

Human-modified habitats dominate the landscape on earth. There is an urgent need for investigations into the diversity of biota supported by different land use systems that replace forests. The plantation of coffee is one such land use that occurs in large tracts of the Western Ghats in Karnataka. An observational study on changes in litter faunal communities caused by conversion of forests to coffee was attempted at the Koppa and Narasimharajapura taluks of Chickmagalur district. Four replicate blocks containing three treatments: forest, polyculture shade coffee plantations and monoculture shade coffee plantations, were selected using detailed spatial information that existed for this area. These included a land cover map, aerial photographs and topographic sheets. The information from these sources was used to obtain a list of possible study sites, the suitability of which were assessed on the basis of field visits and interviews of the locals.

Litter beetle and ant communities were sampled using pitfall traps along two transects within each of the treatments. Measurements of microclimate, vegetation structure and litter parameters were made along with sampling for litter fauna. The organisms obtained in the pitfall traps were sorted out and the ants and beetles occurring in it were identified to the level of morphospecies. Comparisons of the diversity of beetle and ant morphospecies in the forest and two coffee shade treatments were made on the basis of the occurrence and abundance of different morphospecies. Cluster analyses of the twelve sites were done based on the distances between the communities found in them. Patterns revealed using exploratory data analyses were tested using quantitative statistical sampling.

There were significant differences in microhabitat structure between the three treatments. Forests were found to be more humid and had more equitable conditions than either of the coffee systems. The beetle and ant communities in the three treatments were also found to be distinctly different. Beetle morphospecies richness and abundance was highest in forests and lowest in the coffee monoculture shade systems. Ants, while having an equal number of morphospecies across the three treatments, were seen to be dominated in abundance by a few species in the coffee monoculture shade systems. Generally, forest sites were seen to cluster together in

one group while coffee monoculture shade sites clustered in another. The polyculture shade coffee treatments were seen to be intermediate in their community composition between forests and monoculture shade coffee plantations.

The high community turnover rates across the landscape suggest that even remnant forest patches in this coffee dominated landscape need to be protected from further degradation. For further conservation of the litter faunal community, traditional coffee polyculture shade systems need to be promoted to halt conversion to silver oak dominated agricultural systems.

1. Introduction

Each species found in an ecosystem is the unique product of at least 3600 million years of evolution and adaptation to local circumstances. The anthropocentric view to the conservation of biological diversity for its "function" and for its genetic "resources" entirely ignores the existence value of organisms. It is impossible to predict at present the effectiveness of either of these approaches in slowing the processes of human-induced destruction of ecosystems.

Unplanned and dramatic changes in human land use have caused unknown but large extents of change in species assemblages across the world (Chapin *et al.* 2000). Monoculture and the homogenization of landscapes have been associated with the success of agriculture and the industrial revolution in supporting exploding human populations. Diversity in constituent communities has been proved essential to the maintenance of the primary productivity of an ecosystem and to the performance of its biogeochemical cycles (Tilman and Downing 1994, Naeem *et al.* 1995). The long-term survival of the species-poor communities designed by humans is therefore suspect.

The spread of coffee as a plantation crop has led to the extensive clearing of forests in tropical regions (Ramakrishnan 2000). An important feature of commercial coffee systems is their topographic position in regions that correspond to zones of high endemicity. Tremendous losses have therefore probably already resulted in these regions. There is an urgent need to distinguish coffee systems that still support part of the original floral and faunal diversity from those that are relatively depauperate.

Chickmagalur, partly located in the Western Ghats, is the second highest coffee growing district of Karnataka. The impact of coffee plantation on the native fauna in this biodiversity hotspot "where exceptional concentrations of endemic species are undergoing exceptional loss of habitat" (Myers, 2000) therefore merits study.

Very little information exists on patterns of distribution of extremely species rich groups such as the insects, most of which have not even been described (Hughes et al., 2000). A community approach seems most suitable in an initial assessment of the impact of habitat alteration on this group. The definition of the limits of the community can be based on taxonomic grouping, on the sharing of a common resource or on the performance of similar functions (as defined by humans) within an ecosystem (Simberloff and Dayan 1991, Didham *et al.* 1996). Still less information exists on the processes in which insects are involved than on their distribution. Hence, the communities looked at in this study were defined as two taxonomic groups that shared a common resource - the beetles and the ants that were found moving actively in the leaf litter. The distribution and abundance of these two groups was compared in the litter in forests and the two dominant systems of coffee plantation in Chickmagalur District.

A. Literature review

Coffee plantations : Coffee (*Coffea* spp., Fam Rubiaceae) is an evergreen perennial plant that is a native of North East Africa. A well distributed annual rainfall and an elevation range between 500 to 2000m is an essential pre-requisite for its commercial plantation (Central Coffee Research Institute, 2000). The importance of the study of coffee systems stems from their straddling across a strategic elevation belt globally (Moguel and Toledo, 1999). The elevation range of coffee plantations overlaps with the broad mid-elevation peak in diversity that has been proved to occur in taxa such as plants and leaf-litter invertebrates in the tropics (Olson, 1994). 50% of the organisms that are observed at a particular elevation in tropical montane systems are seen to disappear with a change in elevation of 500m (Olson, 1994). Coffee plantations are also often found on mountain slopes in regions that represent areas of overlap between different vegetation types. Coffee has been shown to occur in the zone of overlap between tropical and temperate forests in Mexico (Moguel and Toledo, 1999). In this particular case of the Chickmagalur district of Karnataka, coffee plantations occur in the transition zone between evergreen and deciduous forest types. Such ecotones are theoretically expected to be more species rich than either of the overlapping regimes. Thus, the high levels of diversity assumed to be supported by certain coffee systems (Perfecto et al. 1996) might actually be remnants of much more speciose communities occurring in natural forests in these regions.

Coffee was introduced to India in 1600 but has been planted on a commercial scale only since the 1820s by British initiative. Most of the coffee cultivated in india is restricted to the hilly tracts of the Western and Eastern Ghats (Anon. 2000). The landscape in the coffee belt of the Western Ghats is characterised by settlements in the bottom of the slopes, rice fields in the valleys, coffee plantations in the uphill slopes and a few remnant forest patches at higher elevations (Moppert 2000). The main types of coffee cultivated here are Robusta (*Coffea canephora*) and Arabica (*C. arabica*). The management requirements of these two species are very different. Robusta grows successfully at lower elevations and requires higher temperature and humidity levels than Arabica. Arabica is thus associated with greater shade than Robusta. An important event in the history of coffee in India was the outbreak of a series of pests and diseases in the 1860s. This resulted in the introduction of silver oak (*Grevillea robusta*) and dadap (*Erythrina* spp.) to protect the Arabicas and the eventual propagation of Robusta as a more hardy species (Anon. 2000).

A paper comparing coffee production systems in Mexico distinguishes five main categories according to management level and vegetational and structural complexity. These fall into two broad types - the shaded and unshaded systems. The shaded systems can be either of the polyculture or monoculture type. Different levels of manipulation of the shade trees distinguishes the rustic, traditional polyculture and commercial polyculture systems(Moguel and Toledo 1999). In India, unlike parts of East Africa and the Neotropics, coffee is grown almost exclusively under shade.

Coffee expansion in the Karnataka Western Ghats occurred in different ways. Initially, coffee was grown in the wet deciduous forest area under a canopy of forest trees. The diversity of the canopy layer often reduced with age, with trees being extracted for timber and silver oak and a few fruit-producing species being planted in the gaps. In other cases, all forest trees in a region were cleared and sold as timber and a monoculture of silver oak trees or dadap was planted along with the coffee understorey. The lack of new lands for exploitation is now leading to illegal encroachment of coffee in forests and the conversion of paddy fields to coffee (Moppert 2000).

Leaf litter and its fauna **:** Litter fall and litter accumulation are highly seasonal and associated with leaf flush and rainfall. Most litter falls during the dry season in the tropics, but litter decomposition appears to begin only with the rains (Levings and Windsor, 1982). Total annual litterfall in shade coffee systems in Central America is reported to be between 5,000 and 20,000 Kg/Ha/annum, which is within the range reported for tropical forests (Beer 1988). Litter accumulates through the dry season. Litter accumulation is highest at the start of the rainy season and lowest in the last month in the rainy season. Decomposition of litter appears to stop during the period when litter is relatively dry. Thus, the litter moisture content is likely to be an important factor influencing the distribution of litter fauna, especially in the dry season (Levings and Windsor). A study of understorey insects in wetter and drier sites in a tropical dry season reported an increase in species richness with an increase in moisture levels in forests (Janzen and Schoener 1968). Similar factors are likely to operate on litter forms.

Leaf litter arthropods form exceptionally diverse communities as exemplified in families such as Staphylinidae (Order Coleoptera). Very little is known about litter arthropods in the tropics. (Anderson and Ashe 2000). The litter forms have relatively low vagility and hence are extremely useful in the study of spatial patterns (Olson 1994). Many taxa found in the litter are characterised by such features as lack of pigmentation, lack of wings, and lack of or reduced eyes(Anderson and Ashe 2000).

The category Coleoptera includes a wide diversity of forms from different families. The enormous diversity of species, families and lifestyles makes any ecological generalization about the group impossible (Levings and Windsor). A large proportion of litter beetles are likely to be decomposers along with a some phytophagous and predatory forms.

The ants are a common and very important part of the litter fauna. Many litter groups are generalists, feeding on sugar, scavenged material and prey. Some species are extreme specialists, consuming restricted prey types. Several genera collected in litter samples culture fungus on a variety of substrates for food. As social insects, ants present special sampling problems, since a comparison of their abundance in samples does not necessarily give an accurate picure of their abundance in the environment. (Levings and Windsor).

Impacts of coffee plantations on biota : Most studies of the impact of coffee systems on fauna have been on arthropods and birds, probably due to the entire displacement of larger faunal groups from coffee estates.

Certain levels of vegetational complexity and tree, shrub, herb and epiphytic diversity have been known to be maintained in traditional coffee systems (Perfecto *et al.*, 1996). Shaded coffee systems can be notable reservoirs of species utilised by humans(Moguel and Toledo, 1999).

Studies of avifauna in coffee systems have again proven differential responses to the alteration of forest habitats. A study in the Palni Hills (Tamil Nadu) demonstrated that although coffee estates were as species rich in birds as an adjacent forest, the composition of their community was strikingly different (Shahabuddin 1997). An increase in omnivores along with a reduction in the insectivorous guild was observed in the coffee plantations. Such a response was suggested to be due to differences in availability of food. (Wunderle and Latta 1998).

Studies of arthropod fauna in traditional systems have demonstrated similarity in trophic groups in traditional coffee systems with those of forest arthropods (Moguel and Toledo, 1999). Insect pest outbreaks and large fluctuations in insect pest populations are correlated with the reduction of plant and structural diversity in agroecosystems (Knops *et al.,*. 1999). A very high diversity of canopy arthropods coupled with a dramatic turnover rate of species richness was reported in a shade coffee plantation sampled using fumigation. (Perfecto et al., 1996). Studies comparing arthropods in different coffee systems have proven an expected loss in diversity from shaded to unshaded plantations. Farm management practices were seen to be important in determining the abundances of arthropods. (Nestel et al, 1993; Johnson, 2000). A study of the foraging kinetics of ground ants revealed a higher rate of discovery of food material in an unshaded than in a shaded coffee plantation. Foraging efficiency of the ants was seen to increase with a decrease in the structural complexity of their microhabitat. This efficiency was also related to the presence of an ant species that dominates perturbed ecosystems having high temperatures and the reduction in competing species associated with canopy trees. (Nestel and Dickschen, 1990).In contrast, moths were seen not to respond to differences between coffee and other agricultural systems. (Ricketts *et al.*, 2001). Thus the ecological correlates of species such as their size, vagility, degree of specialization and population density are likely to influence their response to perturbations. (Didham *et al.*, 1998).

B. Goals, objectives and specific questions

When studying two obviously different systems, as in the case of forests and coffee plantations, differences in faunal assemblages are only to be expected. The goal of this study was to document the extent of differences that exist between these systems. The importance of this comparison is in assessing the proportion of forest fauna supported by coffee and in evaluating the harmful (or beneficial) effects of different agricultural systems within the broad coffee land use in the landscape.

The specific objectives were:

1. To compare litter beetle and ant community structure in relatively undisturbed forests with coffee plantations.

2. To estimate the effect of the reduction in shade tree richness in coffee plantations on the litter beetle and ant fauna.

3. To identify the habitat parameters associated with forests and two coffee shade systems which could be the proximate cause for community structure alteration.

The following questions arise from these objectives:

1. Are beetle and ant communties in forest litter more species rich and of a more even structure than in the floor of coffee plantations?

2. Do polyculture shade coffee plantations support a greater diversity of litter communities than silver-oak (*Grevillea robusta*) monoculture shade coffee estates?

3. What are the differences in community composition between forests and the two coffee systems?

4. What are the microclimatic and microhabitat differences between forests and the two systems of coffee? How are these differences associated with changes in species richness and community evenness?

2. STUDY AREA

Four blocks in the Koppa and Narasimharajapura taluks of Chickmagalur District were chosen for the study after a survey of forests and coffee estates in this region.

A. General Description of the Region

Topography : Chickmagalur district lies in the west of Karnataka between 12° 55' and 13° 54' N latitude and between 75° 5' and 76° 22' E longitude. The western boundary of this district is represented by the Western Ghats. The greater part of this district belongs to the *Malnad* or the highland region. In the centre of the district is the Bababudan chain and towards the Western part of this district are two closely associated ridges running North to South. The coffee belt of Chickmagalur district runs along both these topographical features. The rivers Tunga and Bhadra flow through the district and give rise to a number of tributaries spreading over this region. (Yoganarasimhan *et al.* 1981).

Geology and soil : The underlying rock towards the Koppa taluk is generally metamorphic gneiss with granite and quartz mixed locally. In the Mallandurgudda State Forest of N.R.Pura taluk, lime stone, slaty schists, quartzites and rhoylites are found. The soils in this district are mostly classified as oxisols and ultisols. (Yoganarasimhan et al. 1991, Central Coffee Research Institute. 2000b).

