PATTERNS IN SPECIES COMPOSITION AND DITRIBUTION AMONG VASCULAR EPIPHYTES IN LOW-LYING SEMI-EVERGREEN FORESTS OF ARUNACHAL PRADESH, INDIA

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CERTIFICATE

This is to certify that Ms. R. Padmawathe of the Wildlife Institute of India has carried out original research titled **"Patterns in Species Composition and Distribution among Vascular Epiphytes in Low-Lying Semi-evergreen Forests of Arunachal Pradesh, India"** towards the partial fulfillment of the Master of Science (Wildlife Science) degree from Saurashtra University, Rajkot, India. These investigations were carried out under our supervision from November 2000 to June 2001. We also certify that this research has not been submitted for any other degree to any university.

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SUMMARY

The patterns in epiphyte species composition and distribution in the low-lying semi evergreen forests was studied in Pakhui Wildlife Sanctuary and the adjacent Doimara Reserved Forests in western Arunachal Pradesh. Epiphyte community changes due to microclimate and host characteristics were studied by comparing sites of different microclimates namely riverbanks, tree fall gaps, closed forests and logged forests. Systematic sampling showed that epiphyte species diversity, increased marginally from low levels in the tree fall gaps to maximum levels in the riverbanks with intermediate levels in the logged forest and closed forest. There were dominance of certain families and life forms in different sites.

Trends in epiphytic communities were closely related to changes in microclimate and host characters. The environmental variables were summarized by Principal Component Analysis, which yielded three components explaining 75.5% of the variance. Component one was positively correlated with temperature and canopy cover and light intensity in the horizontal zone, whereas relative humidity was negatively correlated. Component two was strongly correlated with vertical light intensities. Component three was purely a temperature factor.

Araceae, Gesneriaceae and Asclepiadaceae correlated with vertical temperature-humidity component, while Orchidaceae and Moraceae were correlated with horizontal temperature. Families Aspleniaceae and Gesneriaceae were positively correlated with component one (qualitative parameters) of the vegetation characteristics, Therefore, epiphyte species richness were significantly different between across bark texture and architectural model of the host. Warty and wrinkled bark supported maximum species and *Champagnats* model of tree architecture supported higher number of epiphyte species. Six species were found only in the trunks and ten species confined themselves to branches. A total of twelve rare species of different families were found in the study area. The major implications of the study are the intimate relationship of epiphytes with diverse factors of climate and host characters, the change in one will trigger corresponding changes in other. Logging as a practice removes lot of trees, which reduces the diversity of substrate and microhabitat conditions available for epiphytes. It is important to maintain atleast a few big trees to serve as mother trees for recovery of the lost species.

1.INTRODUCTION

1.1 General introduction

Vascular epiphytes include two groups namely the 'holoepiphytes' and the 'hemiepiphytes' (Richards, 1996). Holoepiphytes are true epiphytes, which do not establish any contact with the soil *e.g.* epiphytic orchids, aroids and ferns (Benzing 1995). The hemiepiphytes are plants that germinate on branches or trunks of trees and with age send roots to the ground and are dependent on host trees for establishment and support*e.g.* strangler figs (Todzia 1986). Both these types grow on tree trunks and branches and are totally dependent on the atmosphere or the substrate in which they grow, for their water and nutritional requirements atleast in some stage of their life. These factors make the vascular epiphytes sensitive to changes in the macro and micro climatic conditions of the habitat they are known from. These factors, necessary for the growth and development of epiphytes are subjected to greater perturbations when compared to conditions required by other terrestrial plant forms.

Selective logging in forestry involves the removal of mature, overmature and defective trees in such a manner as to leave uninjured an adequate number and volume of healthy residuals of commercial species and other tree species, necessary to assure a future crop of timber and forest cover for the protection of soil and water (Rapera, 1977). But there is invariably a considerable loss in the proportion of valuable timber extracted apart from other damages caused during the felling operations to the neighbouring trees. A Large number of timber trees in tropical and subtropical forests support an array of hosts of epiphytic species and many animal taxa belonging to various groups. The selective removal of host trees severely affects the epiphytes because their growing substratum is lost. Epiphytes need trees for their survival and establishment as they cannot grow on the soil (Benzing 1995). Once the trees are felled selectively, especially a preferred host, the epiphyte loses its habitat. Felling creates gaps in the forests, which alter the microclimatic conditions such as light, relative humidity and temperature to which epiphytes are sensitive and small changes can bring manor changes in the epiphytic community structure.

The state of Arunachal Pradesh that lies in the Eastern Himalayas, supports over 500 species of orchids and a variety of ferns and aroids. The precipitous hills and cool humid climate favour the growth of epiphytes (Chowdhery 1988). The state has the second highest total forest cover in the country (*ca.*68, 621 km^2) or 62% of the geographical area (F.S.I. 1999). Large areas of primary semi-evergreen and evergreen forests still exist as a result of low population densities and inaccessible, difficult terrain (Datta 1998). Though 62%of the geographical area is under forest cover according to remote sensing data (F.S.I., 1995) yet habitat loss/conversion due to logging,*jhum*, and development activities is accelerating in recent years (Katti *et al.* 1992). As timber is a major source of revenue in the state, the forests particularly in the foothills are fast disappearing leading to habitat loss for the epiphytes and other plants and animals. No information is currently available on the extent to which selective logging affects the vascular epiphytes and the study would attempt to answer this question. This study focuses on the patterns of epiphytic diversity and distribution in the low-lying forests of Arunachal Pradesh.

1.2 Review of literature

Benzing (1996) estimates that 10% of all vascular plants are epiphytes. Forty-three genera include at least a hundred epiphytic species, but these belong to only twelve families (Benzing, 1996). Orchidaceae is the largest member family of epiphytes, which includes hundreds of genera and thousands of species of typical epiphytes. Johansson (1974) found that a total of 153 species of macroepiphyte, 101 were orchids in Nimba mountains in Africa. Many of the families are pantropical except for Bromeliaceae, which is neotropical Bromeliaceae is very hardy and that is why there is a luxuriance in epiphytic vegetation in the neotropics (Richards, 1996). Madison (1977) estimated that there were 15, 510 species of macroepiphytes in the neotropical region and only 12,560 in the paleotropics.

In India, most of the studies on vascular epiphytes are restricted to enumeration (e.g. Deva and Naithani 1986, Chowdhery 1998) and very few studies on the ecological requirements have been attempted. It has also been established that orchids are presently, an endangered group, as they are losing their host species to the anthropogenic pressures in Kumaun Himalaya (Samant *et al* 1995), thus emphasizing the need for studies on orchid-phorophyte relationships. In the west, due to advancement in canopy access techniques many studies on epiphytes and their relationships with the environment and other organisms have been conducted (Nadkarni 1995 Ingram and Lowman 1995). Apart from the general distribution of epiphytes, micro climatic requirements and their sensitivity to the changes in these microclimatic factors have also been documented (Cornelissen *et al.,* 1989;Leerdan *et al.*, 1990; Ingram & Nadkarni 1984). Bernabe *et al*, (1999) established the importance of forest interior for the survival of a tree fern species, *Sphaeropterus horrida.* The effects of selective logging on changes in microclimate, breeding sites, nests and refuges for arboreal mammals and birds are mainly the alteration in the distribution and abundance of resources (Johns 1983). Specific studies on the effect of logging on vascular epiphytes are not been done either in the Neotropics or Paleotropics. However, Johns (1983) has documented that logging randomly deletes half of the trees in the forest. Johns (1985) also recognised that the basal area also reduces to about 50%in a primary forest, if logged. Some studies suggest that careful selective logging do not create harmful effects. For example, a study on the pendent nonvascular epiphyte in relation to selective logging revealed that there was no negative effect on the growth of these epiphytes (Romero, 1999). Studies show that selective logging has lead to inbreeding in species like *Shorea megistophylla* (Murawski *et al* 1994). Sub canopy levels of the forest are exposed to increased levels of radiation, increased temperature (Crome *et al* 1992), and decreased humidity (Johns, 1985). This explains the change in microhabitat and vascular epiphytes are highly susceptible to such changes. Further, the abundance of different families of trees before and after logging varied (Johns 1983, Thiollay 1992). Tree species diversity and richness reduced not only due to removal of trees but also due to damage to other species in Malaysian rain forests (Johns 1983). Therefore the host species are under severe potential threat. In the evergreen forests of Kerala and Assam in India Nair (1990) found that selective logging had harmful effects of the regeneration due to invasions by colonizers. If regeneration fails, the epiphytes, in future, will have no host species to grow on.

1.3 Objectives

The principal objective of this study is

To study the patterns in epiphyte species composition and distribution in different microhabitats in lowland semi-evergreen forests.

To achieve this objective, the following questions will be answered.

(i)How are the different life forms of epiphytes distributed in the different sites?

(ii) How does the microclimatic change in the logged and unlogged forests and how does this affect epiphyte species composition and distribution?

(iii) How are the vascular epiphytes spatially distributed in the logged and unlogged forests?

(iv) Does the epiphytic species abundance and composition change with bark texture and architecture of the hosts?

2. STUDY AREA

2.1 Location:

The study was conducted in the western fringes of Pakhui Wildlife Sanctuary, Eastern Himalaya (27°06'N and 92°48'E), earlier a part of Khellong forest Division, covers 862 sq.km came into existence during 1977. It has been elevated to the status of Tiger reserve during February, 2001. Doimara Reserved Forests lies to the west of Pakhui Wildlife Sanctuary in Khellong forest division, which falls as a part of my study area.. The sanctuary is drained by tributaries of the Bhareli and Pakke rivers, both of which flow into the Brahmaputra River. The main streams in this area are Nameri, Khari and Upper Dikari, all of which run in the southern direction. The terrain in the Himalayan foothills (*c* 200-1500m) is undulating and hilly and the sanctuary slopes southwards towards the Brahmaputra valley.

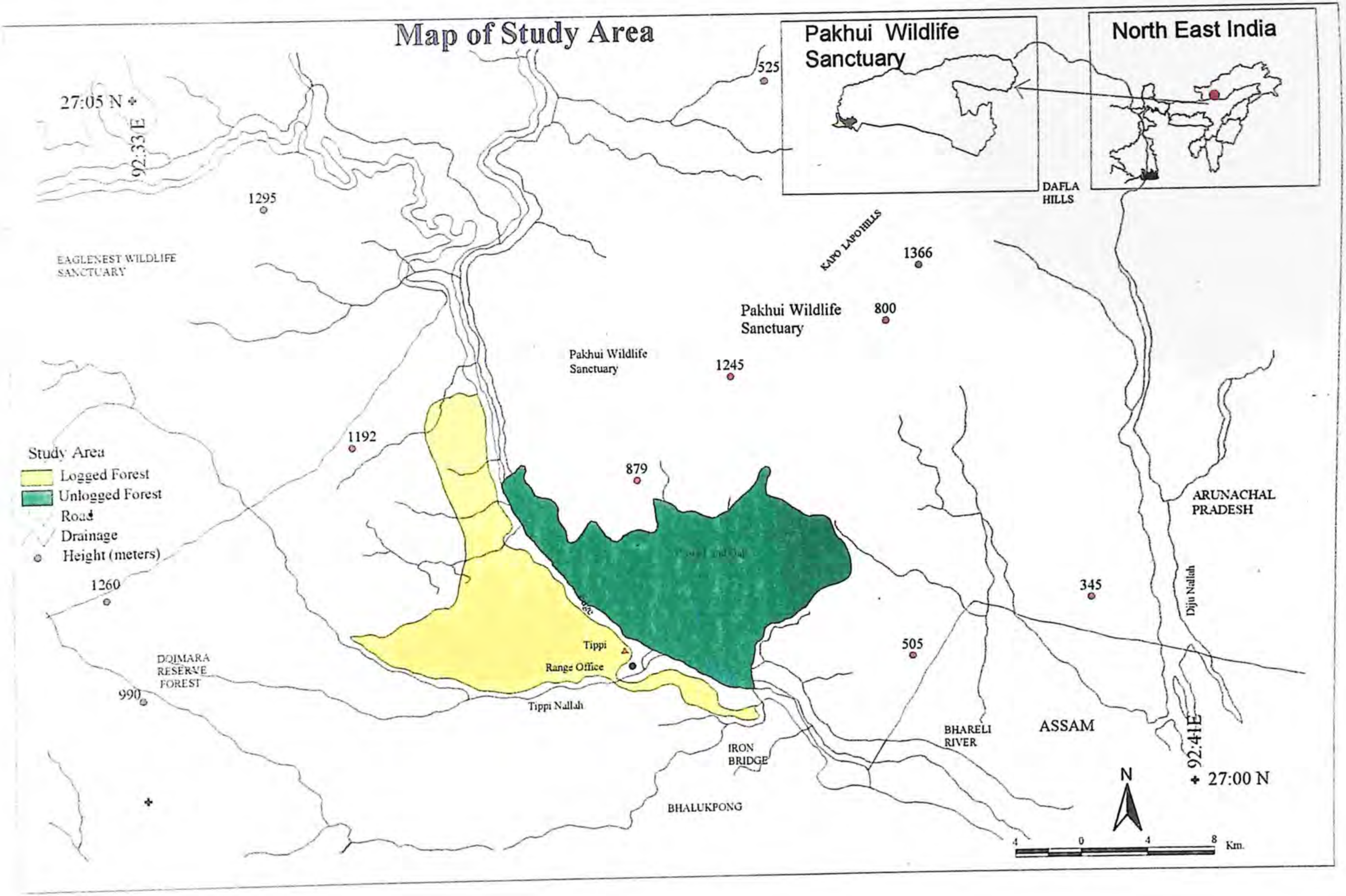
2.2 Geology and Soil:

Geologically, Pakhui Wildlife sanctuary falls under the Lesser Himalaya consisting of Neogere molassic sediments resembling Siwalik formations (Wadia,1967). The rivers bring in new alluvial deposits of clay, silt and shingles. The subsoil is sandy loam in the foothills. The soils on the upper reaches are loamy with a humus layer and the depth of the soil is moderately deep. But shallow soils are common with underlying rocks and boulders. The soil is generally porous in nature despite the heavy rainfall in the area (Sen. 1978).

2.3 Climate and Rainfall:

The study area has a tropical and subtropical climate with cold weather from November to January. It receives rainfall from the Southwest monsoon (May-September) and the North east monsoon (November-April). October and November are relatively dry.

Map of Study Area



May and June are the hottest months. The monsoon lasts till September. but occasional rains occur throughout the year. The southwest monsoon is responsible for more than three-quarters of the annual rainfall. Early morning and late evening hours experience high wind velocity in the river valleys. Cyclonic storms occasionally occur in March-April. The average annual rainfall is 2500mm. The mean (±SD) maximum temperature is 29.3^0C ± 4.2 and the mean minimum temperature is 18.3^0 ± 4.7 based on data from 1983 to 1995 recorded by the Tipi Orchid Research Centre.

There were pronounced annual fluctuations in the total amount of rainfall and the distribution of rainfall for the past ten years. Annual rainfall during 1996 -2000 varied from 1782 mm in 1997 to 3546 mm in 1998 with a mean of 2424.3 ± 751.4 mm for a 5 year (1996-2000) period. Mean annual maximum temperature over a five-year period was 29.32°C ± 1.97, while mean annual minimum temperature was 19.88°C± 3.93.

Mean annual relative humidity (in the mornings) was around 89.87%, with March being the least humid month and June was the month with highest humidity. Mean annual relative humidity (in the evenings) was around 76.63% with March and June again being the least and most humid months respectively.

2.4 Vegetation:

The general vegetation type in the study area has been categorized as Assam valley Tropical Semi-evergreen Forests 2B/C1 (Champion and Seth, 1968). The forests are multi-storied and are rich in epiphytic flora and lianas. The tropical semievergreen forest are scattered along lower plains and foothills, dominated by *Altingia excelsa, Tetrameles nudiflora, Dysoxylum binectariferum, Syzygium syzigioides* and the other middle storey species belonging to Family Lauraceae. Euphorbiaceae and Myrtaceae. The dominant tree species around intensive study area are *Terminalia myriocarpa, Ailanthus grandis, Duabanga grandiflora, Canarium strictum, Pterospermum acerifolium,* *Stereospermum chelonioides, Dillenia indica and Polyalthia simiarum.* The undergrowth is dominated by *Coffea bengalensis, Strobilanthes spp.*

2.5 Logged forests:

These forests are located close to Tipi town, West of Bhareli River in Doimara Reserve forests. The altitude is 500-850 m above mean sea level. There are two sawmills and one veneer mill along with small labour camps. Forests have been logged in this area till 1996 (Rao, A.N. pers.comm) and elephants and small trucks have been used for transportation of timber. To the north of these forests, lies the Eagle Nest Wildlife Sanctuary and to the west and south by Amartala Reserve Forests and the forests of Assam and their villages. The Bhareli river and the Tezpur-Bomdilla highway acts as boundary between Pakhui Wildlife Sanctuary and Doimara Reserve Forests

2.6 Unlogged forests

These forests are on the eastern side of the Bhareli River and the western most part of the Pakhui Wildlife Sanctuary and they are protected from logging operations. The river acts as a barrier to the pressure of human disturbances and occasionally people cross over (Datta, 1998). These forests were selectively logged during 60"s and early70's (Sen 1978)

2.7 Vegetation types of logged and unlogged forests

According to Champion and Seth (1968) the vegetation type is Assam valley tropical semi evergreen forest 2B/C1. But it is also important that selective logging has brought in differences in the nature of forest structure and composition. The logged forests dominated by *Tetrameles nudiflora* and *Syzygium formosum* which were left uncut. Even small trees have been removed for veener and plywood industry. The vegetation on the eastern side is diverse and similar in compostion as described earlier.

3.METHODS

3.1 Selection of sites

A pilot survey was conducted to identify different sites for studying the effects of logging in pakhui wildlife sanctuary and doimara reserve forests. The study sites were selected such that they were similar with respect to topography, altitude and vegetation types. The altitudinal range of the sites is 200 to 400m. The following sites were identified for studying epiphytes (i) River bank edges (ii) Closed forests (iii) Tree fall gaps

(iv) Logged forests

River Bank

Hanging in midair, epiphytes need a constant supply of nutrients and moisture to flourish. River banks form natural edges where light wind and moisture is not limiting. These can be excellent habitats for epiphytes. Along the banks, a linear strip of 25-30 form one sites for the study. The forests along the banks are subjected to inundation desiccating and chilling winds and strong insolation from the peripheries, which reach the ground because of the absence of undergrowth. The left bank of River Kameng in Pakhui wildllife sanctuary was chosen for studying epiphytes.

Closed forests

These forests are characterized by closed continuous canopies with a distinct *Coffea bengalensis* dominated understorey and small trees and saplings in the middle storey. Lianas grow in these patches. Only a small portion of the study area had closed forests. The canopy is subjected to heavy wind and extremes of heat and light.

Tree fall Gaps

The most readily distinguishable sites are the tree fall gaps in the lowland forests. They are characterized by medium to big canopy openings of different shapes and sizes.

The cause for these gaps would be natural or selective logging. Selective logging had been done in the early 60's (ref) inside the sanctuary. *Strobilanthes* spp dominate the understorey. The middle storey is dominated by saplings, which compete to reach the canopy.

Logged Forests

Heavily logged this sites has impenetrable undergrowth, weeds and climbers with open canopy without any canopy continuity. *Eupatorium, Mikania and Clreodendron dominate* the understorey, while the middle storey is totally absent.