Climate : The climate in this region is cool throughout the year, December being the coldest, and March being the hottest months. The mean temperature varies between 16 and 30° C. This is the wettest region of Karnataka, receiving an annual average of

1816 mm rain. July and August are the months of heaviest rain. This region receives the pre-monsoon (March/ April), South-West monsoon (June-September) and the North-East monsoon (October-November).

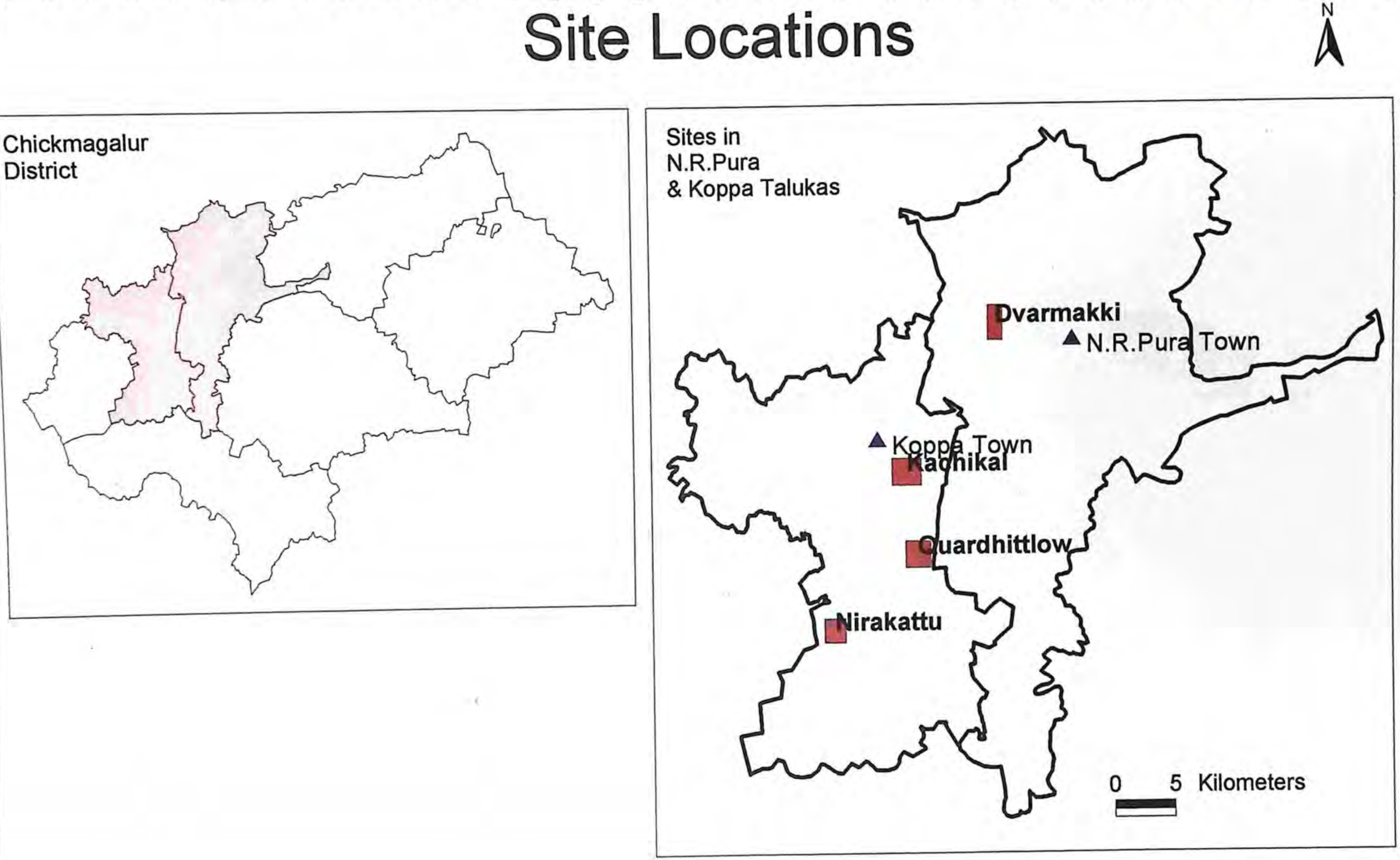
Vegetation : The vegetation type in this region varies from evergreen to moist deciduous. Some of the common trees seen in this region are *Lagerstroemia lanceolata, Terminalia tomentosa, Bischoffia javanica, Vateria indica, Holagarna ernotiana, Syzygium cuminii, Schleichera oleosa, Garcinia kombogia, Caryota urens, Kydia calycina, Ficus glomerata, Artocarpus hirsuta*, and *Mimusops elengii*. The commercial crops grown here are coffee (*Coffea*), tea (*Thea sinensis*), cocoa (*Theobroma cacao*), pepper (*Piper nigram*), cardamom (*Elettaria cardamomum*), areca (*Areca catechu*) and coconut (*Cocos nucifera*).

B. Detailed description of sites

The Koppa and the N.R.Pura taluks are towards the Western part of Chickmagalur district **(Fig 1)**. The approximate geographic extents of these two taluks are 42,000 ha and 30,000 ha, respectively. The rainfall received here is very high, above 2500 mm annually. The soils have medium to low available water content and are predominantly oxisols.

This Koppa region encompasses the transition zone between evergreen and deciduous vegetation and is of considerable ecological significance. However, almost the entire forest belt of the Koppa region has been replaced by coffee plantations and the remnant forests are in small pieces. The forests in Koppa taluk have been broken up into more than 900 fragments that alternate with around 450 fragments of

Site Locations



coffee patches as seen from a classified image with 85% accuracy. Only 7 of these forest fragments are larger than 250 ha. (M. Ramanathan, pers. comm.). No Reserve Forest has ever been declared in the Koppa taluk, and the land owned by the Forest Department, approximately 19,300 ha, is still under the process of survey and notification. Approximately 10,000 ha of land in this region are under coffee cultivation and Robusta is seen to occur to a greater extent than Arabica coffee.

The forests in the N.R.Pura taluk have been better protected, may be due to their drier nature and the lower pressures of coffee expansion on them. There is approximately 10,000 Ha of land under Reserve Forest in this taluk, and an almost equal amount (9000 Ha) exists as forests yet to be notified. The uncertainty in the legal boundary of forests has led to a large extent of encroachment into them, both in the Koppa and N.R.Pura taluks. (Sugara, 1990).

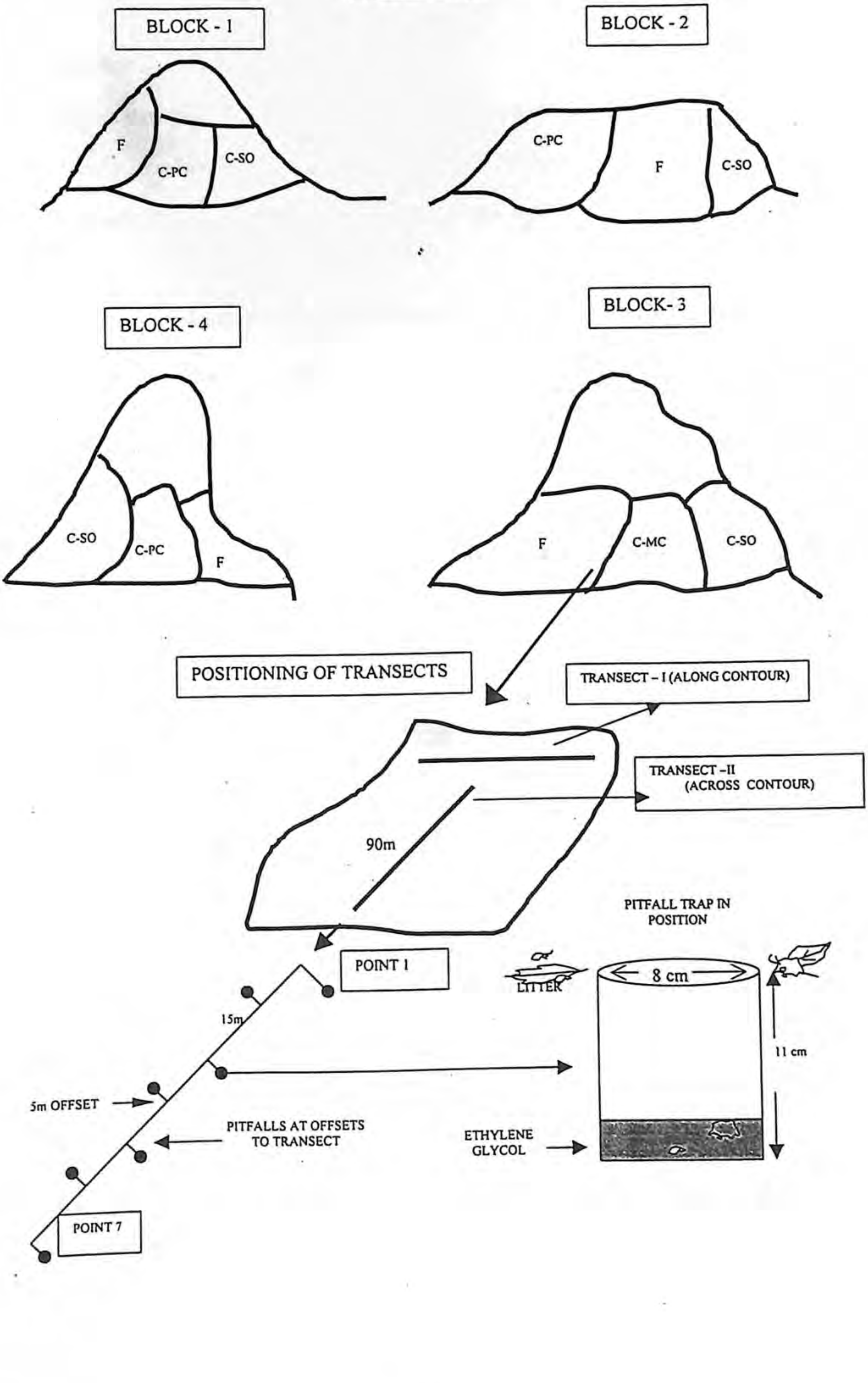
3. METHODS

A. Study design

There are prominent changes in elevation, aspect and slope across small distances in the Western Ghats. These would lead to corresponding changes in local climate since rainfall and temperature are a function of aspect and elevation. Changes in climate lead to changes in vegetation and the fauna present in a region. Soil type, though important in determining the vegetation, can be expected to change only over large distances, and thus not influence a small scale study.

A randomized block design (Potvin, 1993) was chosen to enable comparisons of the forest and coffee plantations by minimising the effects of the differences outlined above. A block was defined as a contiguous region in which topographical, and other features (aspect, elevation, slope and soil) were fairly homogeneous. The size of the block aimed at was 150 ha, based on an average required area of 50 ha per treatment.. The climate associated with a homogeneous topography and the soil type within the scale of a block were expected to be fairly constant. These should have initially given rise to a homogeneous type of vegetation and similarity in faunal communities within the block. Thus, differences in fauna within different land use regimes in a block could be attributed to land use/ land cover change. The use of four such replicate blocks, each containing the three treatments for comparison - forest, coffee with polyculture shade and coffee with monoculture shade - was decided upon. **(Fig 2)**.

STUDY DESIGN



B. Selection of sites

A range of existing spatial information made it possible to design this study according to various requirements. Invaluable tools used were a land cover map, aerial photographs and topographic sheets of the study area.

The land cover map of Chickmagalur district had been prepared for a larger study on the ecological impact of land use change in the Western Ghats. The map, derived from hybrid supervised, unsupervised and visual classification of NRSA IRS LISS-III imagery (Scene number 98-64, February 1997), was used in conjunction with Survey of India 1:50,000 topographic sheets (Reference numbers: 48 O/6, 48 O/7 and 48 O/8) to select blocks which fit the block criteria as closely as possible, and contained both forests and coffee plantations. It was not possible to distinguish between the polyculture and monoculture shade coffee systems on the land-use map. The selected blocks were evaluated on the extent of similarity of the elevation, aspect, slope and size of the coffee and forest patches occurring in them.

Ground-truth was available for some of the blocks from work done for the land-use mapping of Chickmagalur district. This information was used to check for the occurrence of both the types of shade systems in the coffee patches in the blocks. It was assumed that if the coffee and forest patches that fell within the block were parts of larger units of comparable sizes, it would be more appropriate to compare their fauna. In contrast, a tiny patch of forest occurring in a region dominated by large coffee plantations was expected to be invaded to a great extent by fauna from the surrounding region. Hence, the contiguous area of the coffee and forest clusters represented within each block was estimated. Notes on the shape of the coffee and forest clusters (such as whether they were narrow and spread out or whether they were compact) were made using the land-use map.

Aerial photographs (Karnataka Forest Department/ NRSA 1:25,000 scale black and white photographs, dated 1996, Task no. 374) served as a useful proxy for the ground during the selection of sites. Aerial photographs were used both to confirm information on the blocks selected through the classified imagery and to supplement information derived from the less detailed land cover map. Differences in the density and composition of the vegetation, the structure of the canopy and contextual information such as roads in coffee plantations made it possible to distinguish the different coffee-shade systems and forests in aerial photographs seen under mirror stereoscopes. Blocks in which the aerial photographs confirmed the absence of any of the treatments, or where topography was seen to vary highly between treatments, were discarded. Tracings from the aerial photographs were made for the remaining blocks. The outlines of the treatments and surrounding land-use and contextual information (such as roads, ridge lines and water-bodies) were marked on the tracings. The area of the outlined treatments was calculated using a graph sheet under the tracing. Blocks that had treatments of larger sizes were preferred, as edge effects were expected to be less dominant in them as compared to smaller blocks.

The blocks which were found likely to have all three treatments were prioritised for field evaluation. The prioritization was based on the similarity of aspect, elevation, slope, relative sizes of the treatments and the size of the block as a whole. A manageable number of these were shortlisted for field survey. A questionnaire was prepared to obtain information on the treatments in a block from coffee estate owners and managers.

Rough locations of the blocks were known from the toposheets and from information obtained at the Koppa taluk office and the Koppa forest department. The approximate locations of the treatments were determined by showing the topographic sheets, hard copies of the land-use map and tracings from the aerial photographs to locals at the coffee estates and to officials from the forest department. GPS readings were taken to check the exact location of the sites visited. The coffee estate owners were requested to help identify the treatment marked on the land cover map. Some coffee estate owners and managers were interviewed to obtain information specific to the marked treatments and to the adjacent forest in the block. The suitability of the blocks was assessed based on the presence of all three treatments, quality of the control forest and comparability of the two coffee types in terms of their management history and current management practices. Four replicate blocks that had suitable representations of all three treatments were selected for detailed study of their litter fauna.

Of the forty possible blocks initially chosen using the land cover map for the study area, twenty six were found likely to have all three treatments when the aerial photographs were studied. Eighteen short-listed blocks were arrived at for field survey. Fourteen of these were actually visited in field; these included a total of fourteen forest fragments and twenty four coffee estates.

In five of the fourteen blocks visited, the forest was found unsuitable as a control, either due to heavy disturbance or due to illegal encroachments of coffee in the forest understorey. In one case, the forest was absent from the expected location. The polyculture shade coffee and silver-oak shade coffee treatments were absent in two each of the remaining blocks.

C. Sampling for litter arthropods

Pitfall traps (Southwood, 1978) were used to sample for the litter fauna during the early part of the dry season between the last week of December, 2000 and through the month of January, 2001. The traps were laid along two transects in each treatment. One of the transects was positioned along the contours and the other across the contours (**Fig 2**). Each transect was 90m long, with 7 points marked at 15m intervals. The pitfalls were placed at 5m perpendicular offsets from the points on the transects, alternating on either side. The transects and the offset points were marked with paint and ribbons. There were fourteen pitfall traps per treatment giving a total of 168 pitfall traps over the four blocks.

Transparent 500ml plastic jars of 8cm diameter and 11cm depth were used as pitfall traps. The traps were sunk flush with the ground into pits that were dug up. The ground along the edges of the pits, that was continous with the mouth of the traps, was smoothened and the litter around the trap resettled. This was to ensure comparability of the traps and to remove signs of disturbance around it.

60ml of 2% ethylene glycol was poured into each trap (Vennila, 1991). Traps along one transect in each treatment in a block were laid on the same day. The traps were left undisturbed for a week and all traps were removed on the eighth day after they were placed in position. The contents of the traps were filtered to remove the ethylene glycol solution. Larger chunks of soil, pebbles, and litter that had fallen into the trap were removed. The rest of the material, a mixture of the fauna caught and debris, was preserved in separate labelled containers in 70% Isopropyl alcohol. The traps were laid in two blocks within a week and removed the next week.

D. Measurement of litter parameters

Litter from a 0.5m X 0.5m quadrat was collected at a 5m offset from the transect. opposite to each of the offsets for the pitfall traps. The fresh weight of the litter was measured after which it was sealed in a plastic bag and labelled. The litter samples were later dried in an oven at 60° to 70° celsius for 2 days. The period of drying of the litter was standardised at the point where the asymptote of the dry litter weight was reached. The dry litter weight was the litter biomass per quadrat. The difference between the fresh and final dry litter weights gave the moisture content of the litter.

E. Measurement of microclimate

A maximum-minimum thermometer and two atmometers for measuring evaporative rates (Didham and Lawton, 1999) were placed simultaneously at a height of approximately 1.5 m in each of the treatments in a block and readings were noted after an equal length of time greater than 24 hours for each block. Initial and final readings of the water levels in the atmometer gave an estimate of the evaporative rates of water in each treatment. Dry-wet thermometer readings and soil temperature readings were taken one after the other at approximately 1.5 m above the ground in each of the treatments in a block. These were repeated 2 or 3 times in one day per block, depending on the distance between the treatments. Most readings were comparable only within a block and not across blocks.

F. Vegetation analysis

Vegetation was sampled at a randomly chosen point on each of the transects in a treatment. 10m X 10m plots were used to estimate the species richness and density of trees. Two 5m X 5m quadrats were laid within each larger plot along a random diagonal, to estimate shrub density and species richness. A 1m X 1m quadrat was laid at the corner of each shrub quadrat to estimate herb density and species richness. Densiometer readings to estimate the percentage of canopy cover were taken at the points where the pitfall traps were placed, and also at the corners and the centre of the 100 m^2 tree plots. A further description of the vegetation structure was attempted using a distribution of the NDVI values of pixels within the area of each treatment marked out on the land cover map. The NDVI value of a pixel is related to the amount of chlorophyllous material present in it, and is calculated as the ratio of the difference between the near infra-red and red bands to their sum. Thus, forests with a dense canopy cover would tend to have high NDVI values, whereas open areas would have low NDVI values. The distribution of these values for all the pixels within an area gives an idea of how homogeneous its vegetation is. Two indices, one for the amount of vegetation cover in the treatment and the other for the heterogeneity of the vegetation, were calculated for each treatment as follows:

$$\text{Cover index} = \frac{\text{Median NDVI value X Median percentage of canopy cover}}{\text{Maximum (canopy cover X median NDVI)}}$$

Heterogeneity index = Number of peaks in NDVI distribution X Variance of the NDVI value.

G. Sorting and identification of the pitfall samples

The preserved samples extracted from the pitfall traps were observed under a stereozoom binocular microscope. All organisms in it were sorted from the debris. Ants and beetles in the samples were kept separately for identification to the level of morphspecies (Oliver and Beattie, 1993). The rest of the organisms were preserved in 70% Isopropyl alcohol.

A reference collection of the beetle and ant morphospecies was made. Every time a new morphospecies was encountered in a sample, it was added to the reference collection. Noteand diagrams of each morphospecies were made. Beetles in the samples were compared with diagrams to narrow down to the possible reference species. An artificial key was constructed for the ants and each new ant specimen was run through this key to arrive at the morphospecies. A final decision on the morphospecies of the specimen was made after comparison with the reference collection. The different morphospecies and their abundances in each pitfall sample were noted.

H. Quantitative analyses

The software EstimateS 6 was used to compute randomized species accumulation curves, diversity indices (Shannon's H' and Simpson's D) and statistical estimators of true species richness (Chao 1 and Chao2) for each treatment (Anderson and Ashe, 2000; Magurran, 1988; Colwell, 1997). Jaccard, Morisita-Horn and Sorenson's similarity indices were also calculated between samples using this software.

The statistical software package S-Plus 2000 was used for statistical analyses. Scatterplots and box and whiskers plots were used to explore patterns in the data (Ellison, 1993). Formal tests were performed in those cases where a pattern was suspected. Cluster analyses were performed on the similarity matrices obtained between treatments (Pielou, 1984).

4. RESULTS

The following results were obtained using the procedures outlined in the chapter on methods:

A. The site selection process

Twelve coffee estate owners and managers were interviewed to assess the suitability of treatments within the blocks. The area of these estates varied between 5 and 1300 acres (2 to 526 ha), the smallest ones being individually owned. The average age of the estates was 46 $\pm$ 29 years (mean $\pm$ SD). All these estates had been under forests a 100 years ago, while only 5 estates (41%) were under forests twenty-five years ago. The age of the coffee plants in the estates varied between 5 and 60 years. All of the estates visited had occurrences of insect pests, but none to a major degree in the recent past. In 75% of the estates, weeding was done twice a year. Silver oak was used as the commonest tree to fill gaps formed in 11 of the 12 estates. The amount of shade was continuously regulated in 75% of the estates. Only 25% of the coffee estates used pesticides and 33% weedicides as they were perceived to be too expensive. All estates used chemical fertilizers (NPK). Four of the interviewed people said they preferred coffee grown under silver oak shade, three preferred polyculture-shade while the rest indicated no preference. Reasons quoted for the preference of silver-oak shade were: 1.It was considered to be more economical than maintaining a polyculture shade, 2. Silver oak shade was found easier to regulate, 3. It was considered not to compete with the coffee plants and 4. It was considered aesthetic for its uniformity.

Based on the field visits and the responses to the questionnaires, 3 blocks in the Koppa taluk and one block in the Narasimharajapura taluk were finalised for the study.

Detailed descriptions of the four blocks and the treatments in them are given in **Tables 1, 2** and **3**. The following is a brief description of the blocks.

1. ***Dvaramakki block*** : This the northern most of the four blocks, lying in the N.R. Pura taluk. **(Fig 3).** The forest in this block falls within the Mallandurgudda State Forest. The forest has been subject to encroachments from coffee estates around. Poaching and removal of NTFP are reported to occur regularly within it. The vegetation here is drier than in the other blocks. Fires occur regularly during the dry season. The polyculture-shade coffee patch in this block was forest given in exchange for coffee-lands submerged after the construction of the Bhadravati dam. The monoculture shade coffee treatment was created after the clear-felling of 10 ha of forest land in 1981.

2. ***Kachikal block*** : This is the smallest of the blocks. **(Fig 4).** The forests in the Kachikal and Quardhittlow blocks are wetter than in the other two blocks. There are intensive pressures on the forest in this block. There is extensive poaching of its wildlife (pers. obs). The coffee treatments in this block are the oldest of the coffee patches studied, having been planted more than a hundred years ago. Both the polyculture and monoculture shade coffee treatments within this block were subject to similar management over a long period of time and are

TABLE 1: A GENERAL DESCRIPTION OF THE FOUR BLOCKS

Block ID	Location		Aspect	Elevation range (m)	Annual Rainfall range (in mm) 1991 - 2000
	Lat	Long			
Dvaramakki	13° 37'	75° 26'	East	700 to 900	1244 to 2540
Kachikal	13° 31'	75° 23'	West	800 to 900	2082 to 3657
Nirakattu	13° 23'	75° 20'	North-West	720 to 800	2534 to 3980*
Quardhittlow	13° 27'	75° 24'	West	820 to 1060	2311 to 3327

* - Rainfall range for Sringeri, from 1981-1990

Block ID	Soil Type	AWC	Homogeneous area (Ha) within block**		
			Forest	PC Coffee	SO Coffee
Dvaramakki	Deep, well drained, clayey	Medium	28	38	9
Kachikal	Deep, well drained, clayey	Medium	5	3	2
Nirakattu	Moderately deep, well-drained, gravelly	Low	6	14	13
Quardhittlow	Deep, well drained, clayey	Medium	35	30	33

** - Area of the marked treatment boundaries as shown in Fig 2 to Fig 5.

AWC = Available water content.

TABLE 2: TOPOGRAPHY OF THE 12 SITES

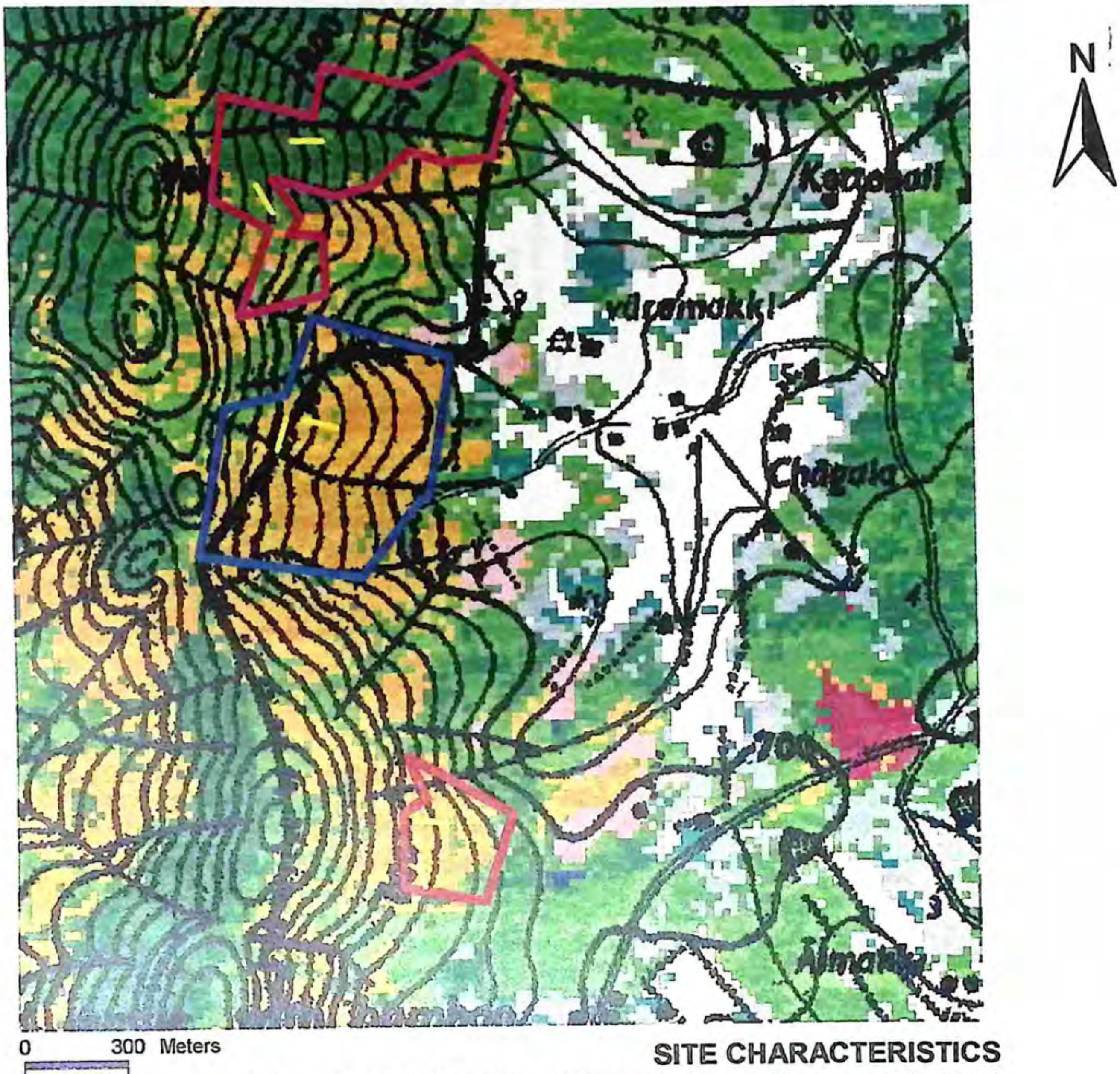
Block	Treatment	Elevation range of treatment	Elevation of transects (m)	Aspect facing	Slope*	Area of contiguous patch in ha. (from landcover map)
Dvaramakki	Forest	700 to 900	780 to 840	East	0.33	230
Dvaramakki	PC Coffee	700 to 840	760 to 820	East	0.30	207
Dvaramakki	SO Coffee	720 to 800	760 to 800	East	0.27	207
Kachikal	Forest	800 to 900	840 to 880	West	0.40	89
Kachikal	PC Coffee	800 to 880	840 to 860	West	0.30	9+72
Kachikal	SO Coffee	800 to 880	840 to 860	West	0.40	9+72
Nirakattu	Forest	760 to 800	780 to 800	North-West	0.10	167
Nirakattu	PC Coffee	720 to 800	740 to 780	North-North-West	0.25	20
Nirakattu	SO Coffee	720 to 800	760 to 780	North	0.15	20
Quardhittlow	Forest	880 to 1060	900 to 960	West	0.60	143
Quardhittlow	PC Coffee	820 to 960	840 to 860	West	0.40	153
Quardhittlow	SO Coffee	820 to 880	820 to 860	West	0.40	153