3.2 SAMPLING OF EPIPHYTES

Epiphytes are a composite group of dicots, monocots and pteridophytes. Most of the epiphytes are modular organisms and thereby identifying individuals in a cluster is difficult. The percentage cover of epiphytes was done by ocular estimate. The percent values were then converted to Braun-Blanquet (Mueller-Dombois 1974) cover classes for analysis.

3.2.1 Estimation of epiphytic cover

Vertical stratification

The host trees were divided into three-meter vertical zones for sampling epiphytes. Bamboo poles were used to delineate different zones in the tree, usually up to 12 metres high. Identifying zones beyond this was done with the help of a table based on the principles of trigonometry. This table gives the height at different angles of elevation at a particular perpendicular distance. Using this table it was possible to identify different vertical zones on the trees by looking at calculated angles of elevation standing at a particular distance.

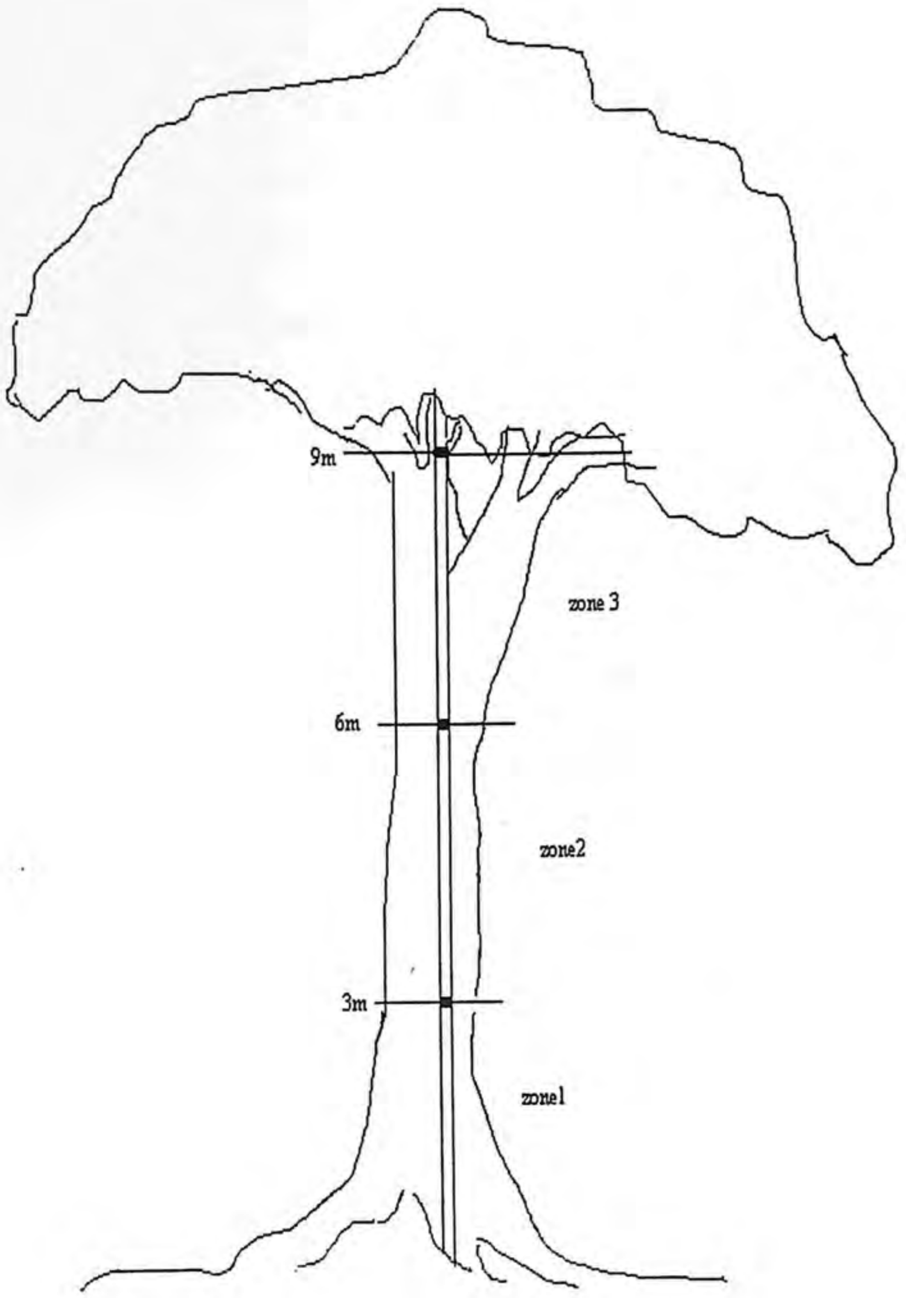


Fig1. Sampling for epiphytes in different zones in a tree.

Estimation of epiphytic cover

Epiphytic cover was quantified in the entire trunk, 50%of primary branches and 25%of secondary branches. The trunks were then sampled for epiphytesat these vertical zones on two different sectors/sides viz., 0 to 180 degrees and 180 to 360 degrees. Each zone was divided into imaginary quadrants and the percentage cover of each species of epiphyte was estimated in classes of 5. During the initial sampling, a square of known area was pasted on the tree for standardizing the cover classes of epiphytes. The percentage cover of epiphytes was estimated in the primary and secondary branches in a similar fashion.3.2 Host characteristics - Square plots of size 25x25m were laid in the logged forests, closed forests, tree fall gaps and riverbank edges in replicates of four. Within these plots all the host species with height more than 5 metres and girth above 30cm were considered for sampling epiphytes. The total height, girth at breast height, canopy width, barks texture, and architecture were recorded for each species. Girth was measured in two ends and in the middle of each zone to get the exact surface area. To measure the girth at different heights in the trees, few trees of different sizes were climbed and the measurements were taken. This was used as a reference and the girth of the remaining trees were estimated. Error tables were generated to correct for the differences between estimated and the actual readings. In each of the primary and secondary branches, girth was measured in the three places, one at the branch initiation, the next in the middle of the branch, and the third at the end of the branch. Tertiary branches were not sampled as they were too small to support epiphytes. The trees were mapped in 25x25m quadrat by laying 5x5 m grids on these plots.

Epiphyte substrate

Bark texture:

a) Scaly bark: Where a stem has discontinuous, overlapping successive periderms, patches of bark will form and can be shed. This is generally termed a scaly bark which resembles the scales of fish.

b) Fissured bark: Fissured bark has a net-like pattern from splitting of the outer and inner bark.

c) Smooth bark: Smooth barks can be smooth and very glossy to dull

d) Exfoliating: occurrence of thick-walled cells alternating with thin-walled cells causes barks to separate like thin wrappers, peeling or exfoliating from where a layer breaks.

e) Cracked bark: As a tree increases in girth, great tension on the bark can cause vertical and horizontal cracking. Cracks may develop along planes of stress or more simply outline boundaries of scaly bark.

f) Furrowed bark: A number of trees have deeply furrowed bark with thick accumulation of cork cells. These cork cells tend to have thin-walls and are filled with air. Corky outer bark may also appear in longitudinal arrangements or wings.

g) Flaky bark: bark removes in thick big or pieces exposing the inner bark.

h) Warty: This bark has small to big outgrowths resembling a toads skin.

i) Wrinkled: this bark type has numerous rings which are discontinouous and staggered and gives an appearance of wrinkled cloth.

j) Papery bark: The outer bark of many species fall as thin papery flakes. Papery bark is smooth and very thin and peels easily from the periderm.

Architecture

Architectural classes for each tree was assigned to each tree species based Tomlinson and Oldeman 's classification. The major criteria used for classification are the nature of branching, flowering and trunk and branch differentiation.

3.3 MICRO-ENVIRONMENT

Each plot was divided into twenty-five, 5x5 m, small grids where the different environmental parameters were recorded at 36 points. All along the borders and at the junction of each grid, temperature, relative humidity, and light intensity readings were taken. Canopy cover readings were taken in four directions at each point on the plots. Temperature and humidity recorders were placed at three different heights (0.5m, 6-7m, 14-15m) in each plot to capture the vertical stratification of environmental parameters. The data loggers were placed for a minimum of 96 hours and a maximum of 240 hours in each plot at different heights within the plot. Light intensity was also measured at these heights by using a luxmeter. All the readings for light and horizontal mapping of microclimate were taken between 9 am and 10 am in the morning.

3.4 DATA ANALYSIS

The major analysis was carried out to find out whether the tree fall gaps, closed, edge and logged forests were different in terms of species abundance and richness, microenvironment and host characteristics. For performing different analysis, epiphytic species composition and richness were used. If the sites are different significantly, the next step was to find out what were the factors that brought these differences.

Exploratory analysis (Box and whiskers) was done to see the differences in the sites for environmental variables. One-way ANOVA was used to test for the differences in microclimate. The environmental variables were standardized to remove the effect of seasonality and also they were converted into Z scores. The environmental variables were reduced into three factors using Principal component analysis with varimax rotation. The different sites were then compared for differences in microenvironment by one-way ANOVA using the extracted factors.

One-way ANOVA was used to differentiate sites based on the vegetation structure and composition. Ordination was done to extract Principal Components for vegetation characters. They were then correlated with family abundances as earlier to check for the relationships. The surface area was regressed against the number of species and the slopes intercepts were compared using the *Arrhenius* (Tokeshi 1993) equation. Rarefaction was done to find out the species richness at a particular abundance value to compare the diversity of the different sites. Also, the differences in epiphyte richness for different girth classes, architecture types, bark texture types were done by using one-way ANOVA. The same statistic was used to find out whether the epiphytic species richness and abundance varied in trunks and branches.

TWINSPAN (Hill 1979) was done to classify different sites based on epiphytic species composition. This performs a two-way indicator analysis on the plots and species abundance data using reciprocal averaging to separate the sampling points and the species into recognizable groups or associations. The dendrogram was ploted using the eigen values calculated by the analysis. This grouping was further tested for differences in their environment using the extracted factors by one-way ANOVA.

In order to relate envrionmental parameters to observed species composition, canonical correspondence analysis with detrending as an algortithm was used. Palmer (1993) found that even with skewed and non-normal data sets with a lot of environmental noise. the analysis was good enough to extract the two significant environmental axes from a simulated data set. The statistical package CANOCO (Ter Brak 1987) was used for Detrended Correpondence Analysis. The weighted log transformation was done as percentage data to make it independent. The second order Polynomial was used for detrending data set.The ordination diagram of the species was plotted using these species scores. Similarly, the species-environmental biplot was also done. The species-envrionmental biplot is an ordination diagram in which the environmental variables are represented by arrows. This arrow roughly points in the direction of maximum variation in value of the corresponding variable. By looking at the angles between arrows one may get an idea of the correlations between species abundance and the environmental variables (Ter Brak and Prentice 1987). The plot of arrows of species and environmental variables also allows a qualitative interpretation by the rules of a biplot (Jongman *et al*, 1987, Gabriel 1981), leading to an approximate values of the covariances between species and the environmental variables.

Since epiphytes are modular organisms, diversity indices could not be calculated. So, rarefaction was done to distinguish the sites based on the species turn over rate for a particular abundance value. The dominant epiphytic families in each plot were correlated with the different environment factors to see if the separation of families matches the separation of plots in which they occur. The proportion of rare and common species was also compared across sites. The life forms of different epiphytes were classified based on Hosakawa 's (1943) life form classification. The similarity of different sites based on life form was also done using hierarchical cluster analysis. To determine how similar these sites are in their epiphytic species composition, programme Two Way Species Indicator Analysis (TWINSPAN; Hill 1979) was used.

4. RESULTS

4.1 FLORISTIC STRUCTURE AND LIFE FORMS

4.1.1 Floristic structure of Vascular Epiphytes

A total of 71 species of vascular epiphytes (ferns and flowering plants) were recorded during the study (Appendix – 1). Of these, 61 species occurred exclusively within the sample plots. Orchids were dominant in species number (57.38%), but not in abundance (17.99%)(Fig. 4.1.1a). Gesneriaceae represented 4.92 % of all species and highest (21.75%) abundance). Ferns constitute 19.68% (35.44% of abundance) of all species. Next in importance were Araceae (14.58% of abundance) with 3.28 % of species, followed by Asclepiadaceae (8.47% abundance, 6.56% of species). Moraceae and Urticaceae were the least represented families (Table 4.1.1). Holœpiphytes and Hemiepiphytes constituted Fifty-five (90.16%) and five (8.19%) species respectively. Of the Hemiepiphytes three were strangers and 1 species was accidental epiphyte. Six species were only found only on the main tree trunks while ten species(16.39%) was present only on branches.

Different families dominated in various sites in different microhabitats (Table.4.1.1). Araceae was dominating in trunks of all the sites, but Orchidaceae dominates in both the trunks and branches in riverbanks. Orchidaceae was the family with highest species richness but it was low in abundance ranking. The other families were species poor but these few species occurred in higher abundances wherever they were present. Araceae was always present in high abundances even though it had a maximum of two species (Fig. 4.1.1b), while the total abundance of Orchidaceae was in proportion to its number of species. The proportional abundance of Orchidaceae was higher in

Table 4.1.1a. Dominance ranking for epiphytic families in different sites

Rank	Closed Forest	Riverbank	Treefall Gap	Logged Forest
1	Gesneriaceae	Orchidaceae	Aspleniaceae	Orchidaceae
2	Aspleniaceae	Gesneriaceae	Araceae	Polypodiaceae
3	Araceae	Polypodiaceae	Gesneriaceae	Asclepiadaceae
4	Orchidaceae	Aspleniaceae	Orchidaceae	Araceae
5	Asclepiadaceae	Asclepiadaceae	Polypodiaceae	Aspleniaceae
6	Polypodiaceae	Vittariaceae	Asclepiadaceae	Urticaceae
7	Vittariaceae	Araceae	Vittariaceae	Vittariaceae
8	Moraceae	Moraceae	Moraceae	Gesneriaceae
9	Lycopodiaceae	Urticaceae	Thelypteridaceae	Accidental
10	Urticaceae	Lycopodiaceae	Urticaceae	Lycopodiaceae
11	Thelypteridaceae	Accidental	Lycopodiaceae	Moraceae
12	Accidental	Thelypteridaceae	Accidental	Thelypteridaceae

Table 4.1.1b. Dominance ranking for epiphytic families in trunk

Rank	Closed Forest	Riverbank	Treefall Gap	Logged Forest
1	Araceae	Orchidaceae	Araceae	Araceae
2	Aspleniaceae	Gesneriaceae	Aspleniaceae	Orchidaceae
3	Gesneriaceae	Polypodiaceae	Gesneriaceae	asclepiadaceae
4	Orchidaceae	Aspleniaceae	Orchidaceae	polypodiaceae
5	Asclepiadaceae	Asclepiadaceae	Polypodiaceae	Aspleniaceae
6	Polypodiaceae	Vittariaceae	Asclepiadaceae	Urticaceae
7	Vittariaceae	Araceae	Moraceae	Vittariaceae
8	Moraceae	Moraceae	Vittariaceae	Gesneriaceae
9	Lycopodiaceae	Urticaceae	Thelypteridaceae	Lycopodiaceae
10	Thelypteridaceae	Lycopodiaceae	Urticaceae	Moraceae
11	Urticaceae	Thelypteridaceae	Lycopodiaceae	Thelypteridaceae

Table 4.1.1c. Dominance ranking for epiphytic families in branches

Rank	Closed Forest	Riverbank	Treefall Gap	Logged Forest
1	Gesneriaceae	Orchidaceae	Aspleniaceae	Orchidaceae
2	Aspleniaceae	Gesneriaceae	Gesneriaceae	Polypodiaceae
3	Orchidaceae	Polypodiaceae	Orchidaceae	Asclepiadaceae
4	Polypodiaceae	Aspleniaceae	Polypodiaceae	Aspleniaceae
5	Asclepiadaceae	Asclepiadaceae	Asclepiadaceae	Araceae
6	Araceae	Moraceae	Araceae	Urticaceae
7	Moraceae	Araceae	Thelypteridaceae	Gesneriaceae
8	Lycopodiaceae	Urticaceae	Urticaceae	Lycopodiaceae
9	Thelypteridaceae	Lycopodiaceae	Lycopodiaceae	Moraceae
10	Urticaceae	Thelypteridaceae	Moraceae	Thelypteridaceae

Figure 4.1.1a. Proportional richness and abundance of the most species rich family

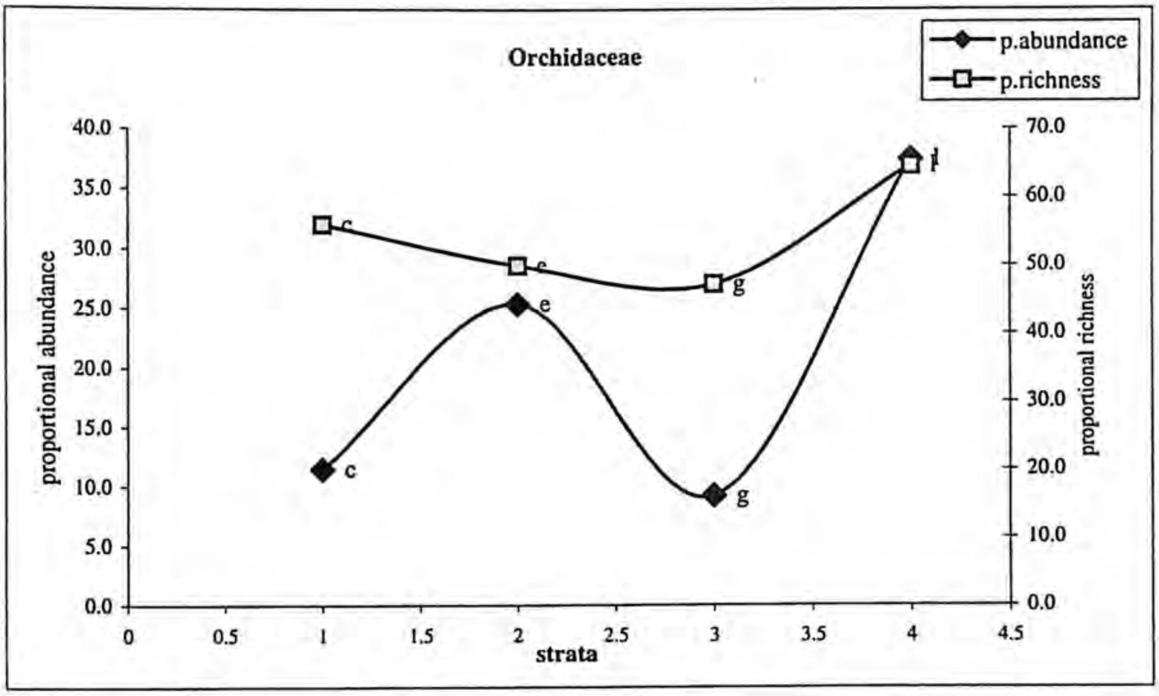
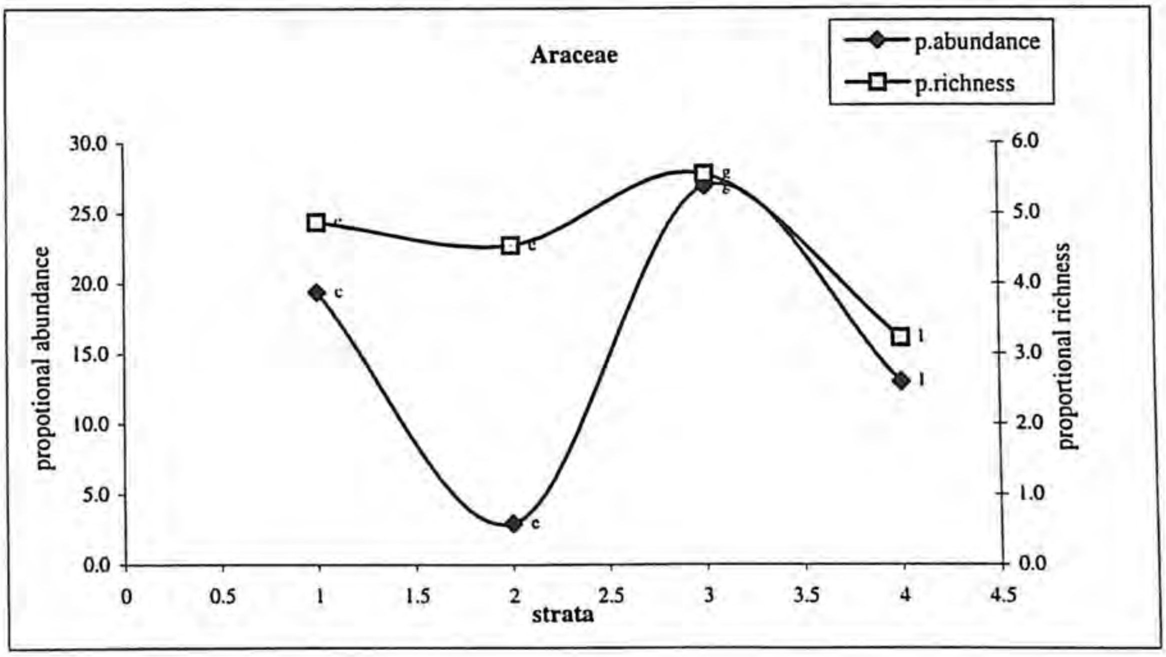


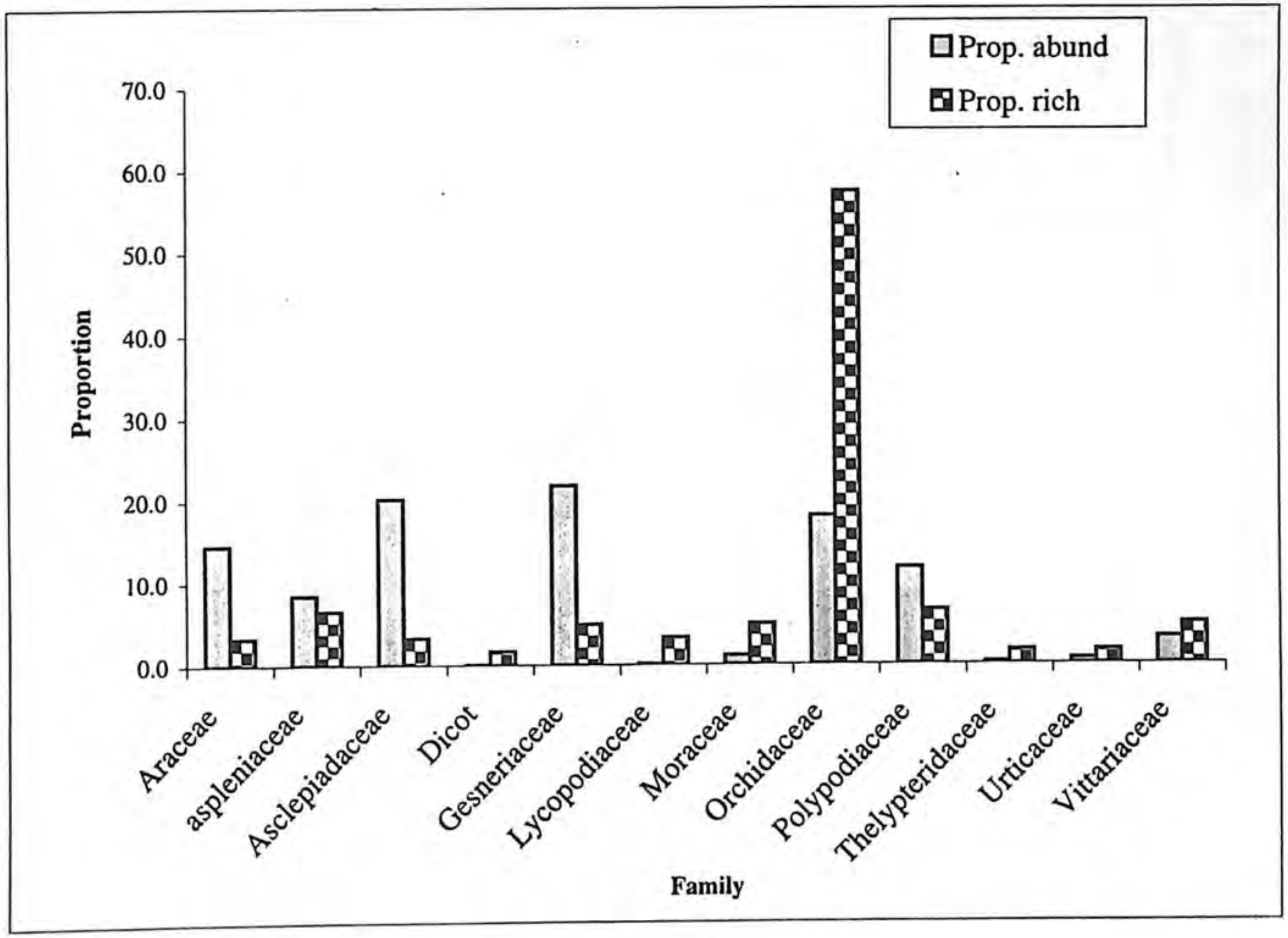
Figure 4.1.1b. Proportional richness and abundance of the least rich family



Legend

c	Closed Forest
e	Riverbank
g	Tree Fall Gap
l	Logged Forest

Figure 4.1.1c. Proportional richness and abundance of all the families in different sites



riverbanks (25.33%) and logged forests (64.52%), when compared to its abundance in other sites. This means that the families do not occur in proportion to their richness (Fig. 4.1.1c) Orchids were comparatively smaller in size and most of them have their buds close to their substrate and lack climbing or twining nature. This results in low abundance value for orchids.

4.1.2 Life form Structure

The Life-form classification (Table. 4.1.2) of Hosokawa (1943) for epiphytes has been modified and used to form the groups of epiphytes for the study area. The climbing and twining life form, *Scandens-vel-volubis* dominated in closed, tree fall gaps and riverbanks. These sites are protected from disturbance. The logged forest was dominated by *Reptatadensa*, the life form where the buds are close to each other as the buds are closely arranged; they occupy less surface area, even though there are many species. This might be one of the reasons for low abundance of epiphytes in this site. Interestingly all the life forms were represented in all sites.

Similarity of sites based on life forms

The sites were classified based on their similarity in life forms using cluster analysis (Fig.4.1.2), which helps to place similar sites together as clusters while separating sites that are different. Morisita similarity indices were used to generate a Dendrogram using hierarchical cluster analysis (centroid method) to depict the degree of similarity across sites in terms of the epiphyte community composition. The results were in concordance with clusters obtained from TWINSPAN (Fig. 4.2e). The epiphytes of the logged forests are very different from the undisturbed forests in their life form. These sites are the first to separate in the process of hierarchical cluster. The closed forests and gaps form one group while the edges form a separate cluster.

Table 4.1.2 . Life form classification of epiphytes (adapted from Hosokawa,1943)

Life form	Description	Example
Altigemmi-epiphyta	upright shoots, apical buds far away from the substrate	
Dendroepiphyta	woody and upright	*Dendrobium nobile*
Monocauli-epiphyta	single herbaceous stem	*Aerides williamsi*
Scandens vel Volubilis	climbing or twining, woody or herbaceous	*Rhapidophora lancifolius*
Succulent	succulent epiphytes	*Hoya fusca*
Terete	leaf modified into cylindrical flehy parts	*Luisia tricorhiza*
Humiligemmi-epiphyta	buds close to substrate	
Mobiligemmi-epiphyta	creeping and rooting close to substrate, stolons	
Reptata remota	buds far apart, shoots or leve scattered	
Reptata densa	buds close to one another	*Bulbophyllum khasianum*
Reptata densa upright	buds close to one another, densely tufted, upright	*Asplenium nidus*
Reptata densa pendula	buds close to one another, densely tufted,pendulous	*Dendrobium aphyllum*
Stabiligemmi-epiphyta	sedantary and no creeping shoots	
Caespitosa	buds on basal portion of plant, upright shoots tufted	*Cymbidium pendulosa*
Sub- caesptisoa	buds on basal portion of plant, partially sedentary	*Bulbophyllum guttulatum*
Fascicularis	rosette leaves	

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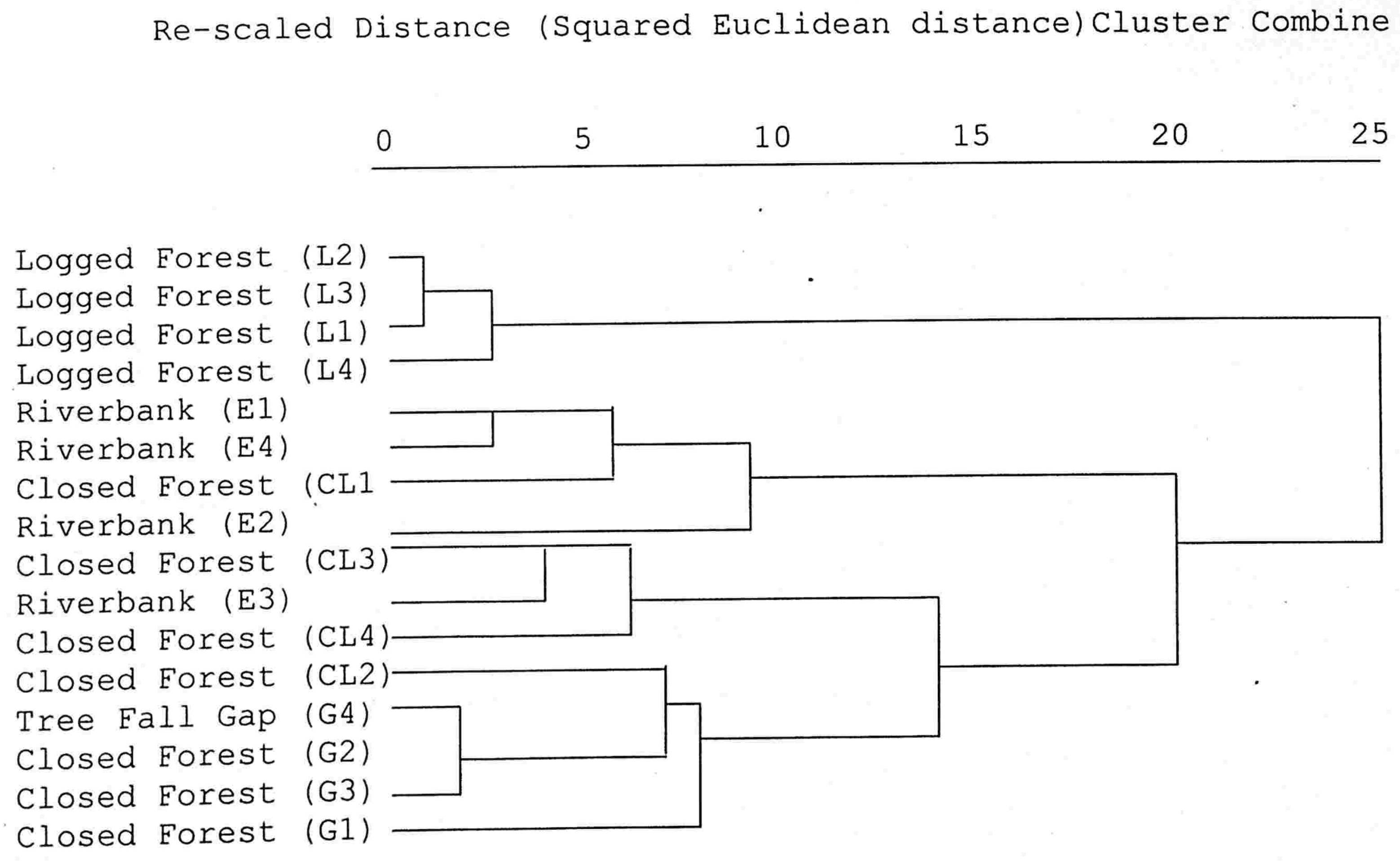
Figure 4.1.2. Similarities among sites according to epiphytic life forms



4.2 PATTERNS IN EPIPHYTE DIVERSITY *–A Comparison across sites*

The mean epiphytic species richness was different among closed forests, gaps and logged forests and river edges ($p<0.10$), while the abundance values were significantly different across sites at compared across different sites ($p<.05$) using one-way analysis of variance (Table 4.2). The riverbanks had the highest mean species richness, while the logged forest had the lowest. These sites showed a significant difference for epiphyte abundance (Duncan's multiple range test, $p<0.05$). Similarly, the mean abundance was the highest for the edges and lowest for the logged forests. Although the mean species richness was intermediate (14.5-25.75) when compared across sites, there was a gradual increase in the number of species in the relatively undisturbed sites.

Species- area curves

The species-area curves (Fig. 4.2a) for different sites were drawn and the slope and intercept values were obtained. Here, the surface area of the hosts at different zones was summed up to correct for the taper as the conventional basal area or surface area formula assume the tree to be a cylinder. The number of species /100m^2 was calculated from the formula (Mac Arthur & Wilson 1967):

$\log_{10}S = \log_{10}C + z\log_{10}A$, derived from the $S=cA^z$

Where: S= number of species; c= intercept of the species- area curve, and z=slope of the species-area curve.

The number of species in 100cm^2 was highest for the logged forests (1.743), while it was lowest for closed forests (1.10). The logged forests and the tree fall gaps had higher intercepts, 0.33 and 0.303 respectively, but lesser slopes, 0.3615 and 0.35. The riverbanks and closed forests had lower intercepts, 0.172 and 0.13 respectively and higher slopes. (closed 0.4655, edge 0.4486). This indicates that the number of species per unit increase

Table 4.2. Changes in epiphytic species abundance and richness in different sites

Category	Epiphyte richness	Epiphyte abundance	Diversity (rarefaction)
Closed forest	$21.75^{a,b}$	380.25	$12.30^{a,b}$
	4.40	53.66	2.26
Riverbank	25.75^{b}	486.88	15.18^{a}
	1.03	31.77	0.61
Tree fall gaps	$19.50^{a,b}$	319.00	11.54^{b}
	2.22	45.28	0.32
Logged forest	14.50^{a}	95.63	12.24^{c}
	2.72	27.44	0.98
N	16	16	16.00
F ratio	2.69	16.302	1.59
	S*	S**	NS

Values in table represent mean values

Values in smaller font represent S.E.s

N: number of sample points in each successional category

F: parametric one way ANOVA

NS : not significant

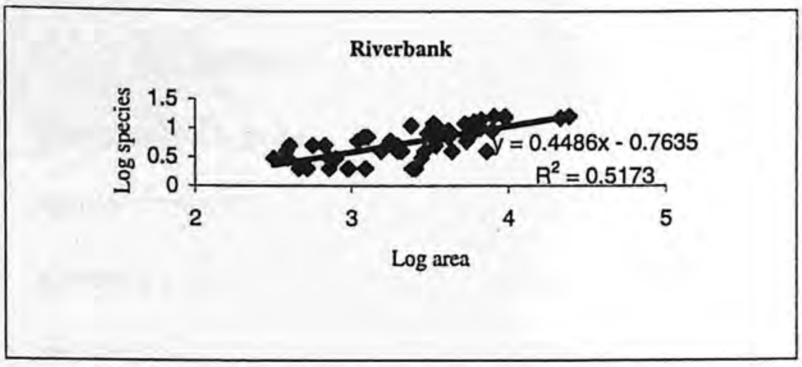
S* : significant result ($p<0.10$)

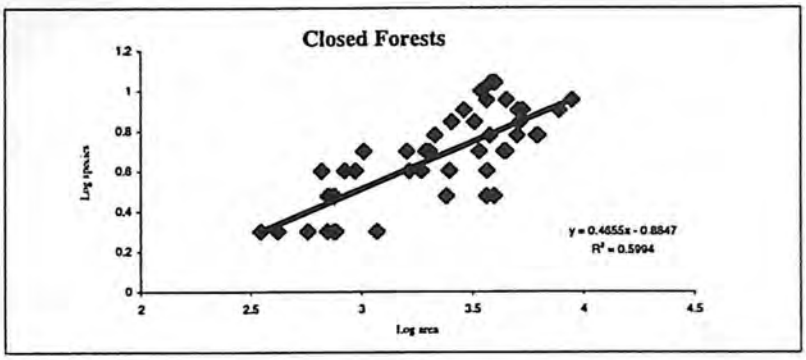
S**: highly significant result($p<0.05$)

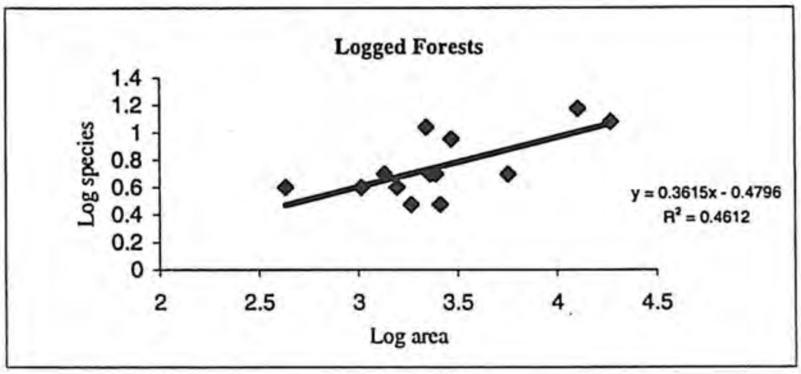
a-c: same alphabet in the superscript of variables indicate multiple comparisons that were not significant (Duncan's multiple range test ,$p<0.05$)

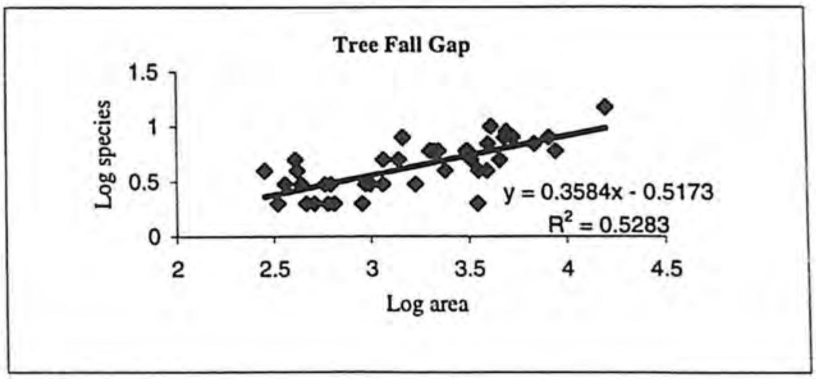
All the variables are means or numbers per 25m^2

Figure 4.2a. Species area curve in different sites









in area is higher for closed and river bank edges and lower in tree fall gaps and logged forests.

The species accumulation curves (Fig.4.2b) reveal that the species accumulate faster in the logged forests but reach asymptote much before the other sites indicating low species richness. This is consistent with the results of species area relationships. The riverbanks have the maximum diversity compared to the closed forest and tree fall gaps showing high favorable conditions for the growth of epiphytes because of constant supply of moisture and nutrients.