*- The slope within each treatment was measured on the topographic sheets as a ratio of change in elevation (measured between contours) per unit distance on the ground,

TABLE 3: DETAILS OF MANAGEMENT IN THE COFFEE PATCHES

Block	Ttmt	Ownership	Age of plantation	Coffee species	Age of coffee plants (years)	Frequency of weeding/ yr	Shade regulation	Pesticides used	Weedicides used	Fertilizers used
Dvaramakki	PC	Individual	40	Arabica	40 to 5	Twice	Yes	Gammaxane	No	NPK
Dvaramakki	SO	Partnership	17	Arabica	17	Twice	Yes	Lindane, Bavastane	No	NPK
Kachikal	PC	Family-owned	100	Robusta	50 to 60	Once	Yes	No	Glysal	NPK
Kachikal	SO	Family-owned	100	Robusta	50 to 60	Once	Yes	No	Glysal	NPK
Nirakattu	PC	Partnership	15	Robusta	15	Twice	Yes	No	No	NPK
Nirakattu	SO	Partnership	25	Robusta	25	Twice	Yes	No	Grammaxone	NPK
Quardhittlow	PC	Partnership	6	Arabica	6	Twice	Not yet	Ekalux	Grammaxone and roundup	NPK
Quardhittlow	SO	Partnership	80	Robusta	15	Twice	Yes	Ekalux	Grammaxone and roundup	NPK

Dvarmakki Site



SITE CHARACTERISTICS
Elevation: 750 - 900 m; Aspect: East; Slope: 0.29 - 0.33
Forest size - 81 ha (air photo)
Polyculture Shade Coffee size - 18 ha (air photo)
Monoculture Shade Coffee size - 7.8 (air photo)

Legend

Transects

Treatment Types

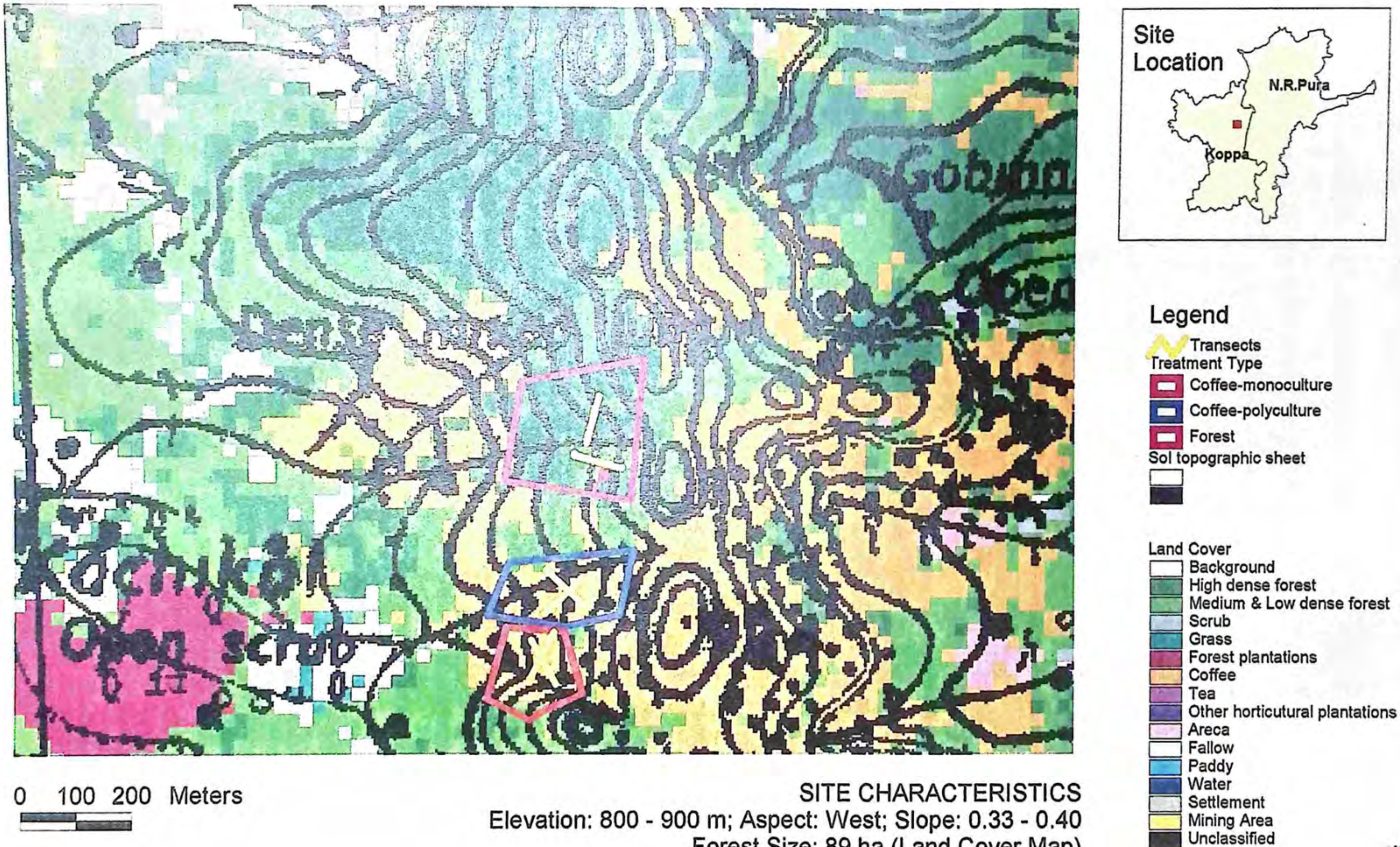
- Coffee-monoculture
- Coffee-polyculture
- Forest

SoI Topographic Sheet

Land Cover

- Background
- High dense forest
- Medium & Low dense forest
- Scrub
- Grass
- Forest plantations
- Coffee
- Tea
- Other horticutural plantations
- Areca
- Fallow
- Paddy
- Water
- Settlement
- Mining Area
- Unclassified

Kachikal Site



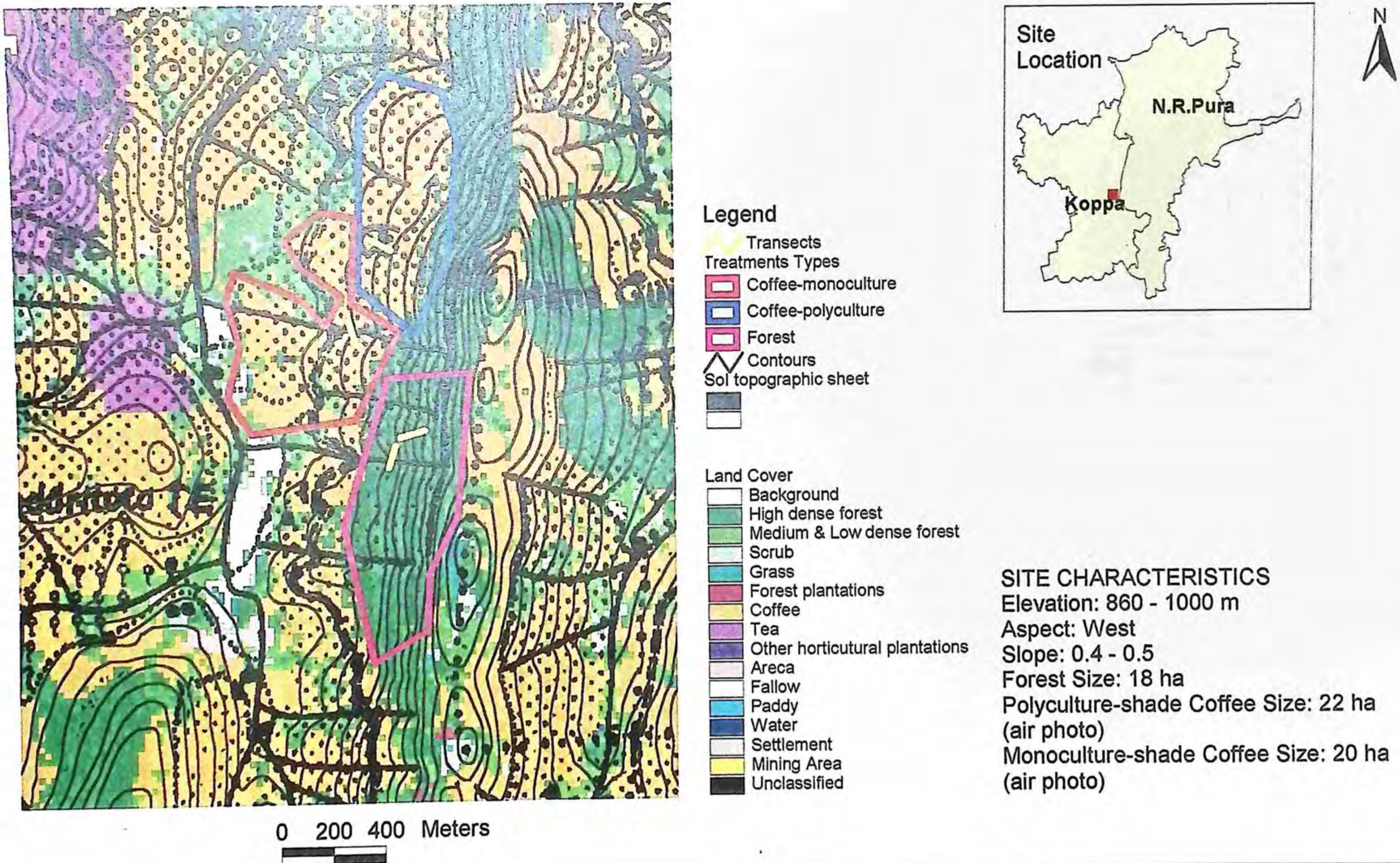
SITE CHARACTERISTICS
Elevation: 800 - 900 m; Aspect: West; Slope: 0.33 - 0.40
Forest Size: 89 ha (Land Cover Map)
Coffee-clump Size: 9+72 ha (Land Cover Map)

not distinctly separated. Naturally occurring shade trees were maintained to a better extent in the polyculture shade coffee, while there was a gradual replacement of the shade layer by silver oak in the monoculture shade treatment.

3. *Quardhittlow block* : It occurs further south of the Kachikal block. **(Fig 5)** The forest in this block is the largest homogeneous stretch of forest in the study. Firewood collection, cattle grazing, use of forest paths and poaching occurs here. The coffee patches are part of the extensive Mysore Plantation Co. Pvt Ltd., where large areas of coffee and tea are cultivated on an industrial scale. The monoculture shade coffee treatment in this block is much older than the polyculture shade treatment, its shade trees having gradually been replaced by silver oak. The coffee in this treatment was replanted fifteen years ago. The polyculture shade coffee treatment was formed by the clearing of undergrowth and smaller trees in a part contiguous with the present forest treatment seven years ago.

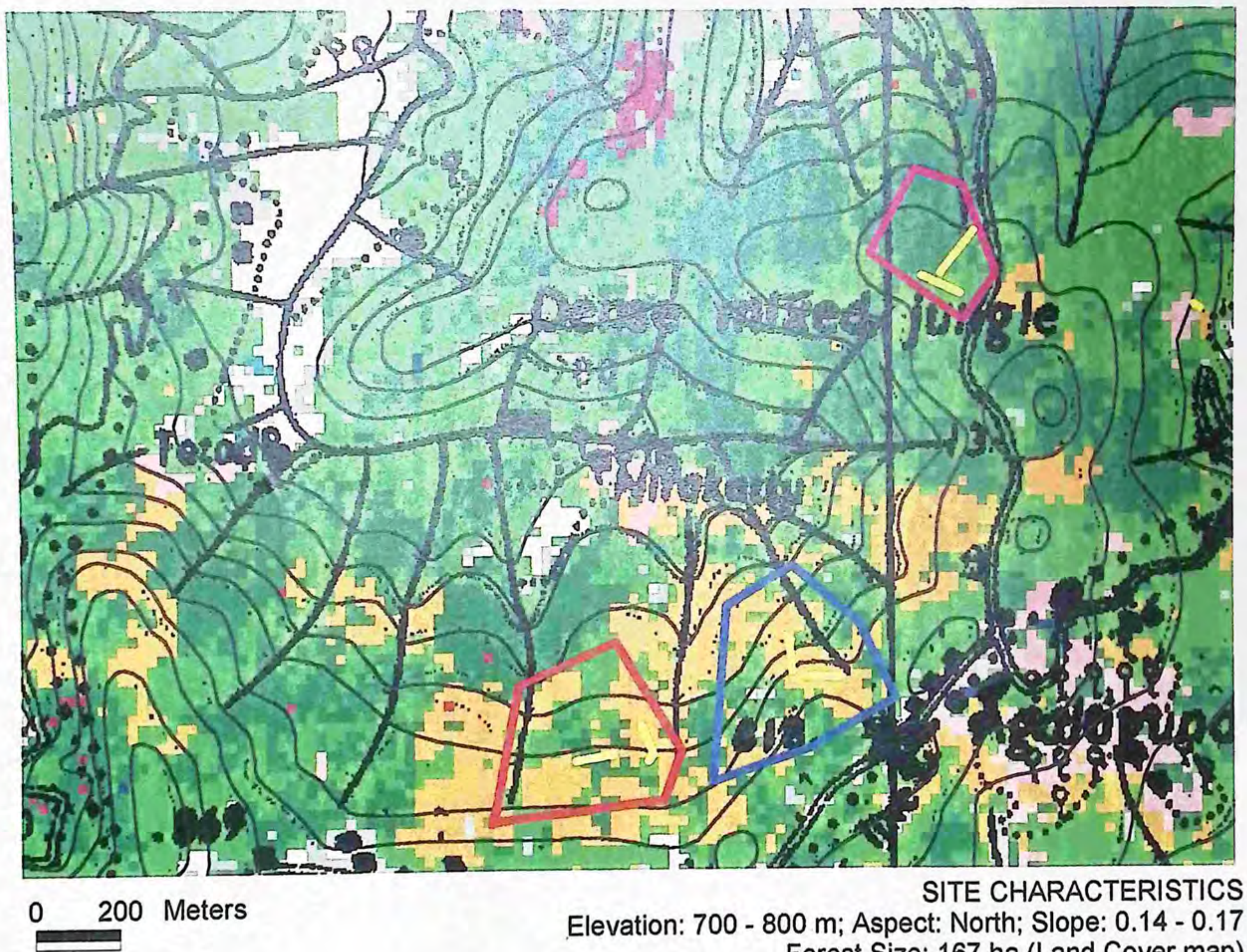
4. *Nirakattu block* : This is the Western-most of the four blocks **(Fig 6)**. The soil type occurring here is different from that in the other blocks, being drier and having a lower available water capacity. The block has a gentler slope than in the other sites. Lopping was noticed to occur here. The forest and the coffee in this block did not share a common boundary. The coffee patches were the smallest across the four blocks. The canopy in the coffee polyculture treatment resembled that of the Quardhittlow block. The definition of the coffee-monoculture treatment in this case was