Species abundance curves

Rarefaction was used to remove the effect of increasing diversity from larger sample sizes. The epiphytic abundances were reduced to the level of the abundance of logged forest and the diversity was obtained for each sites. Species abundances showed significant differences across sites ($p <. 0.05$) (Table 4.2c). From Fig. 4.2c it is clear that the edge of the undisturbed forest along the riverbank has the maximum diversity because the curve is well above the other sites. The rate of increase in cumulative species richness is high for the logged forests compared to other sites. But even when the abundance increases new species fail to appear and the curve reaches asymptote earlier than any other site. The cumulative species richness in closed forest gradually increases and this curve did not reach asymptote unlike the logged forests. The species accumulates faster in the logged forests than other sites. But there are few species in these forests, no new species was found after sampling eleven trees.

Patterns of Rarity and Commonness:

Most striking feature of the vascular epiphytes in the study area was the presence of more common species (4.2d). The status (common, frequent and rare) are based on the published literature (Hegde 1984, Chowdhery 1998). Species reported as common in the

Figure 4.2b. Species-Abundance curves (rarefaction) for different sites

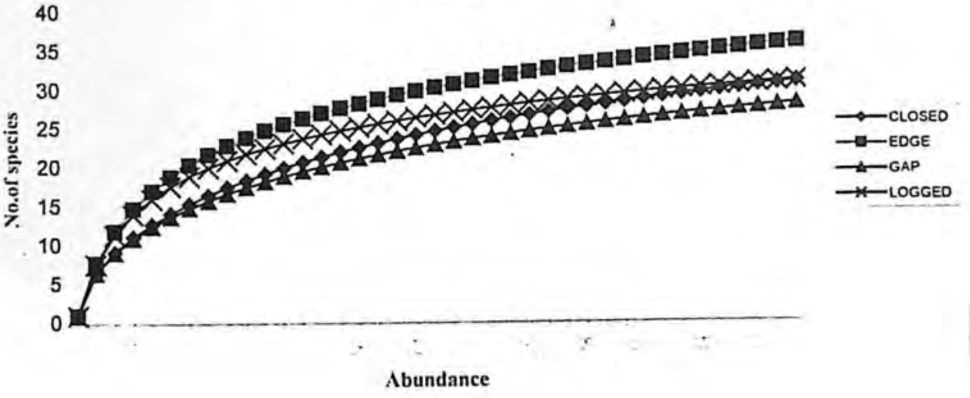


Figure 4.2c. Species accumulation in different sites

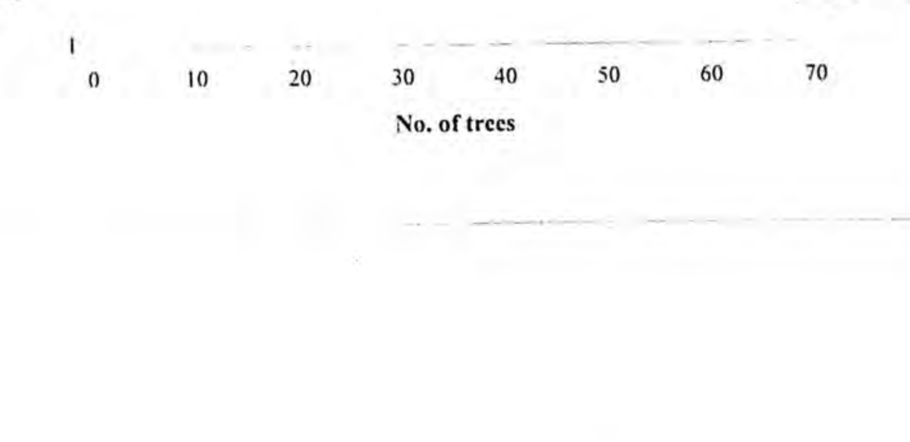


Figure 4.2d. Number of rare species in different sites

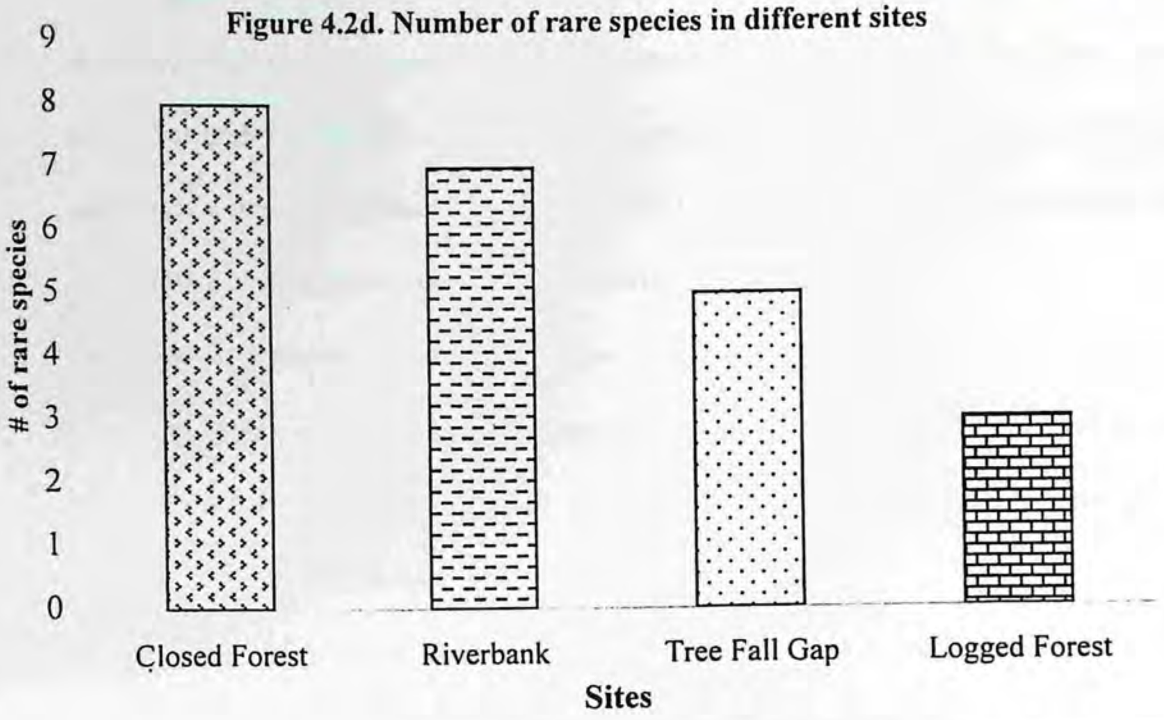
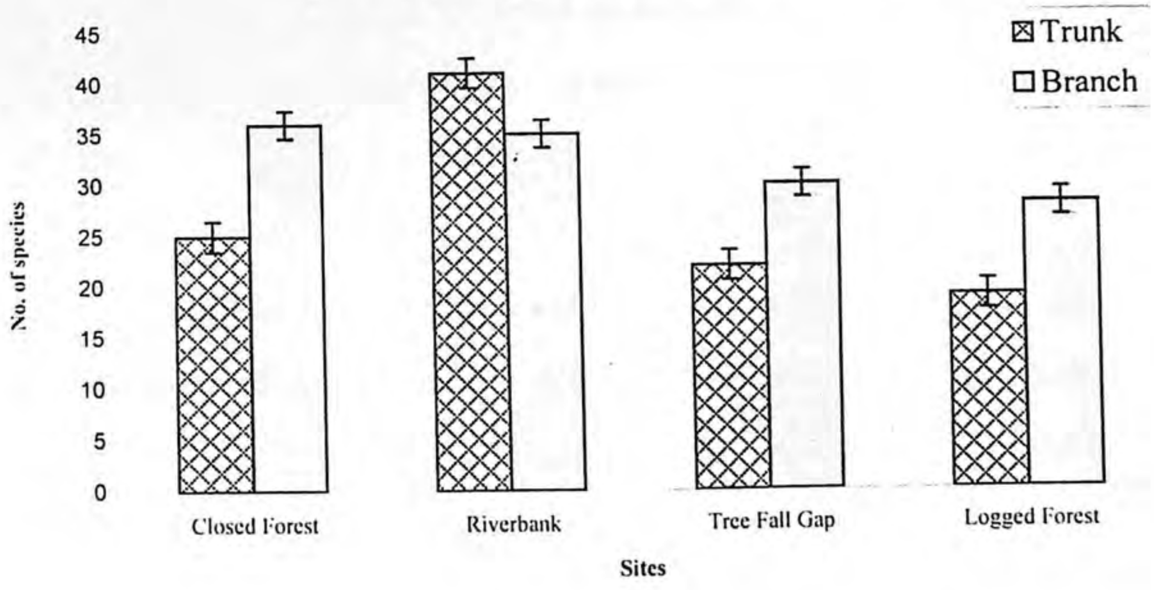


Figure 4.2.1. Epiphytic species richness in trunks and branches



literature constituted 80.33 % of the recorded species and 96% in terms of abundance. The logged forests had very low percentage of rare species (4.91%) possibly indicating the sensitivity of orchids to anthropogenic pressures. The closed forest and riverbanks had 8 (13.11%) and 7 (11.47%) rare species respectively. Tree fall gaps in the primary forest supported a good proportion of rare species (8.19%). Fig. 4.2d shows a decreasing trend in the number of rare species from closed forests to logged forests.

Similarity in epiphytic species composition across various sites:

Species are classified on the basis of fidelity, i.e. using the degree to which species are confined to particular groups of samples. A dendrogram (Fig. 4.2e) was generated from the TWINSPAN results. The important findings were:

i. The logged and primary (unlogged) forests were dissimilar in epiphytic species abundances (eigen value of separation =0.224).

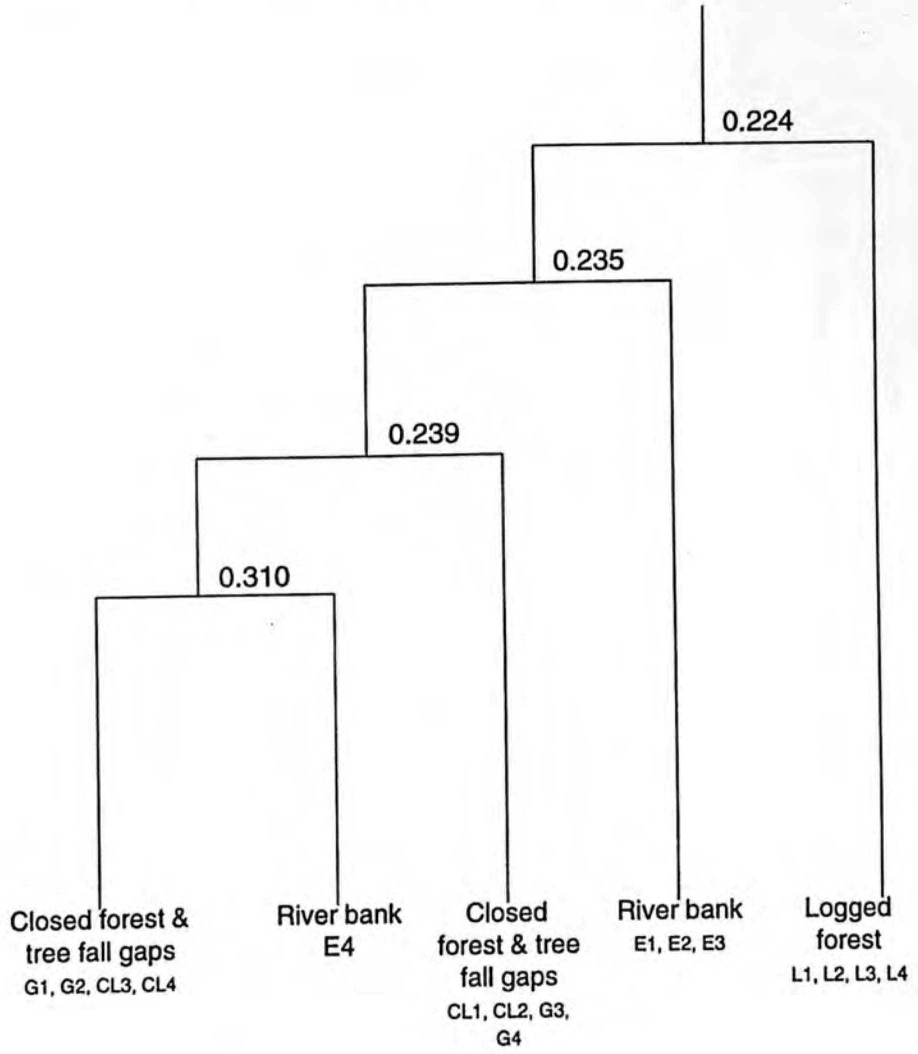
ii. Within the cluster of unlogged forests, riverbank edges showed dissimilarity with the closed forests and gaps (eigen value=0.257)

iii. The closed forest and the tree fall gaps clustered together, deviating from the expected results (eigen value=0.310). It also infers that these plots are away from the riverbanks and thereby falling in one group (fig 2)

4.2.1 Epiphyte Diversity across "microhabitats"

Within a host tree, trunk and branches create different 'microhabitats' due to the combined effect of microclimate along with architectural elements and bark texture of the host species. The number of epiphytes in the trunk in different sites showed significant differences (p<. 001) (Table 4.2.1). The mean species richness in the trunk in closed forests and tree fall gaps were not different, while the logged forests had the least number of species (31.25). The riverbanks were the richest in the epiphytes (21.5). The pattern was similar for the abundance of epiphytes in the braches (p<. 001). The abundance and

Fig. 4.2 e. Dendrogram showing classification of sites using TWINSPAN



richness of epiphytes in the branches followed the trend of overall species richness and abundance patterns in all the sites. It can be inferred that the overall patterns in richness and abundances are influenced by the abundance and richness in the branches. Branches had a higher percentage (88.52%) of epiphyte species than the trunk. Six species (9.84%) were confined to trunk, while 10 species (16.39% of the total) were found exclusive to branches.

4.2.2. Host characteristics- its influence on epiphyte diversity

Hosts influence epiphytes by the substrate they provide for epiphytic growth or by their architecture which tends to influence the microclimate under that individual host. These two factors are highly correlated with host richness ($r = 0.758$).

Girth classes of hosts

The hosts were classified into three girth classes as follows:

i. Small -31-95 cm at breast height,
ii. Medium-95-150cm at breast height,
iii. Large-150-420 cm at breast height

Within a particular girth class, the epiphyte richness was compared across sites. Small trees did not show significant changes in the number of epiphytes (Fig.4.2.2a). The mean number of epiphytes per tree was extremely low (2.3 - 3) in all the trees in all the sites. This proves that small trees do not support large number of epiphytes. Similarly, regardless of the differences between sites, the epiphyte richness gave insignificant results when the sites were compared for species richness in higher girth classes (Fig.4.2.2c). The mean number of epiphyte species per tree was ranging from 5.8± 1.7 to 5.8±0.99 in all the sites. This shows that trees of larger girth classes support large number of species even when they occur in disturbed habitats. The medium sized trees differed from the above trend (Fig.4.2.2b) showing significant differences between sites ($p< .05$). The medium

Figure 4.2.2a. Epiphyte species richness in small girth class tress across sites

Figure 4.2.2b. Epiphyte species richness in medium girth class trees across sites

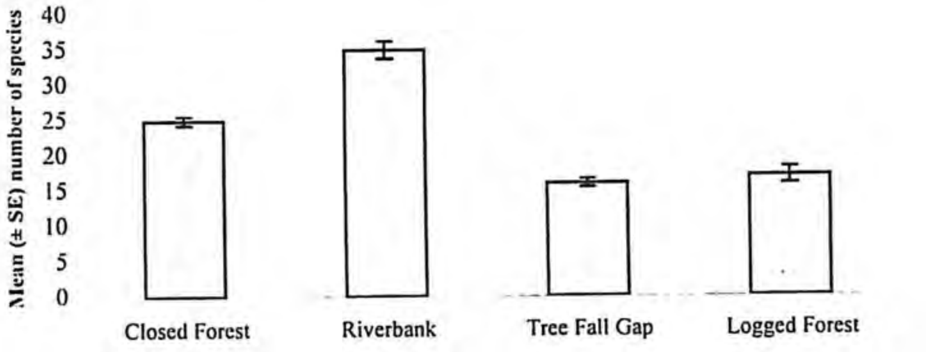
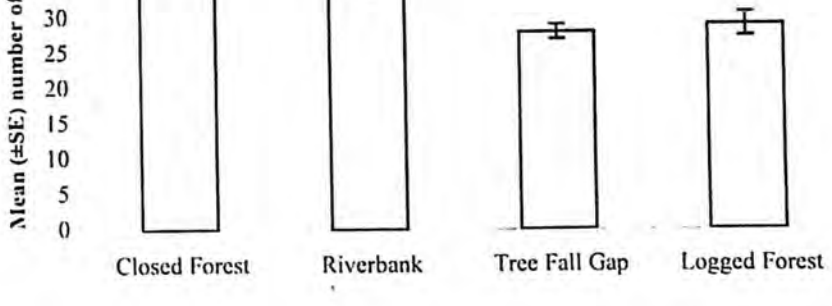


Figure 4.2.2c. Epiphyte species richness in large girth class tress across sites



sized trees in the riverbank edges had a higher mean (8 ±1.24) species richness per tree compared to the other sites.

Host bark texture and architecture

Architecture model (Halle *et al* 1978) the host trees and bark texture were influencing epiphytic richness significantly (p<. 001). A total of 14 bark types occurred in different sites. Two types occurred only once and thereby not used for analysis. Cracked bark supported maximum species (15), followed by warty and wrinkled bark and papery bark come next (Fig. 4.2.2e). Exfoliating barks supported a mean species richness of 2.20 ± 0.49, least of all.

Petitis model, Massarts and Luewenberg models did not occur more than two times. The mean number of species per tree was higher in C*hampagnat* (5.70 ± 1.04) and *Scarrones* (7.85± 1.54) models (Fig.4.2.2d). *Chamberlains* model had the least number of epiphytes (2.1± 0.44).

4.3 EPIPHYTE AND ENVIRONMENT

Environment in vertical zones

. Vertical temperature and humidity values were significantly different in all the fours sites (p< .001) showing vertical stratification of microclimate The mean temperature value at the lower zone (0.5m) was close to zero (0.1225±) in logged forests and edge forest (-0.8239±) indicating similarity with the open. Gaps and closed forests had lower temperatures than the open, the mean temperature value being above 1. As one moves up, the differences become less pronounced. As expected, the logged forests and the riverbanks showed a similar trend as above. But, the closed forests did not show significant differences from the riverbanks, mean values are -0.7226± and -0.7449± respectively. Since, vertical temperature and humidity were correlated, -0.727± for lower level, and -0.936± for canopy and -0.865 for middle layer, the same pattern was observed

Figure 4.2.2d. Epiphyte richness in different bark texture

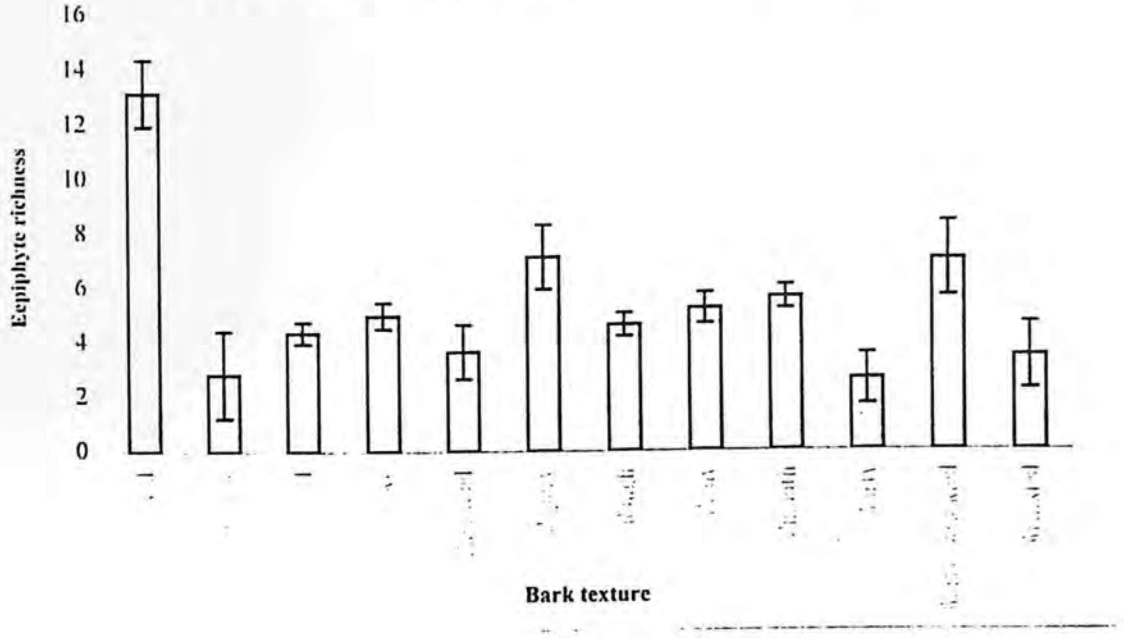


Figure 4.2.2e. Epiphyte richness in different architecture types

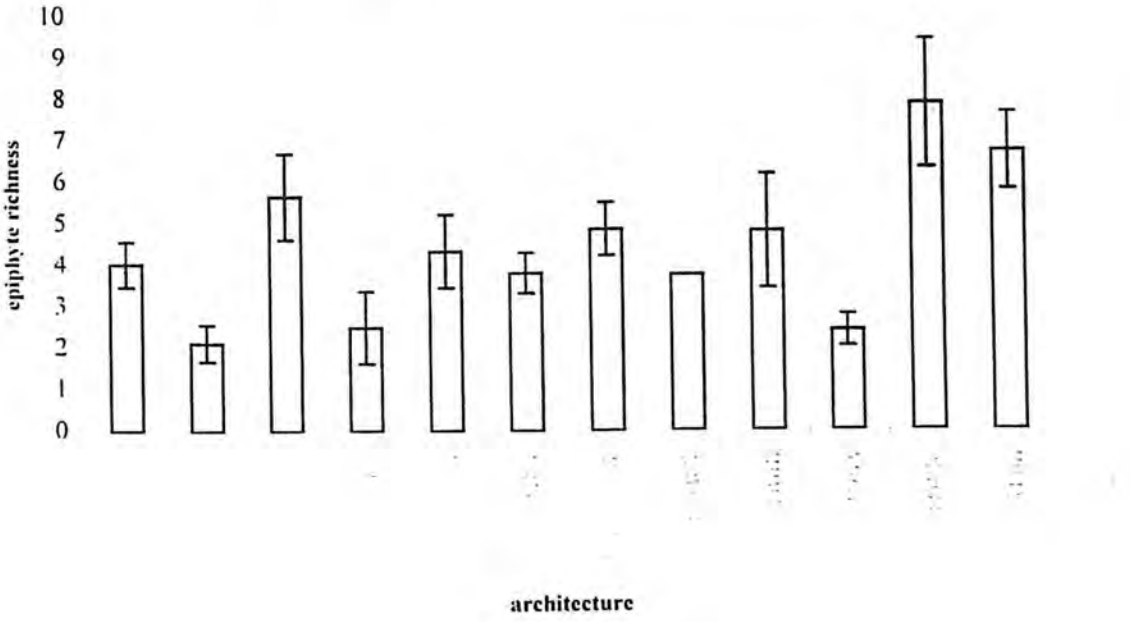


Figure 4.3a. Variation of light intensity in lower strata across sites

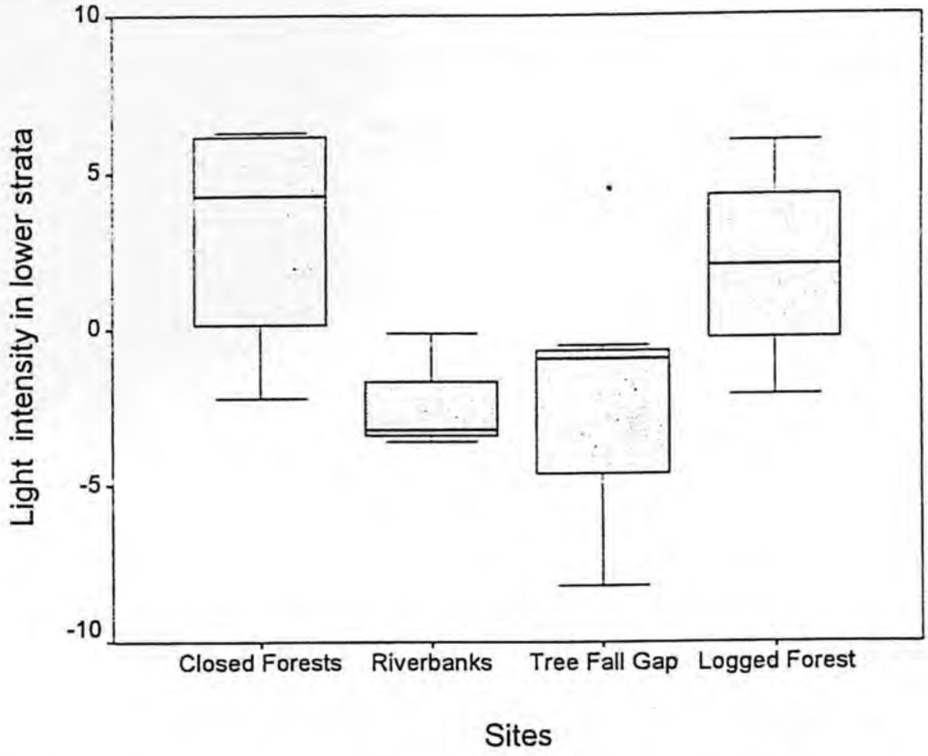


Figure 4.3b. Variation of light intensity in middle strata across sites.

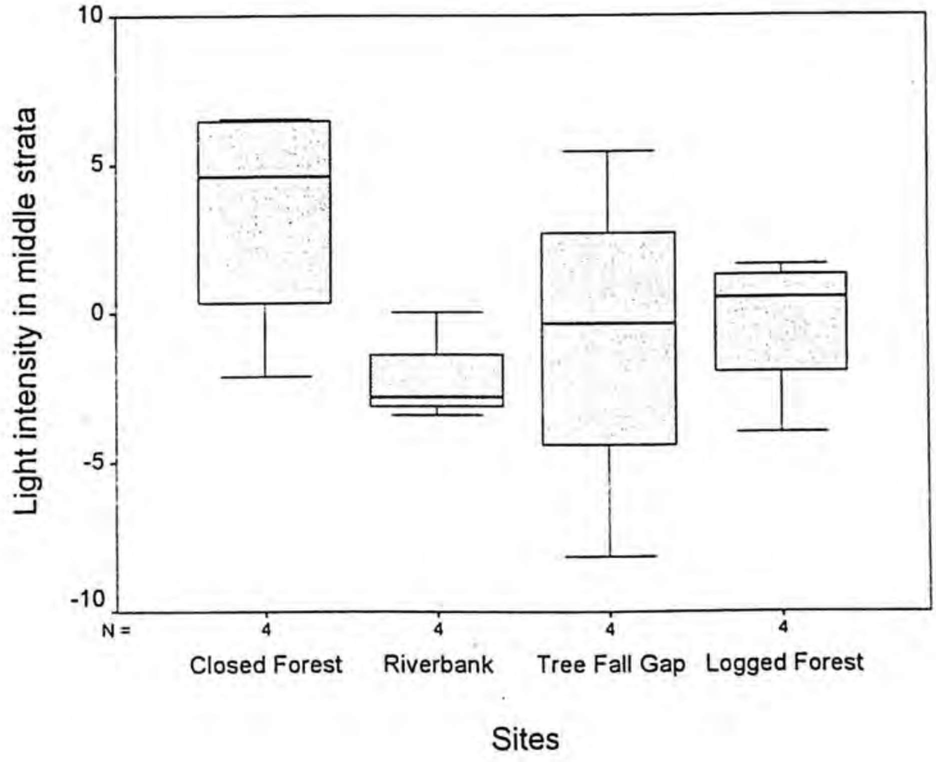


Figure 4.3d. Variation in canopy cover across sites

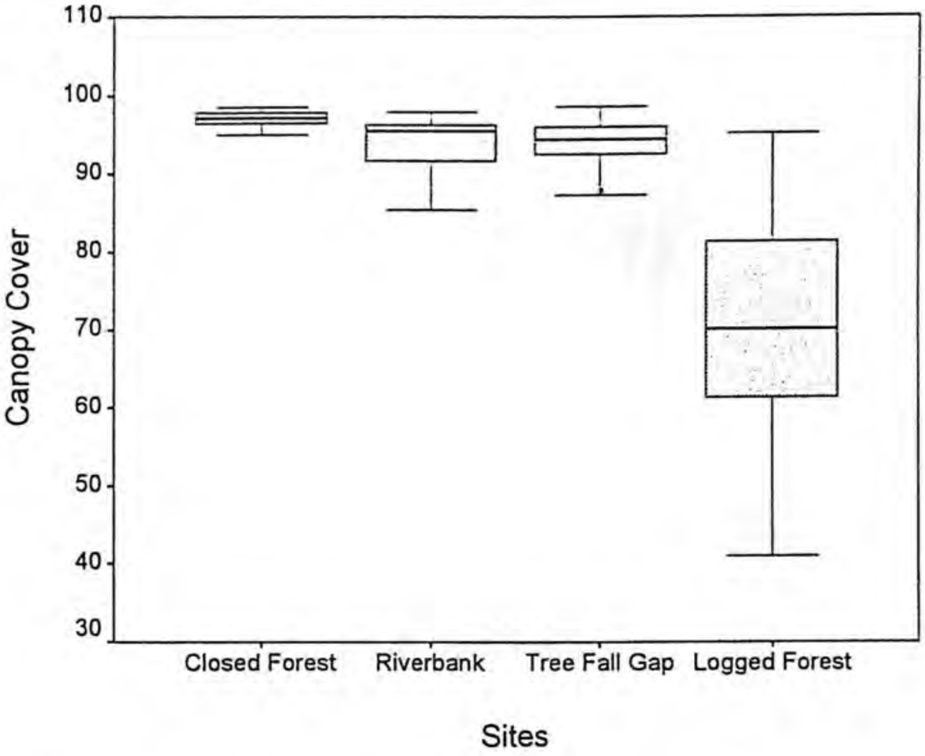


Figure 4.3e. Variation in temperature across sites

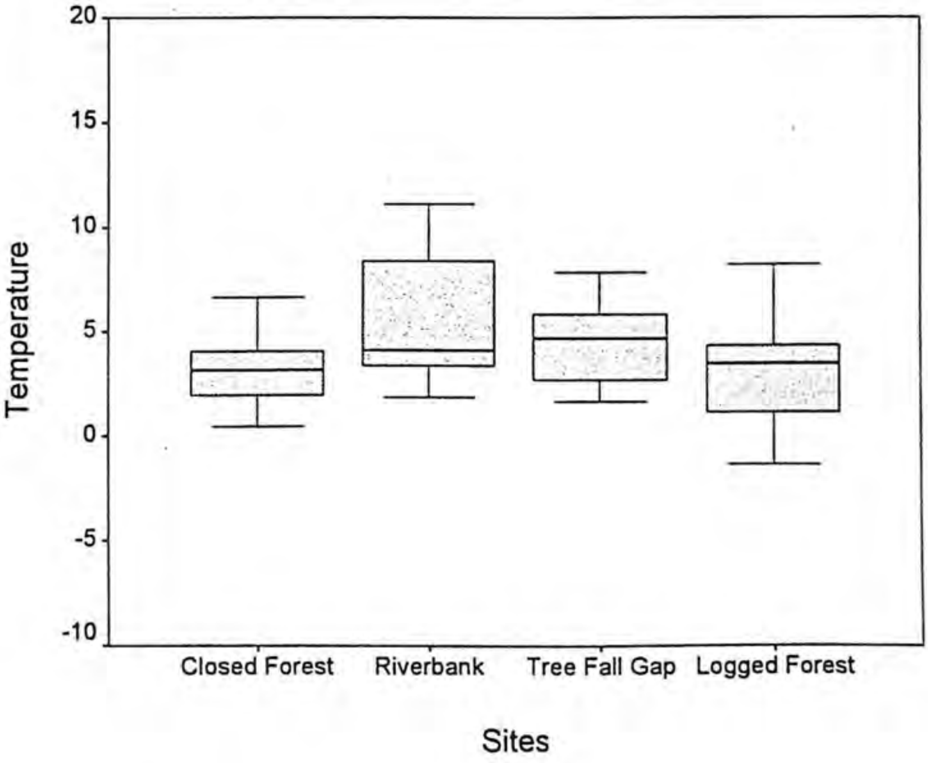


Figure 4.3g. Change in light intensity at horizontal zone in different strata

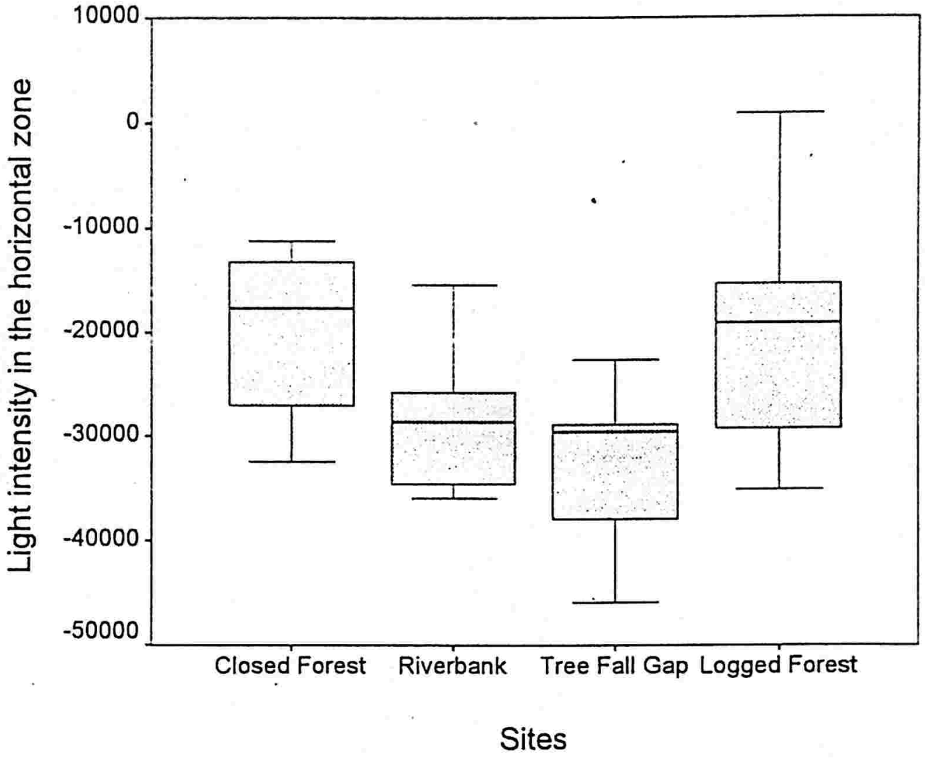


Figure 4.3f. Change in relative humidity at the horizontal zone in different strata

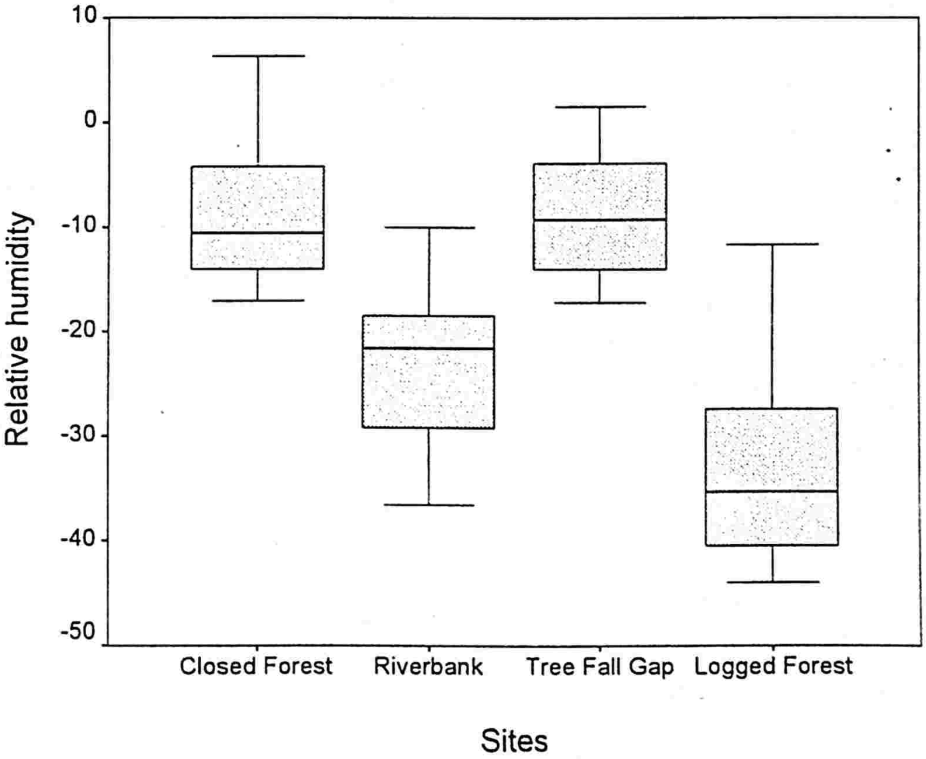
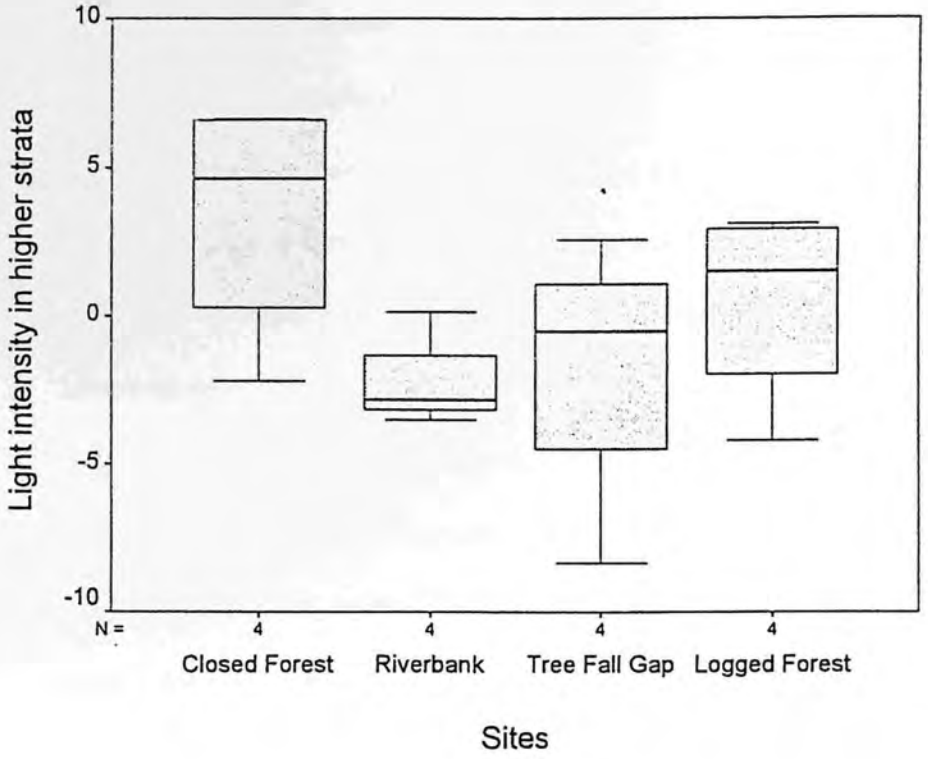