Quardhittlow Site



SITE CHARACTERISTICS
Elevation: 860 - 1000 m
Aspect: West
Slope: 0.4 - 0.5
Forest Size: 18 ha
Polyculture-shade Coffee Size: 22 ha (air photo)
Monoculture-shade Coffee Size: 20 ha (air photo)

Nirakattu Site



SITE CHARACTERISTICS
Elevation: 700 - 800 m; Aspect: North; Slope: 0.14 - 0.17
Forest Size: 167 ha (Land Cover map)
Coffee clump Size: 20 ha (Land Cover map)

subjective, and the patch chosen might better be described as coffee grown under silver-oak dominated mixed shade. This treatment had a denser canopy than the polyculture coffee treatment within the block.

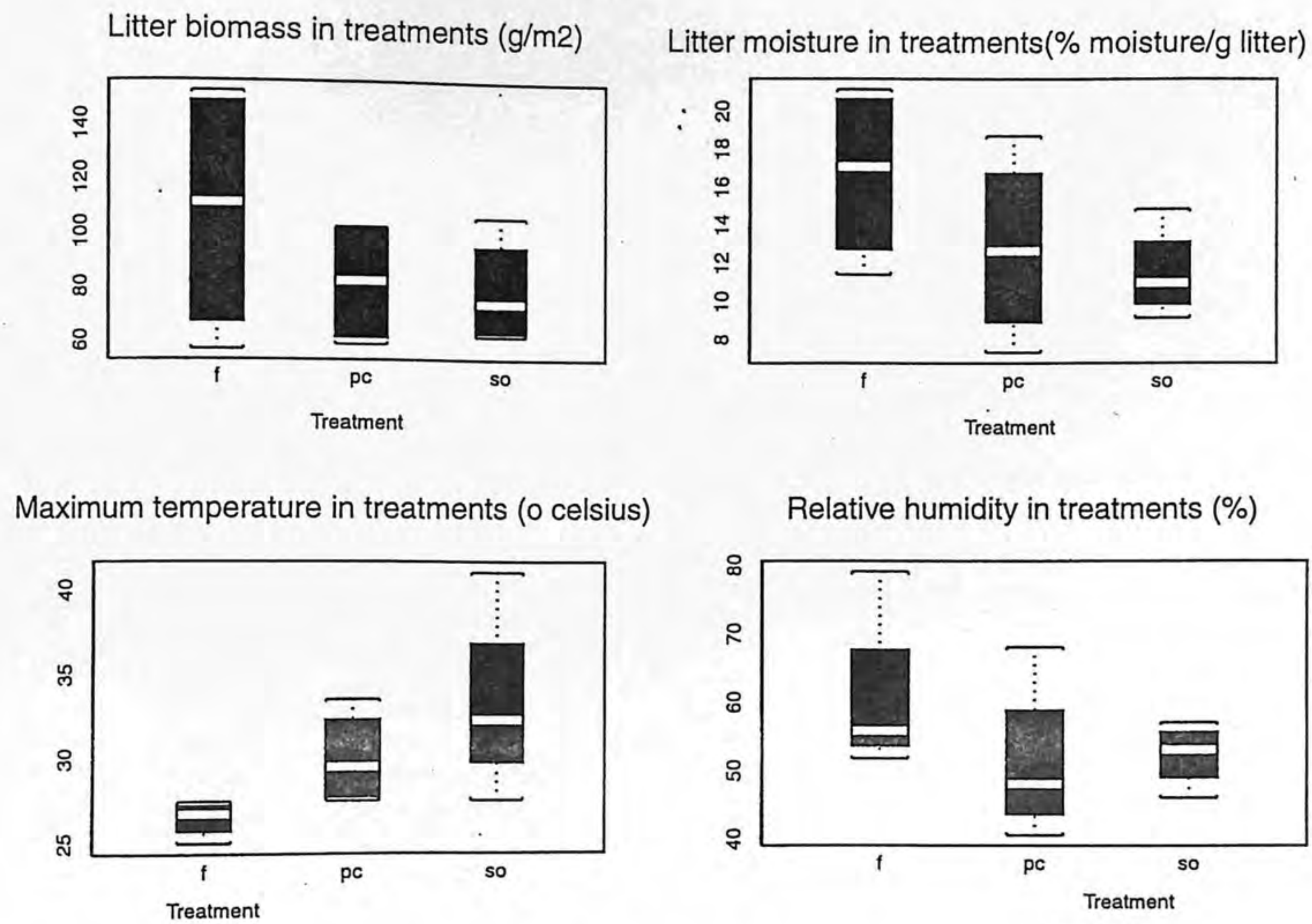
B. The pitfall sampling method

There were very few losses of pitfall traps. Three of the 168 pitfall traps were found to be entirely dry, three had been pulled out by humans, while two had been disturbed by animal movement. Three of these traps, which had no specimens in them, were discarded from analysis. In addition to insects, a large number of a species of skink and a few shrews were captured in the traps. Live skinks were released, while all dead forms were preserved in 70% alcohol.

C. Differences in microhabitat structure, microclimate and vegetation

Box and whiskers plots showed discernible trends in the amounts of litter biomass and litter miosture between treatments **(Fig 7).** The average litter depth for forests was 6.0 ± 0.2 cm (mean ±SD), for coffee with polyculture shade, 5.7 ± 0.6 cm and for coffee with monoculture shade, 5.8 ± 0.3. cm. The forests had higher values for litter biomass (107.5 ± 40.5 gm^{-2}), than was seen in the polyculture shade (81.2 ± 38.6 g) or monoculture shade coffee systems (78.5 ± 28.1), but with overlapping ranges. A similar trend was seen in the moisture content of the three treatments in the same order (16.7 ± 5.7%, 12.8 ± 9.9% and 11.4 ± 5.4%).

The forests were in general moister and cooler with lower variability in temperature than the coffee systems, with especially the monoculture systems having a drastically dry and variable climate **(Fig 7 and Table 4).**



f = Forest
pc = Polyculture shade coffee
so = monoculture shade coffee

Fig 7: Box and whiskers plots showing median and 50% range for 4 habitat variables. Title shows y axis.

TABLE 4: AVERAGE VALUES FOR MICROCLIMATIC VARIABLES MEASURED FROM EACH OF THE SITES.

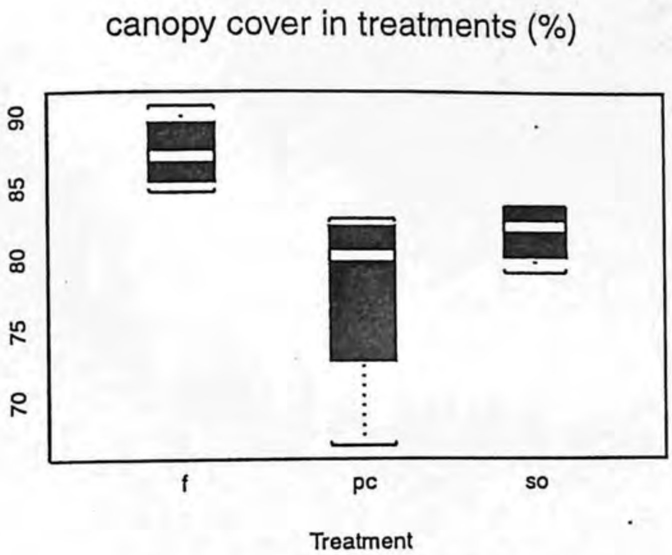
Block	Treatment	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity	Soil temp (°C)
Dvaramakki	Forest	27	17.5	56	19.5
Dvaramakki	Coffee-polyculture	27.5	17	46.7	20
Dvaramakki	Silver-oak coffee	27.5	17	57	19.83
Kachikal	Forest	26.5	19	51.7	18.5
Kachikal	Coffee-polyculture	31	16	49.3	19
Kachikal	Silver-oak coffee	32	17.5	52	19.33
Nirakattu	Forest	27.5	19	55.5	19.5
Nirakattu	Coffee-polyculture	33.5	17	40.5	19.25
Nirakattu	Silver-oak coffee	32.5	17	46	19
Quardhittlow	Forest	25	18	79	18.33
Quardhittlow	Coffee-polyculture	28	20	68	18.67
Quardhittlow	Silver-oak coffee	41	17	54	25.5

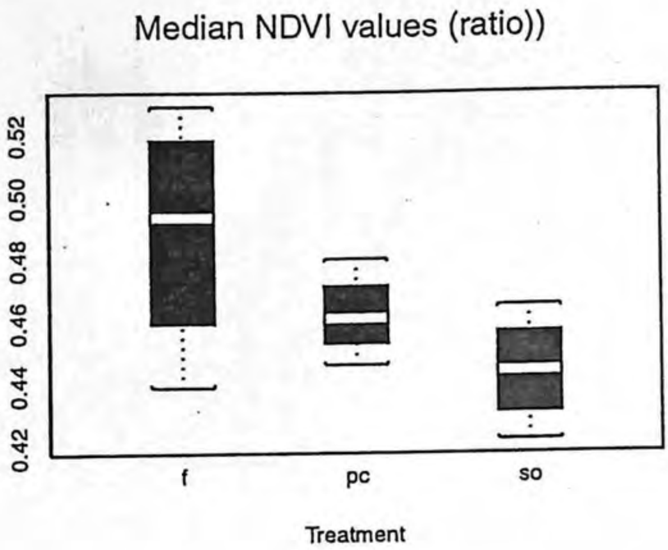
As could be expected, the forests had the highest values for canopy cover, median NDVI values and the cover index. **(Fig 8 and Table 5)**. However, there was high variability in the distribution of the NDVI values of its constituent pixels and this showed up in NDVI density distribution plots **(Fig 9)**. Two of the forests had a bimodal distribution of NDVI values. This represents two distinct sets of pixels, one having higher NDVI values and the other, lower NDVI values. The sets imply regions of high canopy density and areas that were opened up, probably due to human disturbance such as fire, timber removal and fuel wood collection.

Forests had much higher species richness in both the tree and shrub layers than the coffee systems, as could be expected. The values of species richness and densities of the shrub and herb layers are given in **Table 5**. While polyculture shade coffee has higher species richness of trees, it had a lower numerical density than the silver oak shade coffee.

D. Samples from the pitfall traps

A total of 729 individuals of beetles and 5397 individuals of ants were sorted out from the pitfall trap contents. Totals of 112 morphospecies of beetles and 123 morphospecies of ants were identified. When the ants were identified to species levels, they were seen to belong to 58 species (Appendix A). Morphospecies values for the ants were used to compute diversity and similarity indices. This was based on the assumption of equal levels of splitting of species in each of the treatments. This process needs to be repeated using the values obtained using actual species. Beetles in general have much lower levels of polymorphism and the species are distinct.





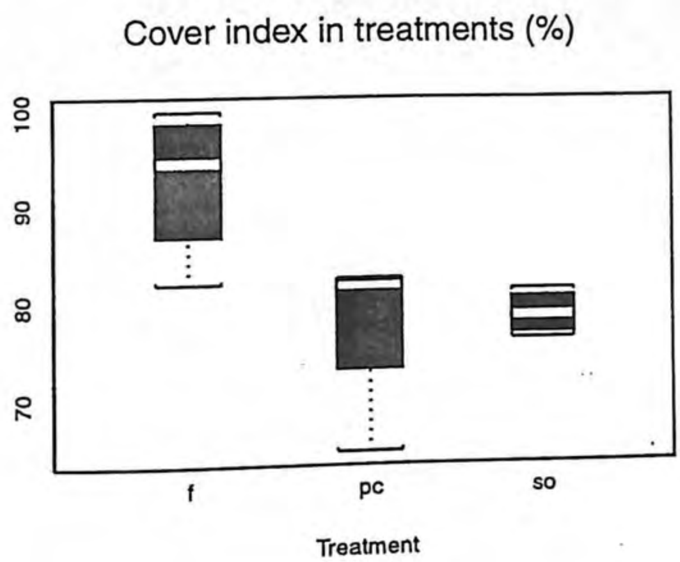


Fig 8: Box and whiskers plots showing vegetation attributes of the sites. Median and 50% range are represented by the central line and the area within the box. Y axis represented on title

f = Forest
pc = Polyculture shade coffee
mc = Monoculture shade coffee

TABLE 5: VEGETATION PARAMETERS OBTAINED FROM THE TREATMENTS.