Figure 4.3c. Variation of light intensity in higher strata across sites.



in the relative humidity values in all the three vertical. The light intensity values did not differ significantly in the canopy and middle storey in all the sites. But, the light intensity in the ground level showed differences between sites (p<. 05) (Fig.4.3.a, 4.3.b, 4.3.c)

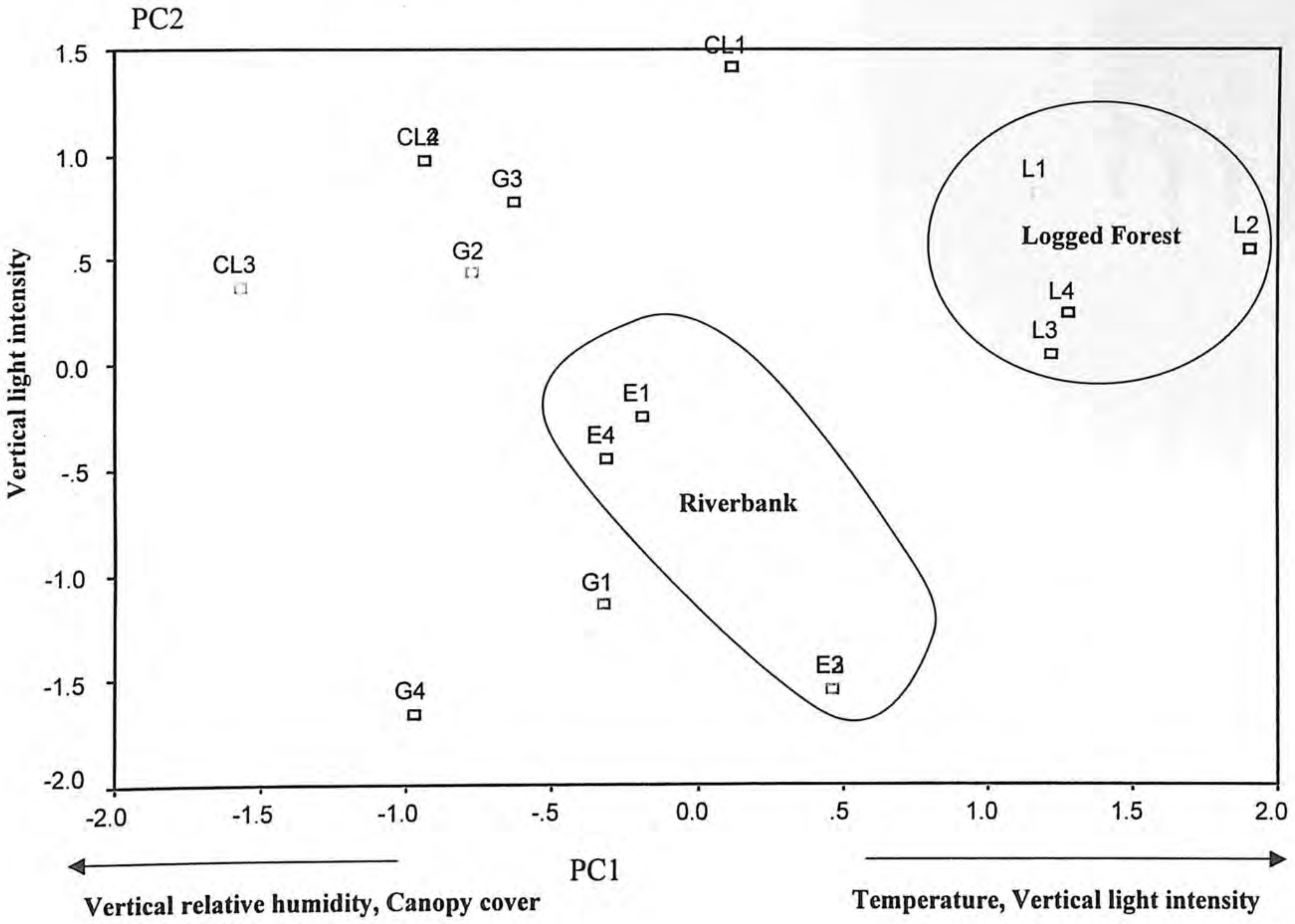
Environment in horizontal zone:

The percentage of canopy covered differed significantly between sites (p< .001). The canopy of logged forests was open (69%) compared to the other sites, which had mean canopy covers above 90%. Closed forests had the maximum mean cover of 96.91%. The temperature at one point of time (9-10 am) at 1.5m from the ground level was not correlated with the relative humidity. The relative humidity showed significant differences between sites (p<. 005). The relative humidity was not different from open in closed and logged forests. The relative humidity values are 8.56±4.14 and 9.30±2.92 in closed and logged forests. In the edges and tree fall gaps, the difference was high (26.5±2.79-edge, 32.24±4.89-gaps) reflecting the drastic variation in relative humidity. The light intensity differed in sites (p<. 01). While the differences in light intensities from the respective standard were high for closed, edges and gaps, logged forests showed the least difference from the open indicating the openness of the logged forest.

4.3.1 Extraction of principal components

There were several auto-correlated environmental variables when the correlation matrix was looked into. Therefore, data reduction technique i.e., Principal Component Analysis (PCA) was employed to extract meaningful components of environmental factors. This extracted three components, which explained 85% of the variance (KMO value-0.575). The other components were dropped for the purpose of analysis as the *eigen* values were less than 1. The first principal component was positively correlated with vertical temperature, light and relative humidity in horizontal zone and negatively correlated with vertical humidity and canopy cover. The second component was positively correlated to

Figure 4.3.2. Ordination of plots in relation to environmental variables



vertical light intensities (Table 4.3.1). The third component was positively correlated with temperature in the horizontal zone. Out of the three principal components, two explained 75.55% of the variance. Therefore, these two components were used for two-dimensional graphical interpretation. The graphs (Fig. 4.3.1a, 4.3.1b, 4.3.1c) present the scatter of all the plots in different sites in the environment space.

The component 1 can therefore be called as temperature-humidity component and PC 2 as the light component relates to increasing vertical light intensities. Logged forests had highest (-2.9820± 1.8) temperature and lowest relative humidity value, while closed forests and gaps had low temperature and high humidity. The edges had intermediate temperature and humidity. The effect of forest structure is pronounced in case of increase in vertical light intensity in the closed forests and decrease in horizontal light intensity. The horizontal light intensity was increasing towards the logged forests and it was the least (-32127.78±2193.86) in closed forests and tree fall gaps (-29211.68 ± 5837.82)

Correlation of epiphyte abundance with environment

The principal environmental components were correlated with the abundance of different families, as there were no significant relationships at the species level. Pearson's product moment correlation was done to establish the relationship between the different factors and the abundance of different families. Gesneriaceae, Araceae and Aspleniaceae were significantly correlated with PC1 (temperature-relative humidity-canopy cover component), ($p \leq 0.05$). Orhidaceae, Moraceae and Polypodiaceae were correlated with the PC3 (temperature at the lower sites), the horizontal temperature component, $p \leq 0.05$. The dominant families of the closed and tree fall gaps were correlated with component one, while the dominant family in the logged forests, Orchidaceae was correlated with PC3. These different environmental components were related to the genera abundances in a family in a similar fashion as their respective families.

Table 4.3.1a. Rotated component matrix for environmental variables

Category	F1	F2	F3
Canopy cover	-0.8321	0.0206	-0.1599
Light intensity	0.7230	-0.0901	0.2394
Temperature	0.0586	0.1242	0.9409
Relative Humidity	0.8775	-0.1240	-0.2386
Temperature in lower strata	0.9459	0.0047	-0.1349
Temperature in the canopy	0.9228	0.0244	-0.0527
Relative Humidity in the lower strat	-0.8451	-0.1171	-0.3569
Relative Humidity in the canopy	-0.9305	-0.1399	-0.0610
Light intensity in the lower strata	0.1637	0.9568	0.1182
Light intensity in the middle strata	-0.1343	0.9545	0.0657
Light intensity in the canopy	-0.0090	0.9774	0.0080

Table 4.3.1b. Rotated component matrix for environment variables in the trunk

Category	PC1	PC2	PC3
Canopy cover	-0.8931	-0.0038	-0.1044
Light intensity	0.8240	-0.0718	0.1706
Temperature	0.0454	0.1290	0.9586
Relative Humidity	0.8879	-0.0923	-0.2607
Temperature in lower strata	0.8756	0.0353	-0.1242
Relative Humidity in the lower strat	-0.8396	-0.1399	-0.3433
Light intensity in the lower strata	0.1571	0.9601	0.1055
Light intensity in the middle strata	-0.1657	0.9615	0.0688

Table 4.3.1c. Rotated component matrix for environment variables in the branch

Category	F1	F2
Canopy cover	-0.88	-0.05
Light intensity	0.77	0.02
Temperature	0.08	0.78
Relative Humidity	0.88	-0.26
Temperature in the canopy	0.89	0.05
Relative Humidity in the canopy	-0.90	-0.20
Light intensity in the canopy	-0.04	0.69

Table 4.3.1d. Correlation of environment factors with epiphytic families

Family	F1	F2	F3
araceae	**-0.6107	-0.3278	0.2176
ascelapiadaceae	0.1502	-0.1398	-0.3652
aspleniaceae	**-0.7277	0.0779	-0.2808
accidental	0.1323	-0.1894	-0.3733
gesneriaceae	**-0.5069	-0.1736	-0.2910
lycopodiaceae	0.0710	0.1419	-0.3284
moraceae	0.0174	-0.0745	**-0.6709
orchidaceae	0.2557	-0.1351	**-0.5137
polypodiaceae	0.1028	-0.2734	**-0.512
thelypterdaceae	-0.2293	0.0341	0.0695
urticaceae	0.1942	-0.1019	0.0087
vittariaceae	-0.1314	-0.3475	-0.3438

** significance at .05 level (2 tailed)

The spatial distribution of the most species rich family was done across sites using the software ARCVIEW . The plots were divided into 25 grids and the orchid abundance was overlaid on these grids. Corresponding temperature, relative humidity, canopy cover and light intensity values for each grid were all brought to one scale for facilitating comparisons across variables. It was very clear that orchids distribution were intimately related with light. As the light intensity decreased, the number of orchid species also reduced (fig.4.3.1d-g). Relative Humidity had the least influence; temperature and canopy cover was highly related to the abundance of Orchidaceae. Closed forests had the least abundace of orchids whereas the logged and the edges had higher abundances.

Detrended correspondence analysis

The species-environmental biplot, for the first two canonical axes, explained 63% of the variation. The detrended correspondence analysis was done for the epiphyte species ordination. The epiphytic community in the logged forest is shaped mainly by temperature, while the epiphytic community in the unlogged sites is influenced by relative humidity, canopy cover and light, auto- correlated variables (fig.4.3.1h-i)

Relationship of environment with trunk and canopy-dwelling epiphytes

The environment is stable in the trunk compared to the canopy as it is under the shade of canopy and well insulated from the fluctuations in the temperature and humidity and other factors. To test this, the trunk and the canopy were separately related with the environment at that level. The principal component analysis was done for trunk and branch environment separately. Three components were extracted from the trunk environment and two from the canopy. The PC1 of the trunk and branch environmental variables were negatively correlated with canopy cover and vertical relative humidity and positively correlated with horizontal light and temperature. The PC2 of the branch was positively correlated with both horizontal temperature and vertical light while the trunk

Figure 4.3.1d. Spatial distribution of orchidaceae in edge forest in relation to micro-climate

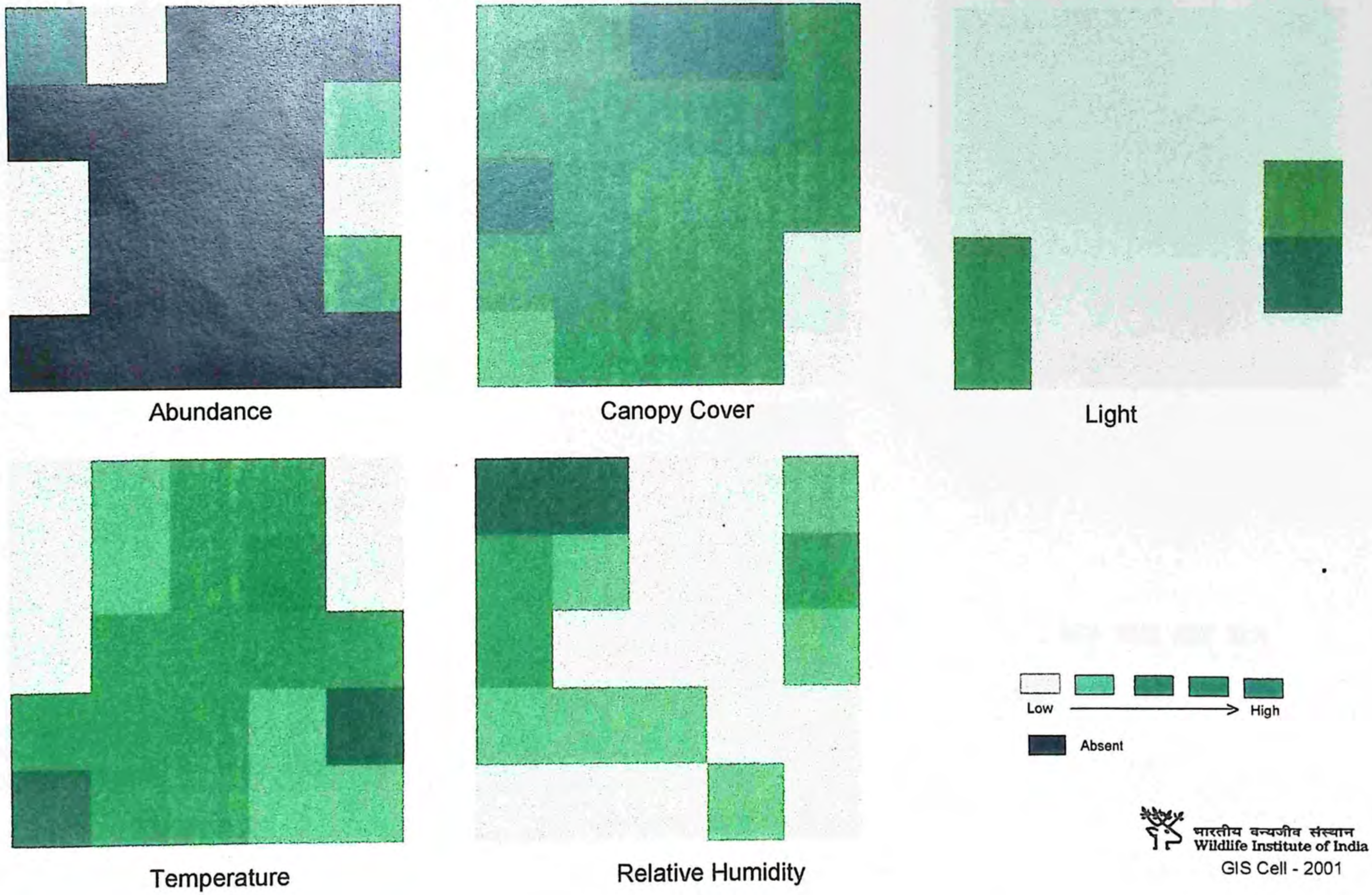


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Figure 4.3.1e. Spatial distribution of orchidaceae in tree-fall gap in relation to micro-climate

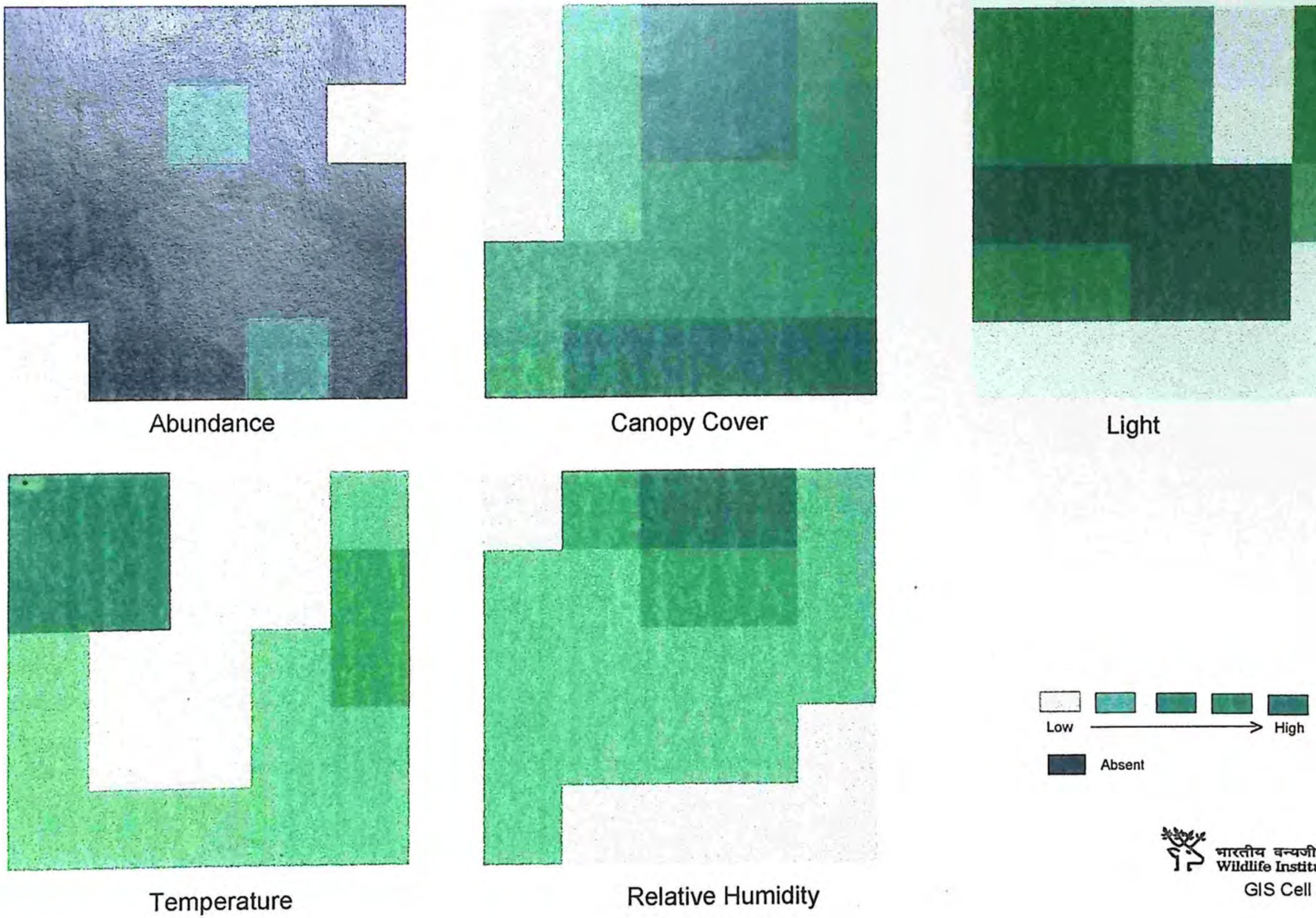

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Figure 4.3.1f. Spatial distribution of orchidaceae in logged forest in relation to micro-climate

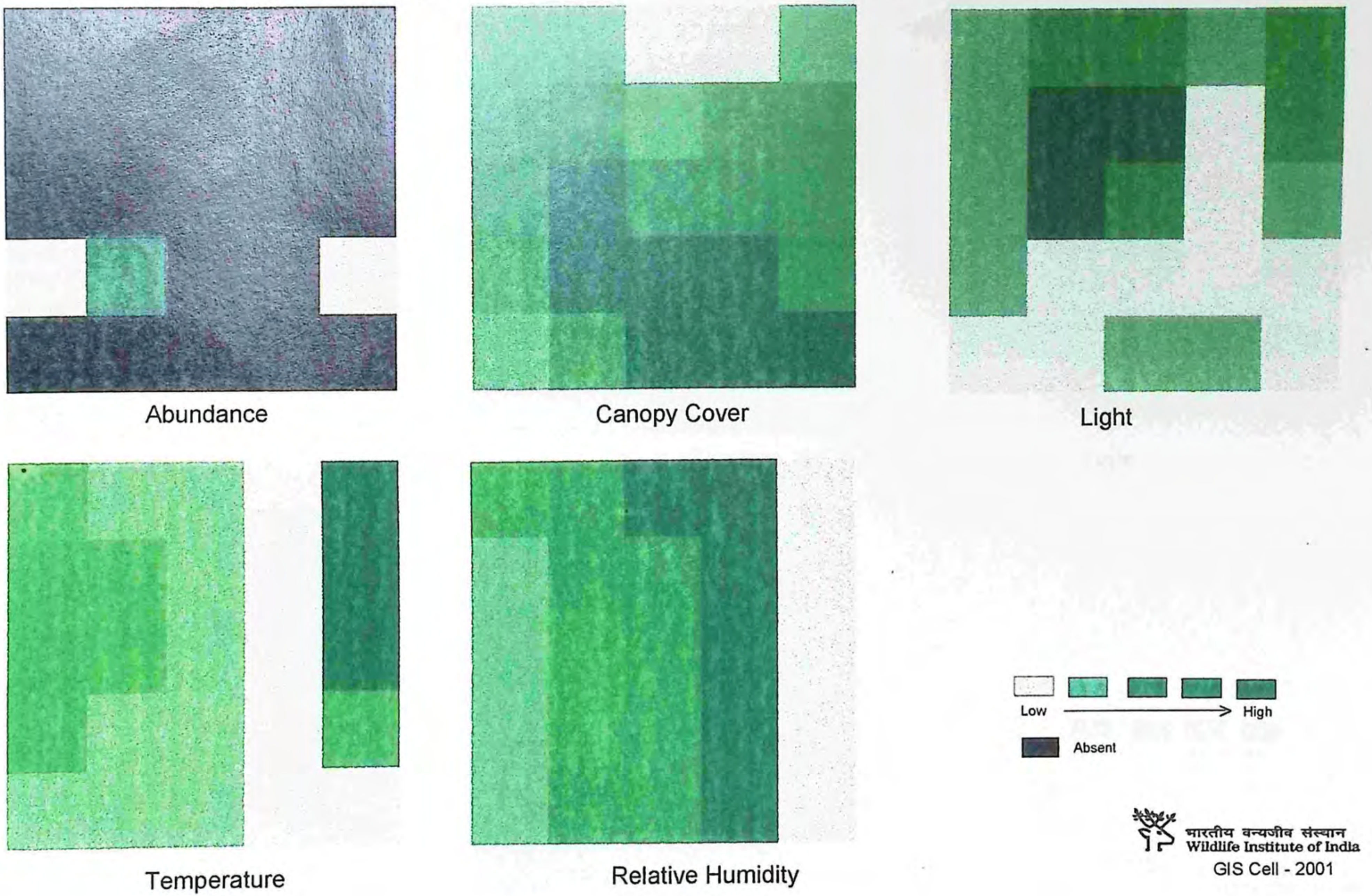
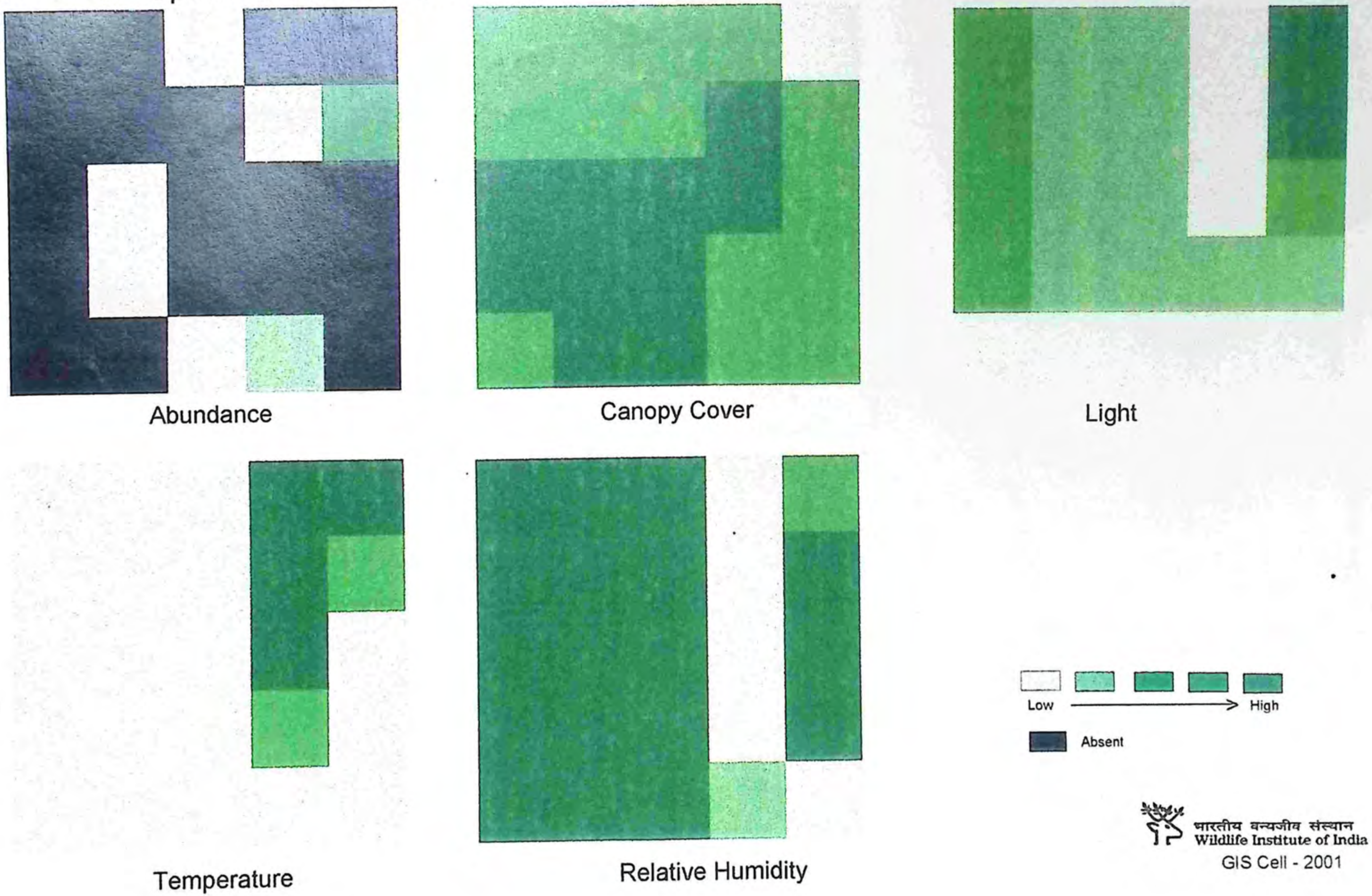


Figure 4.3.1g. Spatial distribution of orchidaceae in closed forest in relation to micro-climate



4.3.1h

Figure . Biplot of Epiphytes – Microclimate associations as constructed by Detrended Correspondence Analysis in CANOCO.

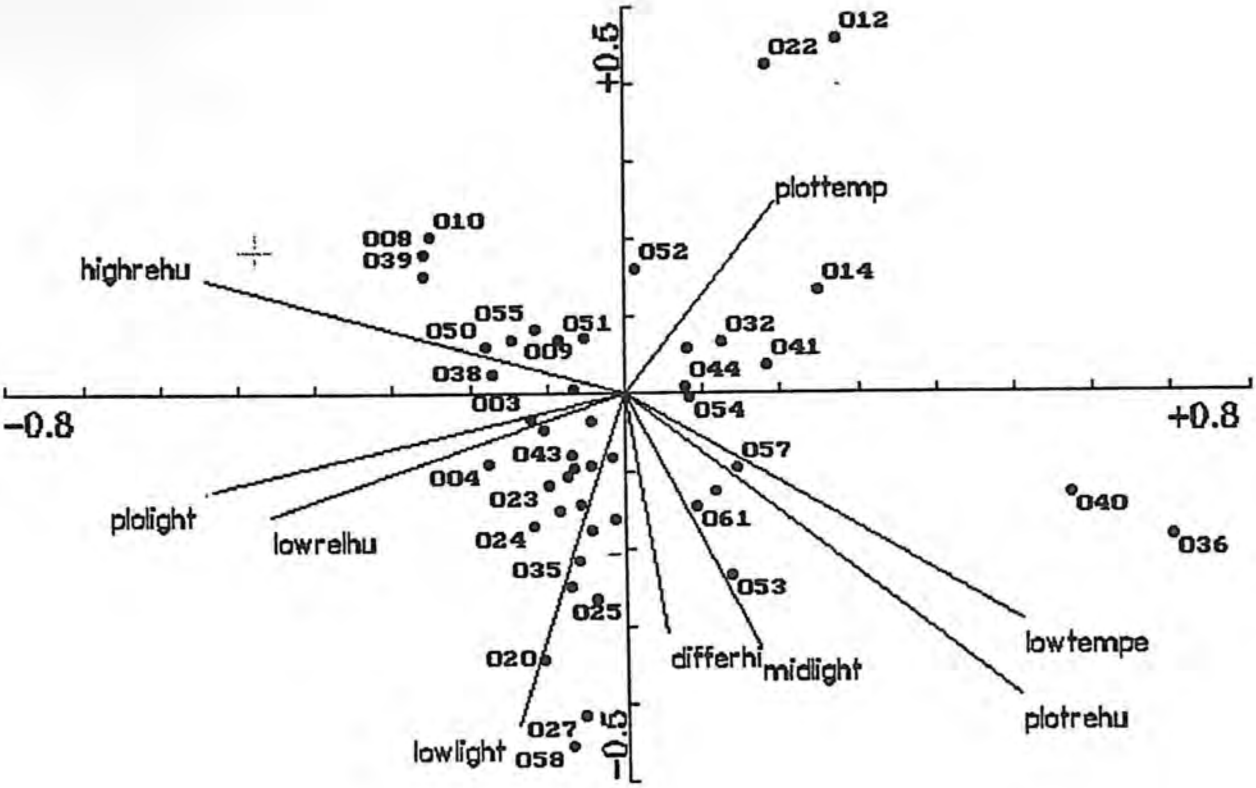
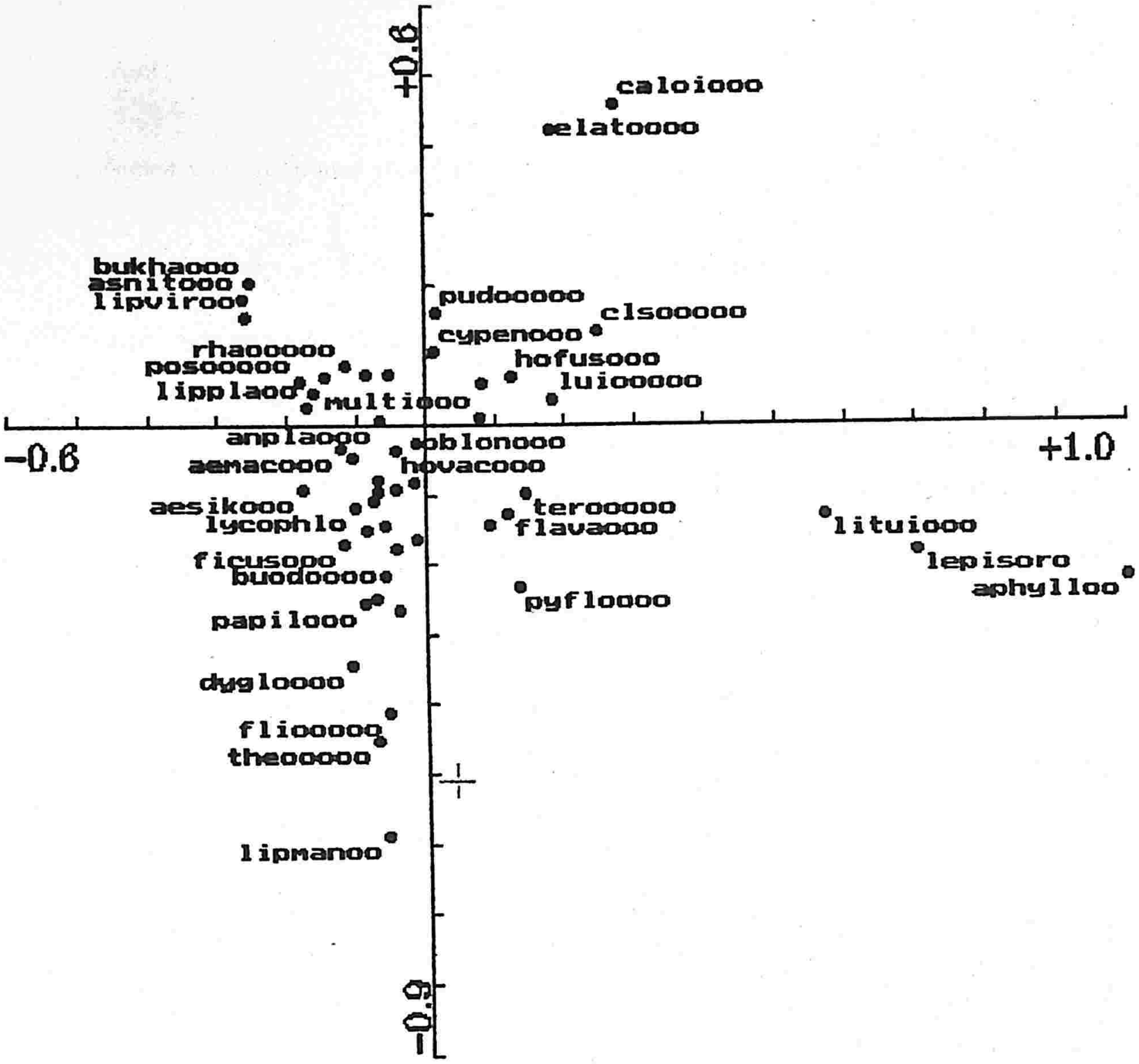


Figure. Epiphyte species distribution in ordination space by DCA in CANOCO
4.3.1i



had a separate component of temperature. This infers that in branches, there exists a correlation between light and temperature, whereas in trunk the change in the light need not relate to a change in temperature. The closed forests show a distinct clustering in the scatter of trunk components. In the scatter for branch environment, the closed forests and tree fall gaps occurred together indicating similar environment conditions in these forests in the trunk.

4.3.2 Forest structure and its relation with epiphytes

The bark types, host architecture models and host richness showed significant differences between sites (Table 4.3.2). The host abundances varied with site ($p<.05$). As expected, logged forests had lowest mean host species richness (4 ± 0.577) and abundances (5± 1.08), while the other sites were similar in host richness and abundance (Table 4.2.2b). The architecture types were similar in tree fall gaps and logged forests. Also, the closed forest, gaps and edges did not differ significantly for epiphyte species richness. The canopy width and surface area did not differentiate the sites. The mean number of higher girth class trees were also different between sites ($p<.10$). Most of the vegetation attributes differentiated only logged sites from unlogged sites.

The ordination of structural and compositional variables of vegetation yielded two components which had *eigen* values more than one. The first component is more composition-related as it is highly correlated host richness; bark richness, architecture types, host abundance (Table 4.3.2) and the second component is positively correlated with surface area, a structural variable. The only obvious result from the graph obtained by plotting the two regression factor scores is the separation of logged and other sites. As expected, the logged forest was very poor in composition-related vegetation variables because the number of trees was less. The correlation of vegetation factors with family

Table 2: Changes in vegetation structure and composition in different sites

Category	No. of big trees	Architecture	Bark texture	Canopy width	Host richness	Abundance of host trees	Surface area
Closed forest	$3.75^{a.b}$	6.25^{b}	6.25^{b}	10.08^{a}	10.50^{b}	15.00^{b}	19223.84^{a}
	-1.11	0.95	0.95	0.75	1.44	2.65	18817.19
Edge (river)	5.25^{b}	7.25^{b}	7.00^{b}	10.61^{a}	8.75^{b}	13.75^{b}	516.98^{a}
	0.85	0.75	0.58	0.90	1.18	1.11	52.21
Tree fall gaps	$3.00^{a.b}$	$5.00^{a.b}$	6.75^{b}	9.30^{a}	8.25^{b}	13.00^{b}	12926.07^{a}
	0.58	0.82	0.75	0.52	1.11	1.35	8145.72
Logged forest	2.25^{a}	3.00^{a}	3.25^{a}	11.22^{a}	4.00^{a}	5.00^{a}	198.73^{a}
	0.25	0.41	0.63	1.23	0.58	1.08	36.48
N	16	16	16	16	16	16	16
F ratio	2.79	5.85	5.51	0.85	6.03	7.32	0.85
	S*	S**	S**	NS	S**	S**	NS

Values in table represent mean values

Values in smaller font represent S.E.s

N: number of sample points in each successional category

F: parametric one way ANOVA

NS : not significant

S* : significant result ($p<0.10$)

S**: highly significant result($p<0.05$)
a-c: same alphabet in the superscript of variables indicate multiple comparisons that were not significant(duncans multiple range test ,$p<0.05$)

All the variables are numbers or means per 25m^2 area in different sites

Table 4.3.2a. Rotated component matrix for vegetation variables

Category	PC1	PC2
Architectute types	0.88	0.19
Bark texture	0.95	0.05
Abundanceof host trees	0.93	-0.01
Surface area of the host	0.07	0.95
Canopy width	-0.62	0.35
Host richness	0.93	0.01

Table 4.3.2b. Correlation of vegetation factors with epiphytic families

Family	VEG1	VEG2
Araceae	0.3205	0.1650
Ascelapiadaceae	0.2286	-0.1810
Aspleniaceae	**0.837	0.4038
Accidental	0.2472	-0.0252
Gesneriaceae	**0.7980	-0.0142
Lycopodiaceae	0.1958	-0.1807
Moraceae	0.2295	0.1138
Orchidaceae	0.0395	-0.0033
Polypodiaceae	0.2043	-0.2060
Thelypteridaceae	-0.0091	-0.1879
Urticaceae	0.0349	-0.2413
Vittariaceae	0.3157	-0.0339

abundance values showed significant correlations only for two families ($p<.001$) (Table.4.3.2b) Overall, the surface area did not correlate with abundance of families.