Block	Treatment	Median NDVI	Cover index	Rank from Heterogeneity Index	Tree species richness (No. of spp/100m^2)	Tree density No. of trees per 100 m^2	Shrub species richness No of spp/25m^2	Shrub density No of shrubs in 25m^2
Dvaramakki	Forest	0.48	92.08	3	8	12	18.5	109
Dvaramakki	Coffee PC	0.46	82.8	4	4.5	6	11	29.75
Dvaramakki	Coffee SO	0.44	77.65	11	2.5	19.5	1.5	3.75
Kachikal	Forest	0.507	100	10	12.5	17	27.25	69
Kachikal	Coffee PC	0.462	81.98	8	1.5	14	7	21
Kachikal	Coffee SO	0.448	81.53	2	2.5	17.5	4.5	7.75
Nirakattu	Forest	0.439	82.22	12	8	10	14.25	98
Nirakattu	Coffee PC	0.446	64.88	9	5	5	5.5	14
Nirakattu	Coffee SO	0.465	79.78	6	3	8.5	11.5	39.75
Quardhittlow	Forest	0.529	97.39	7	10.5	19	16	103.5
Quardhittlow	Coffee PC	0.48	82.17	1	1.5	8	7.5	26.5
Quardhittlow	Coffee SO	0.422	76.38	5	2	4.5	4.75	34.5

Coffee PC - Coffee with polyculture shade
Coffee SO - Coffee with silver oak shade

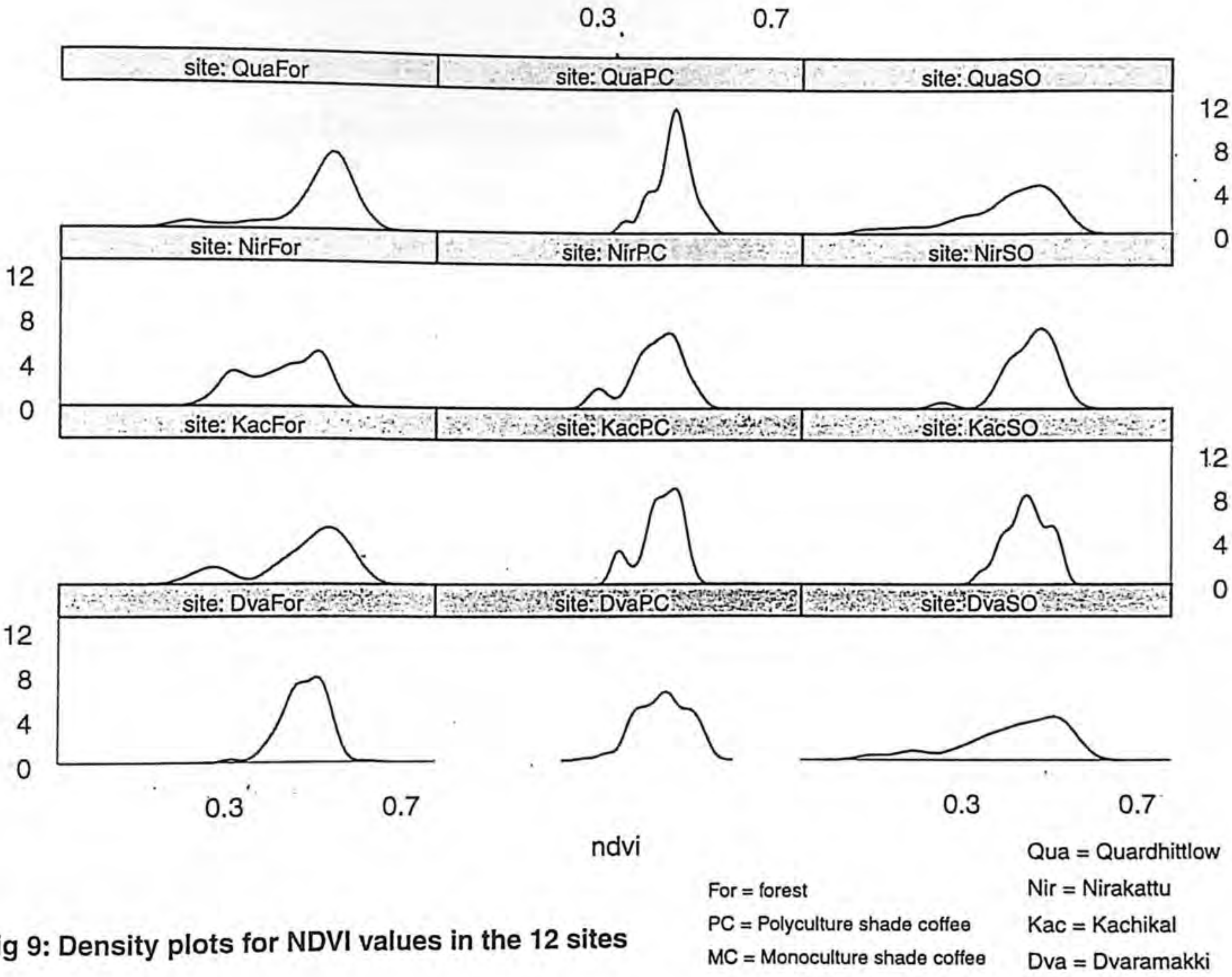


Fig 9: Density plots for NDVI values in the 12 sites

Although no systematic attempt was made to identify beetles to any level lower than morphospecies, the samples were generally seen to be dominated by families known to be associated with the litter (Appendix B), either as decomposers or as predators (Fowler, 1912).

Diversity indices based on morphospecies

Beetles : There was a dramatic decline in species richness and abundance in the gradient from forest to polyculture shade coffee to silver-oak shade coffee **(Fig 10).** Kruskal -Wallis analyses (H=7.14, df=2,p = 0.02) and analysis based on ANOVA confirmed the difference in species richness between treatments (Forest=30.5 ± 2.7, Coffee polyculture shade=21.5 ± 2.7 and Monoculture shade coffee=15.2 ± 2.7)(mean ± pooled SE). The abundance, too, was proved to be higher in the forests, followed by the polyculture shade coffee. (Kruskal-Wallis H=6.5, df=2, p=0.03). Shannon's and Simpson's diversity indices were also seen to show similar trends.

When randomised species accumulation curves were constructed for the beetles **(Fig 11)**, the curves were observed to flatten out in only 2 coffee treatments out of all 12. Again, the curves had the highest values for forests and the lowest values for monoculture-shade coffee, with the polyculture-shade coffee falling intermediate.

Non-parametric estimators of true diversity based on the number of rare species present in the samples (Chao 1 and Chao2 from Anderson and Ashe, 2000), showed a pattern similar to that for the species richness, but with less distinct differences. The average predicted value for Chao 1 in the forest, coffee polyculture shade and coffee

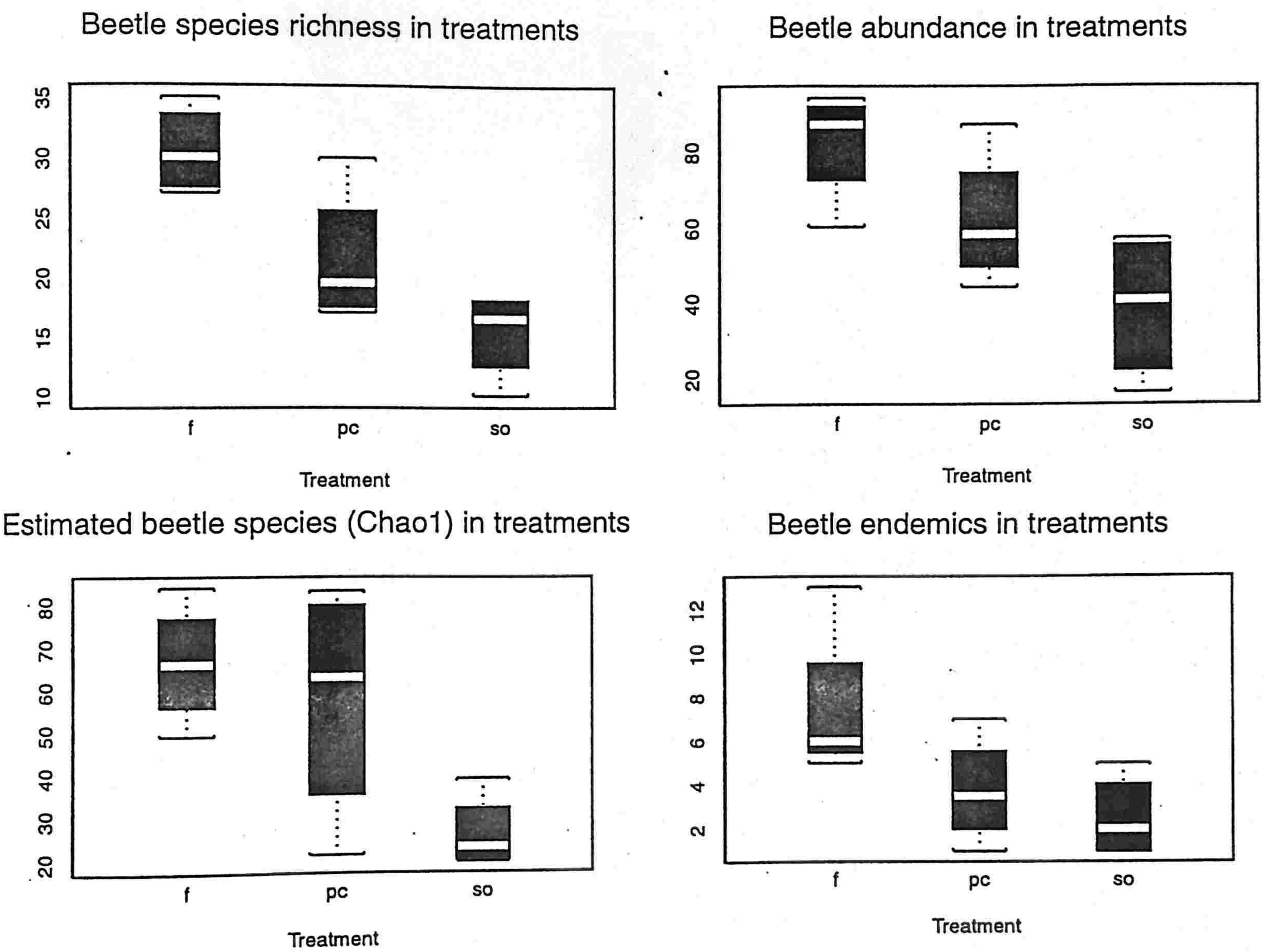
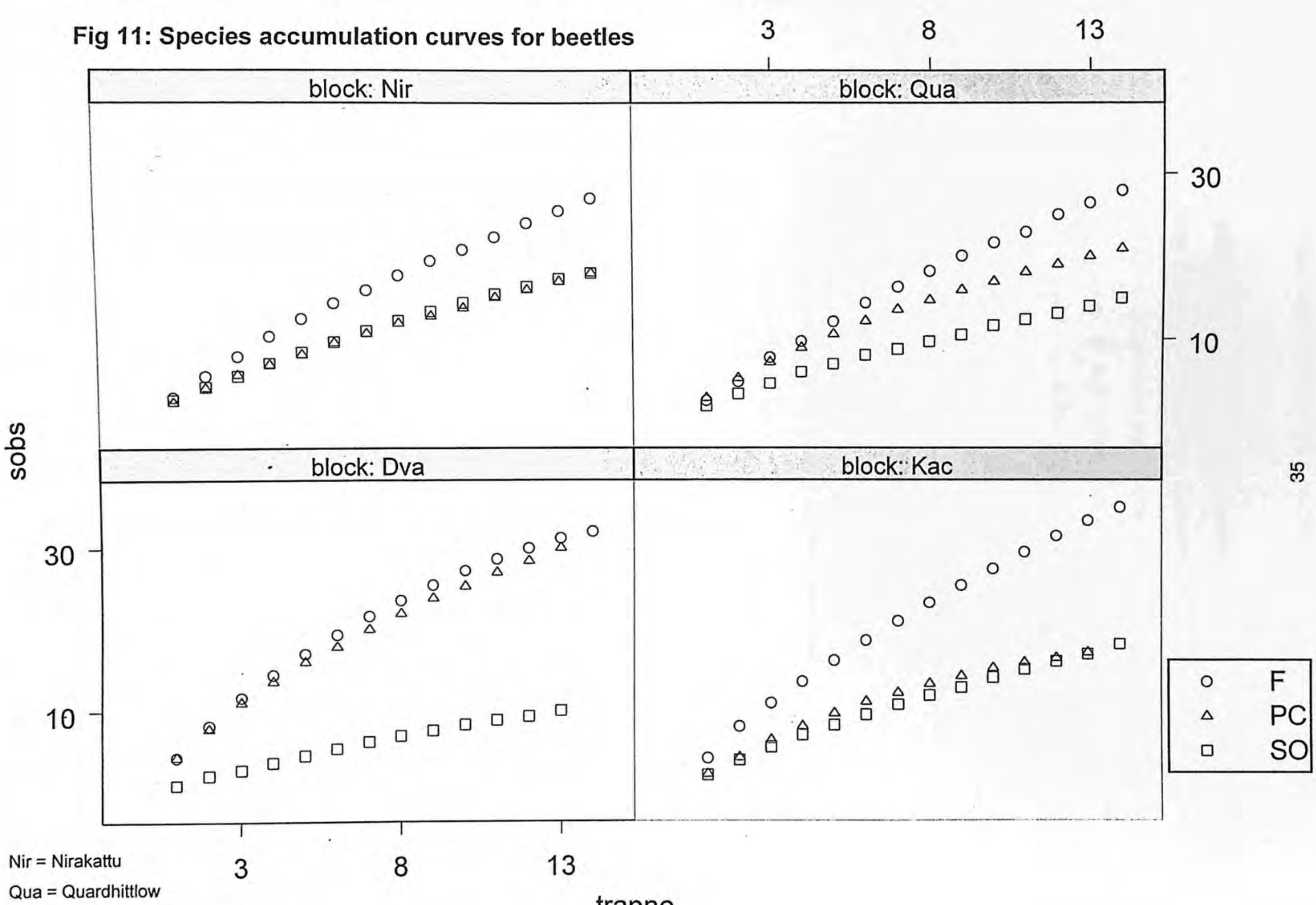


Fig 10: Box and whiskers plots for beetle species richness, abundance, number of endemics and Chao 1 estimates

f = Forest
pc = polyculture shade coffee
so = Silver oak shade coffee

Fig 11: Species accumulation curves for beetles



Nir = Nirakattu

Qua = Quardhittlow

Dva = Dvaramakki

Kac = Kachikal

monoculture shade treatments were 66.4 ± 29.0, 57.7 ± 48.0 and 26.3 ± 13.2 respectively.

Ants: The three treatments were equally species rich in the ant morphospecies (Kruskal-Wallis H=0.1277, df=2, p=0.9). However, there was a large jump in the abundance of ants in monoculture shade coffee system with forests being the least abundant (**Fig 12**, H=5.34, df=2, p=0.07). This resulted in a decrease in Shannon's diversity from the forest to the coffee systems (Fig 12).

The species abundance curves constructed for ants showed no clear patterns and the values of estimated ant morphospecies richness based on Jackknife richness estimators were equal for the treatments (Colwell, 1997)

F. Similarity in community composition between treatments

Jaccard and Morisita-Horn sample similarity indices were calculated for the treatments (Magurran, 1988).

Beetles : The cluster analyses of distances between treatments based on the Jaccard **(Fig 13)** and the Morisita-Horn similarity indices gave rise to different clusters of sites. All forest sites clustered in one major branch, while most silver-oak shaded coffee sites clustered on another branch. The polyculture-shade coffee systems tended to cluster with the forest sites.

Ants : The cluster analysis of distances between the sites based on the Jaccard index pooled three of the forest sites in one group, while all the other sites were pooled into another set **(Fig 14).** All the treatments in the Nirakattu block were pooled into one group, reflecting greater similarity in community composition within the block than with similar treatments in other blocks. Cluster analysis based on the Morisita-Horn index pooled all forests and 2 of the polyculture shade coffee treatments together, while most of the coffee silver-oak shade treatments occurred in another cluster.

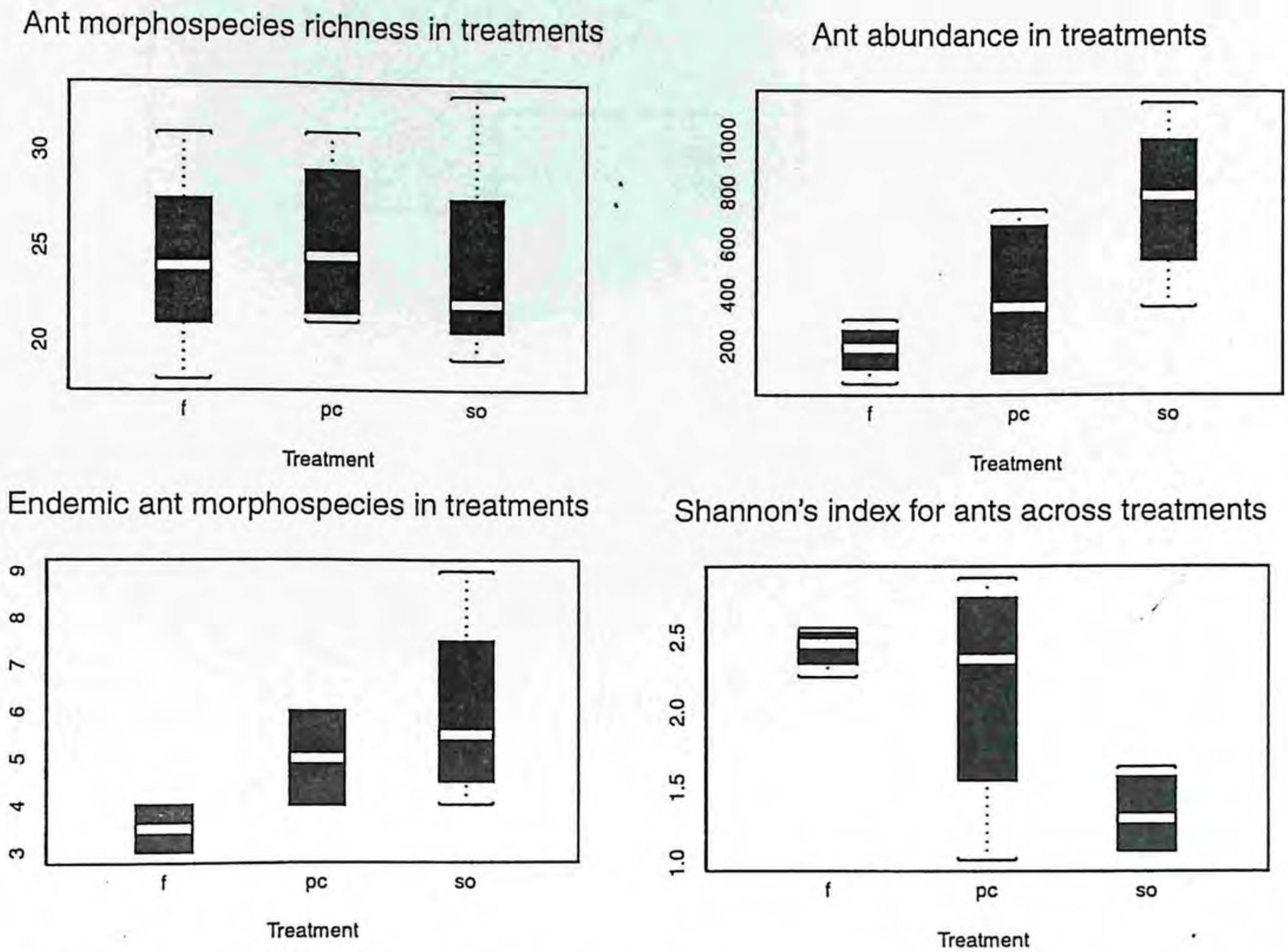


Fig 12: Box and whiskers plots showing ants morphospecies richness, ant abundance, endemic morphospecies and Shannon's diversity across treatments

f = Forest
pc = Polyculture shade coffee
so = silver oak shade coffee

Fig 13 Clusters of sites based on Jaccards distances between Beetle communities

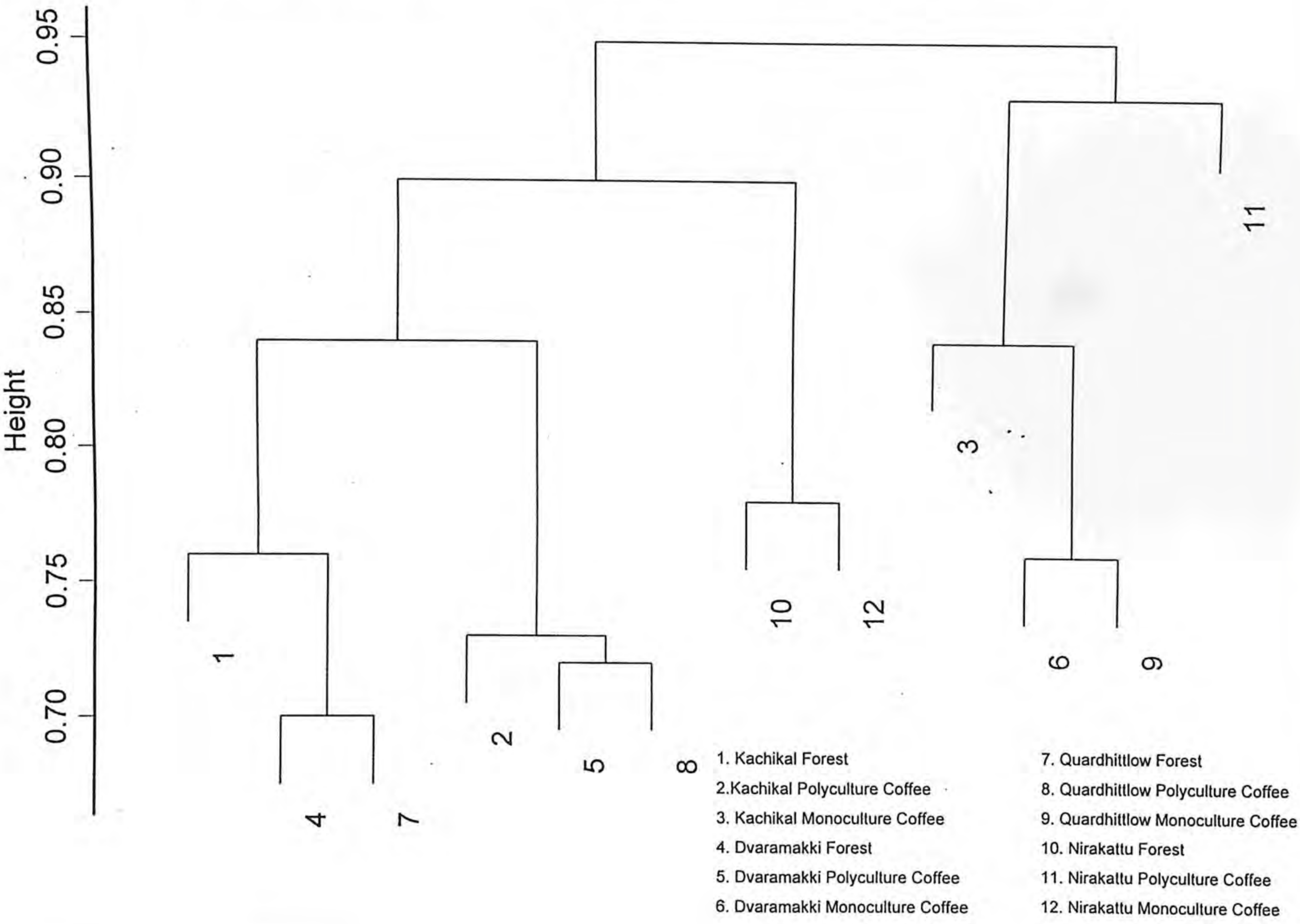
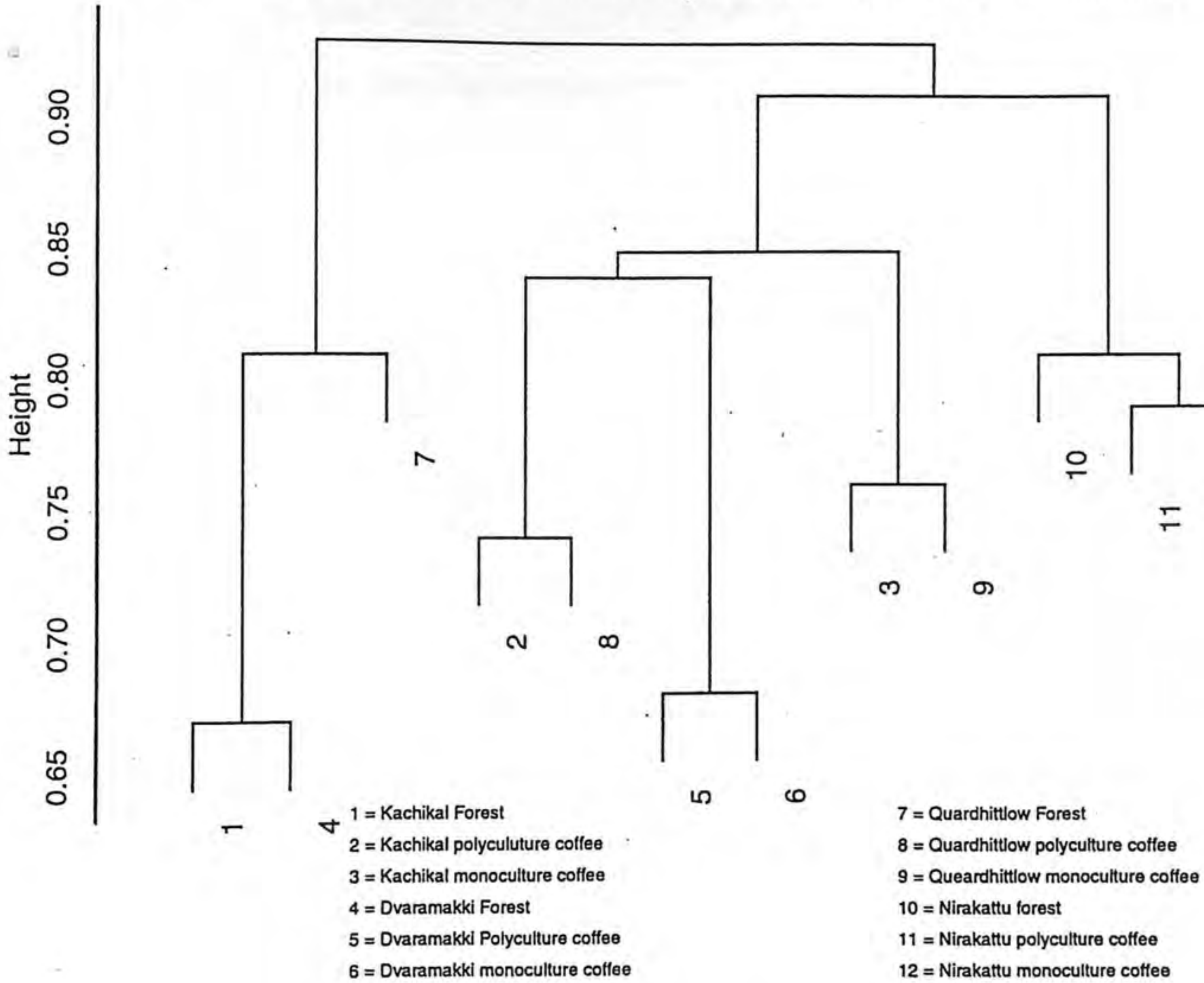


Fig 14 Site clusters based on Jaccard distances between ant communities



5. Discussion

Out of the 572 square kilometers of land in Koppa taluk, the largest patch of forest that is still fairly intact is approximately between five to seven square kilometers (M. Ramanathan, pers. comm.). This patch has survived probably because it is outside the main coffee belt. Sampling for litter fauna in some very small and disturbed forest fragments in this region (ranging from 5 to 35 Ha) during a dry season revealed a high diversity in beetle and ant morphospecies. One can thus conjecture the kind of diversity that would have existed in continuous forests in this region.