Ecological grouping of different sites

The different sites were reclassified based on the their similarities in epiphytic species composition and tested for differences in their environment. The epiphyte clusters showed significant differences based on the microclimate ($p<. 001$). The logged forests and the riverbanks formed separate groups, while the closed forests and gaps did not form respective groups. Two plots of each made one group by this classification. This indicates that the environment in the edges and logged forest are very different from the rest in their microhabitat.

5. DISCUSSION

To briefly recapitulate, epiphyte richness and abundance only differed marginally among the different sites, especially between closed forests, forest edges and tree fall gaps. This is due to the unevenness of understorey and also the individual and interspecific differences in the density of tree crowns. Therefore the epiphytic communities are not well defined at varying heights above the ground. (Benzing 1996). The microclimate, forest structure and composition were different among the sites and different families responded to these factors. Orchidaceae was found dominant in the logged forest and the riverbanks, while the closed forests and tree fall gaps were rich in members of Gesneriaceae, Aspleniacaeae and Araceae. In terms of epiphytes richness and abundance, riverbanks had the largest number of species.

5.1 Why do certain epiphytic families dominate in different sites?

Orchidaceae is the largest member family of epiphytes, which includes hundreds of genera and thousands of species of typical epiphytes. Orchidaceae formed 50% of the macroepiphytes (vascular epiphytes) in the different sites, although they were predominant in the human altered habitat (logged forest). All the species comes from only 11 families. It is very clear that orchid species increased in number in disturbed sites. The species area curves show maximum intercept values (0.33) for the logged. The proportional abundance and richness of Orchidaceae is equal (fig 4.1.1c) in riverbanks and logged forests indicating co-occurrence of higher number of species in a smaller area. This may be due to several reasons

Colonization

In the old world, orchids are commonly the first macro epiphytes to establish themselves in a new site, because of their water holding ability, they often provide starting points for other epiphytes (Johansson 1974). When seeds of epiphytic orchids reach the substrate much before ferns and angiosperms, they do behave like weeds (Sanford 1974). But, unlike weeds, it is rare for a single dominant orchid species to be found unless the site is highly disturbed and environmental pressure is great Orchids are exceptionally adapted to canopy life with their ability to use scarce resources with unusual effectiveness. (Benzing 1995). They have efficient water storage system, velamen, which prevents evaporation of water from their exposed roots. These properties make them excellent colonizers. So, we find predominance of family Orchidaceae in the logged forests. Riverbanks are also rich in orchid species. It is also very clear that forests in the riverbanks are the most diverse (Table.4.2, Fig.4.2b) among all the sites. Then, how can the disturbed site and the most species rich site be dominated by orchids. Orchids are wind dispersed and need mycorrhiza for their germination as they do not have endosperm. At any point in time, the seed bank in a cm^3 of air would be higher in the open places and along the riverbanks. The main difference is the constant supply of nutrients and moisture in the riverbanks due to persistent wind. Both trunks and branches are hospitable environment for colonization of epiphytes next to the river and there is a gradient of decreasing light intensity as we move inside due to luxuriant growth of trees. We get a heterogeneous environment, which favours different species as it meets the requirements of all the species. One peculiar situation in epiphytic succession is that it might not reach climax stage, because the host tree might die much before the climax is reached (Sanford 1974).

Competition

Epiphytic ferns and other angiosperms compete for resources with orchids (Sanford 1974). Removal of the competitors will favour the suppressed species. This might be the mechanism behind increased species richness in the disturbed site as protoepiphytes of family Gesneriaceae and Araceae and Aspleniaceae with poor water conservation mechanism fail to survive in the open habitats unlike Orchidaceae. There are two different strategies adopted by families of these different sites. Orchids try to maximize water storage by producing pseudobulbs, and thick leaves and occupying less surface area to reduce transpiration and evaporation. The shade living families maximize the area they occupy by climbing or twining, and capture the filtered light for photosynthesis. This explains for the dominance of certain groups in different sites (Table. 4.1.1). There might be yet another reason for the increased intercept value in the species area curve for the disturbed site (Fig.4.2.a). Probably it is very difficult to remove orchids from any exposed site due to advanced water storage. We also tend to infer that, species are disappearing from the disturbed forests, and the only remaining ones are the orchids. On further depredation, this might also disappear. We might have been quantifying in the lag phase as it takes many years for an orchid to establish.

If this holds true, the species found in the logged forest should be a subset of the undisturbed area. Species like *Dendrobioum anceps* and *Dendrobium aphyllum* deviate from this rule and they were not represented in the undisturbed sites even in the exposed riverbank edges. This supports the theory of colonization.

Habitat homogeneity and heterogeneity

The human eye simplifies and lump microhabitat together. The sharp contrast in day and night changes in these forests in relative humidity, light intensity and temperature, (Fig.4.3a) and differences in canopy cover (Fig.4.3d) creates a mosaic of micro environment. A complex set of vertical and horizontal gradients of environmental variables operate within this system and understanding these small changes in microclimate is very difficult (Leerdam et al. 1990). This creates suitable environments for different species to grow in concurrence. The main thing that makes logged forest different is the induced heterogeneity, where there are both remnant patches of relatively closed patches and also very open environment. One important thing that has to be kept in

mind is the seed source. As the logged forests are not very far from the undisturbed forests, there is no question of lack of seed bank. The main process determining the failure or success of a certain species would be its strategy to cope up with the created environment as explained earlier. Micospatial diversity regulates community diversity in many taxa. (Pianka 1966, Mac Arthur and Wilson 1973, Rosenzwieg 1969) As the canopy cover increases, large continuous patches appear and the abrupt pattern disappears in bird species diversity (Roth 1976). This will very well apply to epiphytes where the habitat is homogenous under the canopy in the trunk habitat and heterogenous in the canopy. That is the reason for the dominace of family Araceae is observed in the trunk (section 4.1.1)
The main difference might be the induced heterogeneity in the logged forests due to selective removal of certain trees and inherent natural heterogeneity. That is why there is an increase of species richness and accumulation in the logged forests also due to presence of both remnant species and new colonizers. I might have studied the transition phase where the colonized species is establishing and the remnants are disappearing in a very slow rate, because of the slow growing nature of the species. This might be the reason for the disappearance of family Gesneriaceae in the logged forests; the changes in microclimate will be dealt later in the discussion.

The fidelity of certain species to particular site shows that the closed forest and gaps are very similar in epiphyte species composition. In the river banks the richness values are much higher due to the reasons mentioned initially in the discussion. This may be due to microclimatic conditions or due to host characteristics of that particular site.

5.2 Epiphytes and Forest structure.

Changes in forest structure can influence epiphytes in two ways. First, by altering the microclimate and second by changing the nutrient availability, by influencing leachates, anchoring sites and the degree of ephemeral nature of the habitat. This is by influencing host species, and its bark and architecture. (Table 4.2.2d, 4.2.2e). It is therefore logical to discuss the influence of microclimate on epiphytes and relate host characteristics and epiphytes.

Host-Epiphyte relationships

The epiphytic species composition on the individual trees largely depends on the age and species. Went (1940) and Yamada (1995-1997) found that young trees below 10cm diameter at breast .height had only 38% of epiphytes. As the girth at breast height reflects the age of the species, in most cases, it was expected that trees of larger girth support large number of epiphytes. When the host trees were classified based on the girth classes (Fig.4.2.2 b,c,d), irrespective of the sites, all the small trees were very poor in species richness and all the large trees were species rich. This may be attributed to the different stages of colonization of non-vascular epiphytes (lichens and mosses) and creation of suitable habitat for the growth of macro epiphytes. The differences in abundance and richness differed according to the bark texture and architecture of the species. Cracked bark had the maximum species richness, while the exfoliating bark supported only three epiphytes per tree because the bark falls off easily if the epiphytic load increases. Warty and wrinkled bark has numerous tubercule like projections and folds in the bark, which acts a anchorage for the epiphytes.

The architectural model is defined by a combination of different morphological feature for e.g. monopodial or sympodial branching, determinate or indeterminate growth etc., Scarrone model supports maximum epiphyte because of multiple tiers of branches and increased asymmetry of the branch complex, a factor of increased surface area. In Champagnats model, the tree takes the form of shrub creating a environment where light reaches the crown at all levels faciliatitng epiphytic growth. Trees belonging to trolls model have only plagiotropic branches (perpendicular to tree axis), which facilitates easy settlement of epiphytic seeds. Also these branches have opposite phyllotaxy and thereby the leaves do not intercept all the light. Benzing (1996) said that the differences in epiphyte-phorophyte relationships might not be related to physical factors like roughness of bark and architecture etc., but the chemical differences in stem flow or the acidic or alkaline nature of the bark.

Epiphyte-environment relations

Microclimatological conditions change along the branch. The measurements of microclimate for a more temperate mountain forest in Japan, reveal the existence of gradients in mean temperature, vapour pressure deficit, mean wind velocity and spectral quality of light. (Leerdam etal 1990). The epiphytic habitat is different from the other habitats because it is exposed to a wider range of microclimates than the terrestrial habitat. Certain species grow in sunny exposed areas, showing preferences to high light intensities, while some other species can come up entirely in shade. The most important regional environmental determinant of epiphyte success is highly linked with rainfall distribution over the years (Gentry and Dodson 1987). Cool and continuously humid sites support the greatest diversity and usually the largest biomass of arboreal flora. But, local gradients are also important in determining the commuity of epiphytes (Benzing 1995).

The relative humidity and temperature values were plotted against time of the day to see the changes in microclimate in a day between sites. As mentioned earlier, the relative humidity and temperature were negatively correlated. From graph.1 it is clear that the relative humidity values are negative for the logged forests and positive for all the other sites. The temperature and relative humidity near the ground level had the minimum standard error (Figure 4.3.1) indicating equitable microclimate at this zone at all sites reflecting the effect of vegetation cover. The relative humidity was maintained at a constant level from 7 pm to 7 am. Around 9.30 am the relative humidity value reaches the maximum and falls gradually till 7 pm. But the temperature becomes constant onlyafter 9-9.30 pm till 6.30-7 am in the morning. The difference in temperature from the open becomes pronounced between 7 am and 7 pm. The temperature is lower under vegetation cover during the day till 4 pm after which the forests remain warm till 7 pm indicating that the microclimatic effects of vegetation. Overall, the logged forests do not differ from the open.

At the middle storey, the logged forests show maximum fluctuation in temperature and humidity during the day (Figure 4.3.1 b). Conversely, the relative humidity fluctuated more than temperature in this zone. While the temperature was almost constant throughout the day except between 3 pm to 7 pm, the relative humidity reached constancy only around 8:30 pm till around 8 am. Up in the canopy, whichis exposed to insolation, wind, the same trend of variation as in the middle layer was observed. The relative humidity of logged forests in the canopy was more consistent throughout the day than the other sites (Figure 4.3.1c) temperature varied drastically during the day in all the sites.

Trunk

In a closed forest, there are microclimatic gradients from soil level to the canopy level. While the environment conditions are extremely stable in the lower layers, they almost approximate open environment in the canopy. As trunk is protected from climatic variability, it can be said that it is a stable environment. This might not hold true for riverbanks, because they face variation in insolation, wind speed, inundation. As mentioned before, trunks of logged forest are totally exposed or colonized by *Mikania,* a weedy climber. So, the microclimate varies between each site in the trunk. Although the temperature fluctuates, the relative humidity remains constant throughout. This is the reason, why *Rhapidophora lancifolius* dominates in the closed and tree fall gaps and in only one plot of logged forests. The next dominant family in this site was Orchidaceae. This is supported by the significant correlation of this family with Principal Component 1 (refer table and graph). Orchidaceae is correlated with PC3, a temperature component. This also proves that there are different microhabiats in the logged forest.

Canopy

Canopy microclimate and the stand microclimate are closely related and one keeps influencing the other in many ways, which is beyond the scope of this study. Ideally, the microclimate of the canopy should not differ significantly between sites, as the forests are multilayered, except for the logged forests were the canopy continuity is lost. The species richness in the canopy was marginally different unlike the trunk (Table. 4.2). The number of species might be the same, but the species composition is the key factor of distinguishing different sites. Unlike the trunk where one species dominated, Canopies are taken over by many species belonging to the major families in different sites, which is very similar to the overall dominance of families in that site. This also implies that the species richness and abundance of epiphytes in the branches influences the overall patterns and masks the differences and similarities in the trunk.

Gesneriaceae is dominant in the closed forests mainly by *Aeschynanthus gracilis and Aeschynanthus macualata*, all having climbing life forms.The canopy of tree fall gaps comprise of *Asplenium nidus* and *Asplenium nitidum* , which are basically humus accumulating trash basket types to cope with the sudden changes in the environment where big gaps are found between canopies. The logged forests and the riverbanks are rich in orchids due to high degree of insolation, even in the lower canopy. It is very interesting to see the correlations of different families with the Principal Components of the branches. None of the families correlate with the temperature- humidity component of the branch. While Aspleniaceae and Gesneriaceae correlated to the humidity, temperature and canopy cover component PC1. Because both the lower canopies and upper canopies where combined, most of the families were found. Steege and Cornelissen (1989) found maximum number of species in the lower canopies of the forest, and the families are also spatially separated in different regions in the canopy (Nieder et al 2000).

5.3 Habitat specialists and generalists

With few plots in each site, it would be difficult to classify if the epiphytes observed are generalists or specialists. Assigning the status of specialists to any epiphytic species would not be easy, as the study is short termed and the area surveyed and sampled is less than 20 $km^{2.}$ With the observed patterns, I have put them into such categories based on their distribution. Specialists can be trunk or branch specialists or it can have fidelity to certain sites. The genera *Hoya* was found in all the sites. If we look into the life history, these species exhibit high degree of succulence in the growth form and therefore can occupy in fully exposed areas. Their ability to twine and climb along with their succulency helps them to spread very fast and in high abundance. Not all species of orchids are found in the disturbed forest. Except for two species of *Dendrobium* all the orchids found are subsets of the species found in the undisturbed area. *Cymbidium pendulum, Liparis manii,* was found only in the riverbanks and *Pronephrium spp* a climbing fern occurred only in the tree fall gaps. Humus accumulating birds nest fern; *Asplenium nidus* did not show any specific affiliation. But, *Asplenium nitidum* , a rarer species occurs only in the tree fall gaps and closed forests, basically in the interior of the forests. Closed forests had 3 orchid species, *Liparis plantaginea, Bulbophyllum devanagiriensis and Dendrobium nobile* has been exlusive to closed forests. But, during reconnaissance *Dendorbium nobile* was also found in the riverbanks on old trees. The number of non-orchidaceae members in the generalist's category was around 56% and fifty percent of those species were contributed from the dominant families.

There were certain species, which were present either in the trunk or branches. Only four species of non-orchidaceae members were specializing the trunk or canopy as their habitat. *Lycopodium phlegmaria and Vittaria elongata* were found in the branches of trees in the undisturbed sites.

Conclusions

Vascular epiphytes are a diverse group of plants consisting of monocots, dicots, and pteridophytes adapted to live in a soil- less environment trapping moisture and nutrients from the host substrate and atmosphere. Epiphytes are influenced by numerous environmental factors and the host on which they grow. The microclimate in the tropical forests is so diverse, numerous epiphytes occur in different heights responding to local environmental gradients. The present study attempted to document the response of epiphytes to change in microclimatic regimes in trunks and canopy caused by natural and man made changes in their habitat. Disturbance, logging, has caused an overall reduction in the number of epiphytic species as it has reduced the number of host trees and thereby their richness.. It should also be kept in mind that different families respond in different ways to disturbance, While the families with a wide range of tolerance like Asclepiadaceae and Orchidaceae are found in all the sites, species belonging to Gesneriaceae tend to avoid highly disturbed habitats. Ferns respond differently. Humus accumulating ferns like *Asplenium nidus* did not show any preference for their habitat. Polypodiaceae, which produces fleshy leaves occur in all the sites.

Logged forests as such is depauperate in epiphytic species, while the river banks had the maximum due to constant recolonization as there are seeds available in the air especially during post monsoon time and most important the trees in those sites have access to these seeds and spores. Permanent availability of nutrients and moisture and light adds to the cause of increased species diversity in the undisturbed riverbanks. This act as gene pools as they spread the epiphytes towards the interior of the forest and also to other places by releasing millions of seed and spores, which are readily carried away by the wind. Logging affects the epiphytes by directly removing their hosts. Further, if the big trees

(180-520cm GBH were spared, they did support many epiphytes, no matter wherever they were (Fig.4.2.2d, e). The number of rare species reduced by half in the logged forests. This decreasing trend tells us how fast the rate of species extinction is and if this is not checked we are going to lose these biological nomads.

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Appendix 1. Presence Absence matrix of epiphytes in different sites

Species	**Closed**	**Banks**	**Gaps**	**Logged**
Strobilanthes spp		▨		
Aeschynanthus gracilis	▨	▨	▨	▨
Aeschynanthus macualatus	▨	▨	▨	
Aeschynanthus sikkimensis	▨	▨	▨	
Eria amica	▨			▨
Antrohymus plantaginea	▨	▨	▨	▨
Dendrobium aphyllum				▨
Asplenium nitidum	▨		▨	
Asplenium nidus	▨	▨	▨	▨
Bulbophyllum khasianum	▨			
Bulbophyllum odoratissimum	▨	▨		
Cymbidium aloifolium		▨		▨
Cleisocentron trichromum		▨		▨
Cleisostoma subulatum	▨	▨	▨	▨
Cymbidium pendulum		▨		
Dendrobium anceps				▨
Dendrobium catcarthii	▨	▨	▨	
Bulbophyllum devanagiriensis	▨			
Dendrobium moschatum	▨	▨	▨	▨
Drymoglossum heterophyllum	▨	▨		
Eria ferruginea	▨	▨		▨
Elatostemma rupstre		▨	▨	▨
Eria fragrans	▨			
Ficus spp	▨	▨	▨	
Ficus hookeri		▨		
Eria flava	▨	▨	▨	▨
Flickingeria fugax		▨	▨	
Ficus rhododendrifolia	▨			
Gastrochilus spp	▨	▨	▨	▨
Agrostophyllum khasianum	▨			
Bulbophyllum guttulatum	▨	▨	▨	▨
Hoya fusca	▨	▨	▨	▨
Hoya lanceolata	▨	▨	▨	▨
Hoya vaccinioides	▨	▨	▨	▨
Pholidota imbricata	▨	▨	▨	
Lepisorus spp		▨	▨	▨

Species	**Closed**	**Banks**	**Gaps**	**Logged**
Liparis manii		▨		
Liparis plantaginea	▨	▨		
Liparis viridiflora	▨		▨	
Dendrobium lituiflorum			▨	▨
Luisia tricorhiza	▨	▨	▨	▨
Lycopodium phlegmaria	▨			
Lycopodium selago		▨	▨	
Aerides multiflorum		▨		▨
Dendrobium nobile	▨			
Dischidia raffesiana		▨	▨	
Eria pannea	▨		▨	▨
Papilionanthe teres		▨	▨	
Phalanopsis manii				▨
Pothos scandens	▨	▨	▨	
Pronephrium			▨	
Eria pudica	▨	▨	▨	▨
Pyrossia flocculosa	▨	▨	▨	▨
Pyrossia nummularia	▨	▨	▨	▨
Rhaphiodophora lancifolius	▨	▨	▨	▨
Eria stricta	▨	▨	▨	▨
Pteroceros suaveolens	▨			▨
Thelasis longifolia		▨	▨	
Vittaria elongata	▨	▨		
Vittaria subconfluens		▨		
Aerides williamsii	▨	▨	▨	▨