A. The site selection process

It was seen that a combination of methods, incorporating information from satellite imagery, aerial photographs, toposheets and some prior information of the study area was invaluable in the search for suitable study sites. However, field visits and interaction with the local people was found to be an equally important criterion in distinguishing fine details, such as the differences between different coffee shade systems.

Although a treatment size of 50 ha was aimed at, the actual range of size obtained for treatments was 2 to 38 ha. This was due to the extensive fragmentation and intermingling of different land cover categories occurring in this region.

An important issue was the continuous gradient in shade tree species richness found between the entirely polyculture or monoculture shade extremes. This phenomenon makes the classification of the intermediate systems subjective. The practice of plantation of silver oak in greater than 90% of the estates interviewed indicates that all sites are undergoing further homogenization. In the Nirakattu block, the chosen silver oak shade coffee treatment could more properly be defined as mixed shade coffee dominated by silver oak. Such an intermediate form is the result of the process of homogenization – polyculture shade systems tend towards lower diversity in shade trees with age. There is thus some subjectivity in the classification of treatments for this study.

An important piece of information obtained from the questionnaire was the fact that pesticides and weedicides were not applied as universally as chemical fertilizers in the estates (Table 3), due to the expense involved. Therefore, coffee systems in this region may be friendlier to insects than in other places.

B. Sampling method

The recovery rate of 95% for the pitfalls prove the practicability of this widely used and simple method of sampling.

C. Microhabitat conditions

Differences in microclimate, litter structure and leafy biomass were noticed between the three treatments (Fig 7). The actual existence of more extreme conditions in the monoculture shade coffee treatment as compared to either the polyculture shade coffee or the forests is very likely to be the predominant factor in determining the community it supports. The differences in microhabitat between the coffee systems is important in the context of their being indistinguishable on remotely sensed images.

This demonstrates the limitations of remote sensing based cover classification in predicting the biodiversity attributes of different land cover/ land use types.

D. Diversity indices

The question about whether certain coffee systems support greater diversity than others is clearly answered through this study. Although there was variability within the coffee-polyculture shade and the coffee monoculture shade systems, there was a fairly consistent difference between the two treatments in terms of the diversity of the beetles and ants they supported (Fig 10 to Fig 12).

The difference in the number of endemics is again variable for ants and beetles. The reason for the decline in beetle endemics from forests through polyculture shade coffee to silver oak dominated coffee is very likely due to the immediate response of many delicate, litter dwelling beetles to the inhospitable conditions in coffee estates. However, the increase in the number of endemic morphospecies of ants from forests to coffee systems with highest values for the silver oak shade system, is intriguing. A confirmation of this pattern based on information of actual ant species would be necessary to disprove an increase in the different polymorphs of a species being caught with their increasing abundance.

E. Relation between microhabitat and diversity

Scatterplots between each of the microhabitat variables and the morphospecies richness and abundance of ants and beetles failed to reveal clear patterns. This could have been either due to confounding block effects or due to species responding to an interaction between the habitat factors rather than to any single component. However, a surprisingly strong positive relationship was observed between median NDVI values for a treatment and the species richness of its beetles (R = 0.64, p = 0.02). Correspondingly, a negative relation was observed between the median NDVI value and the abundance of ants reported for the sites (R = 0.73, p = 0.007). The NDVI values for a treatment thus appear to captûre the variation in the microhabitat that probably causes differences in faunal community structure.

F. Similarity in community composition

The clusters formed on the basis of the incidence of beetle morphospecies in the treatments indicate that beetles perceive forests and monoculture shade coffee systems to be entirely different. They find the polyculture coffee sites more similar to either the forest or the monoculture shade coffee treatments, probably based on the site specific characters. The Jaccard index is calculated based on the number of species shared between two sites and the number of species that are found only in one of the two sites. This index captures a different component of community composition as compared to the Morisita-Horn similarity index. The Morisita-Horn index takes into account the abundances of species while arriving at a similarity estimation for two sites. It is strongly influenced by the presence of a few commonly shared, high abundance species. Such species were observed to occur both in the beetle and ant communities. This probably accounted for the different clusters of sites formed on the basis of these two similarity indices for the beetle communities.

Divergent patterns of clustering were noted for the ant communities also. In terms of species incidence, ant communities in forests were distinct from those in all the coffee estates. The combining of all treatments in the Nirakattu block into one group was an interesting observation, the only such pooling seen to occur. The soil type in Nirakattu is different in its being more gravelly as compared to the soil in all the other blocks and probably inflences the activity patterns of the ants found there (Paton et al., 1995). This could be a reason for the distinct ant community composition noticed here. Even more interesting is the possibility that the difference in soil type does not seem to matter too much to the beetles. Clusters of the ant communities based on the Morista-Horn index pooled the forest and the coffee polyculture shade systems together and distinct from the monoculture shade systems. This shows the influence of a few highly dominant species in the coffee monoculture shade systems on the clustering.

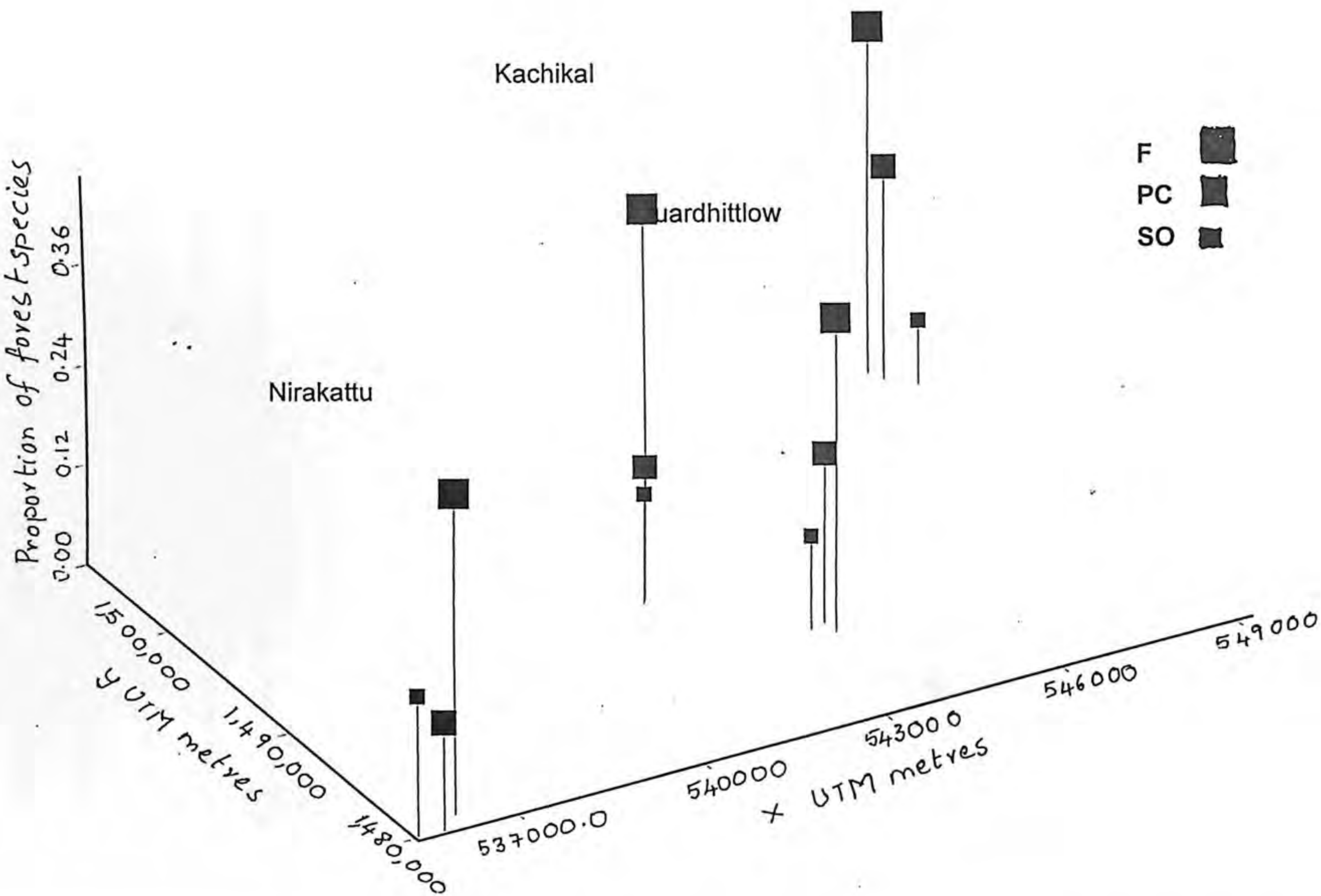
The contrasting responses shown by the two taxa considered in this study demonstrate the shortcomings of "indicator taxa" that are chosen to measure impacts of tropical forest modification (Lawton et al., 1998). The obvious reason behind the differing responses of beetles and ants lies in their differing ecological requirements. Although both these taxa were sampled from the litter stratum, it is not implied that these groups are restricted to this layer. Beetles are often highly specialized on narrow ranges of resources; thus the beetles caught in this study might actually be specialists of the litter layer. Most ant species, however, utilise a wide range of food resources and survive microhabitat alterations better due their colonial nature.

A rough reconstruction of the landscape as it was likely to have been a few hundred years ago would probably show forests extending continuously between the four blocks chosen for this study. The sum of all the beetle morphospecies found in the four forests studied can be used to represent the forest pool of species that would have occurred across the entire landscape. **Fig 15** represents the proportion of this "Forest species pool" that was seen to occur in each of the treatments. The highest proportion of the forest pool represented in a treatment was only 46%, and this was in a forest site. Pairwise differences between the proportions of the forest pool represented at each forest site would help in estimating a minimum proportion estimate of the beta diversity across this landscape.

The average change in the proportion of the total pool between forest sites was seen to be approximately 6 %. The average distance between the four forest sites was 14.6 km. One beetle morphospecies is thus estimated to be replaced locally over a distance of 3 km. An average similarity index for forests (calculated from the pairwise Jaccard similarities for forests) gave a similarity index of 0.22 for two forests separated by approximately 15 km.

This study represents an attempt to use spatial databases in the design of an observational ecological experiment. The approach followed in this study was to substitute space for time (Pickett, 1989), due to the inability to follow the changes occurring in a forested region with its conversion to a coffee system. Spatially distinct systems are selected to represent temporal changes of ecosystem evolution. Due to the large number of assumptions involved in this process, site selection is a critical step determining the reasonability of the substitution. The initial expenditure of time in study design helped improve the confidence with which results could be interpreted.

Fig. 15. A representation of the proportions of the forest beetle species pool occurring at each site. The x and y axes indicate location of the site. The height on the z axis shows the proportion at each site.



Future directions

This study was restricted to morphospecies level identifications of beetles and ants. Insights into the particular processes that are affected within these communities would arise with comparisons between ecological needs of the families and genera of organisms constituting these communities. It is necessary to stress the point that no data obtained for research through the destructive collection of organisms be wasted. Thus, the taxa other than the ants and beetles in pitfall trap samples obtained for the study should be used to validate or question patterns observed in the beetles and ants.. It would also be interesting to make inferences on the influence that landscape position has had on the communities occurring in each of the sites using the land cover map.

One feature of this study that was both an advantage and a limitation, was its being restricted to the dry season. The advantage was in obtaining a snapshot of the community during a resource crunch, wet litter being the limiting resource. Those organisms that survive such a crunch are probably the ones that would repopulate the habitat in the wet season. A study in the wetter period of the year could likely demonstrate the breakdown in differences in microhabitat between treatments and thus the relative importance of the treatment as regions for exploitation by the forest fauna.

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APPENDIX A

SPECIES LIST OF ANTS OBTAINED FROM PITFALL SAMPLES

Aenictus spp 1
Anoplolepis longipes
Campanotus spp 1
Camponotus (near angusticollis)
Camponotus compressus
Camponotus rufiglaucus
Cardiocondyla spp?
Cardiocondyla spp 1
Cardiocondyla spp 2
Cerapachys spp
Crematogaster spp 1
Crematogaster spp 2
Dolichodorus spp 1
Dolichodorus spp 2
Dolichodorus spp 3
Leptogenys chinensis
Leptogenys dentilobus
Leptogenys diminuta gp
Leptogenys lutepes gp
Meranoplus bicolor
Monomorium floricum
Monomorium minutum (Mayer)
Monomorium spp 1
Monomorium spp 2
Monomorium spp 3
Odontomachus semilimus
Odontoponera transversa
Oecophylla smaragdina
Oligomyrmex spp
Pachycondyla lutepes gp
Pachycondyla tesirinoda
Paratrechina spp
Pheidole spathifera
Pheidole spp 1
Pheidole spp 2
Pheidole spp 3
Pheidole spp 4
Pheidolgeton diversus
Plagiolepis spp 1
Plagiolepis spp 2
Polyrachis excersita
Polyrachis illudata
Polyrachis simplex
Ponera spp
Prenolepis spp
Recurvidris recurvispinosa (Forel)
Strumigenys spp 1
Strumigenys spp 2
Tapinoma melanocephalum
Tetramorium spp 1
Tetramorium spp 2
Tetramorium spp 3
Tetramorium spp 4
Tetramorium spp 5
Tetramorium spp 6
Tetraponera aitkini
Tetraponera spp 1
Triglophothrix valshi

Reference: Bolton, 1995.

APPENDIX B

Colepteran families identified so far from the pitfall samples.

Family	Number of morphospecies
Staphylinidae	27
Lampyridae	3
Tenebrionidae	5
Carabidae	7
Anthicidae	3
Ptilidae	4
Scolytidae	6
Nitidulidae	6
Scarabaeidae	9
Chrysomelidae	7
Dermestidae	1
Curculionidae	6
Lathridiidae	6
Anobiidae	1
Pselaphidae	2
Melandryidae	1
Oedemeridae	2
Throseididae	1
Scaphidae	1
Mordellidae	2

Based on Fowler (1912) and Borror and Delong (1971).