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Effects of selective logging on vascular epiphyte diversity in a moist lowland forest of Eastern Himalaya, India

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Abstract

Effect of selective logging on vascular epiphyte diversity was investigated in a moist lowland forest of Eastern Himalaya. Three epiphytic groups viz. orchids, pteridophytes and non-orchid angiosperm epiphytes were specifically studied in closed, selectively logged and in unlogged forests with treefall gaps. Logging reduced the structural complexity of the forests and altered their microclimate. With logging, there was a general decline in richness and abundance of epiphytes except orchids. The abundance and species composition of pteridophytes and non-orchid angiosperm epiphytes were related to microclimate and substrate features while their richness were correlated only with canopy cover. In contrast, orchid species composition was related to forest structure. A combination of management strategies is required for conservation of all epiphyte groups. A mosaic of logged and unlogged forest patches with undisturbed forests in proximity would maintain the diversity of pteridophytes and other angiosperms. However, for full representation of orchids, it is necessary to maintain the structural diversity of the tree forms.

Keywords: Selective logging; Vascular epiphytes; Pteridophytes; Orchids; Environment; Rainforest

1. Introduction

Lowland rainforests are one of the most threatened tropical habitats in the world and are the most prolific of all plant communities (Collins, 1990). In India, these forests are restricted to a few pockets in Eastern Himalaya, and Western Ghats, both of which are recognized as biodiversity hotspots (Myers et al., 2000). The lowland forests in the foothills of Eastern Himalaya are tropical evergreen or semi-evergreen and are known for their valuable timber trees. Selective extraction on a commercial scale has been carried out extensively in these forests in the recent past (Katti, 1992; Katti et al., 1992). This procedure involves harvesting of a certain proportion of the commercially valuable trees from a forest (Johns, 1985). Even though this proportion is about 4%, as much as 50% of the stand suffers heavy incidental damage during logging operations (Johns, 1983, 1988). Very often, the trees extracted are random in terms of both individuals and tree species cut as opposed to being selected methodically (Johns, 1983).

Vascular epiphytes form a quarter of the entire flora in a lowland rainforest (Collins, 1990; Gentry and Dodson, 1987). Since epiphytes are adapted to life above the soil layer, their dependency on the environment is higher than their terrestrial counterparts (Engwald et al., 2000). Furthermore, the colonization and establishment of vascular epiphytes is a very slow process, hence a small disturbance in the epiphytic succession would affect the seral stages and ultimately their growth (Zotz, 1995; Nadkarni, 1999). These factors make epiphytes sensitive to changes in the environment. Epiphytes also influence ecosystem processes such as mineral cycling and nutrient storage (Benzing, 1995). They also provide habitats and resources for many arboreal arthropods, frogs,

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salamanders and a variety of macro- and micro-flora (Benzing, 1996). These characteristics make vascular epiphytes potential indicators of habitat quality. It has also been suggested that epiphytes can be used as bioindicators of climate changes, pollution and ecological damage (Richter, 1991; Lugo and Scatena, 1992).

Logging affects epiphytes by reducing the available habitat and by altering the microclimate in the forest (Barthlott et al., 2001). When large trees are removed, epiphytes that either require large branches as substrate or those with a long life cycle will be affected by changing their population structure. Large openings in the canopy reduce the abundance, distribution and diversity of shade epiphytes because they require high atmospheric humidity (Hietz, 1999). About 62% of vascular epiphytes were reported to be extinct from Singapore owing to extensive deforestation in the last decade (Turner et al., 1994). Studies done by Hall (1978) in Ghana established that the abundance of epiphytes reduced by four times in secondary forests when compared to closed canopy forests. Other studies emphasize the importance of big trees in maintaining the "epiphyte species capital" and how they could act as potential nuclei for further dispersal of epiphytes and their regeneration in forests (Freiberg, 1996; Barthlott et al., 2001). Most research on the impact of logging in tropical areas has been done on birds and mammals (Johns, 1985; Thiollay, 1992; Datta, 1998).

There has been no study on the impact of forestry practices other than clear cutting on epiphyte diversity in the tropics (Hietz, 1999), apart from a case study on the response of non vascular epiphytes to forest disturbances by Kuusinen (1996).

The present paper describes the effects of selective logging on diversity and species composition of vascular epiphytes in a lowland rainforest in northeast India based on a quantitative study and suggests strategies for their conservation.

2. Study area

2.1. General description

The study was conducted in lowland, semi-evergreen forests of Pakhui Wildlife Sanctuary and the adjoining Doimara Reserve Forest located at the foothills of the Eastern Himalaya in the state of Arunachal Pradesh, India (27°06′N and 92°48′E) from November 2000 to April 2001. The Kameng River separates the reserve forests from the wildlife sanctuary. The terrain is undulating and slopes south towards the Brahmaputra Valley. It has a tropical climate with mild winter during November to January. The area receives heavy rainfall between May and November while occasional rains occur throughout the year. The average annual rainfall is 2500 mm as recorded in the Tipi Orchid Research Station. Mean annual maximum temperature is 29.3 ± 2.0 °C (absolute max 35 °C), while mean annual minimum temperature is 19.9 ± 3.9 °C (absolute min 9.5 °C). The altitude ranges between 500 and 850 m above mean sea level. The area experiences high-velocity winds during morning and evening, being located in Kameng River valley, which is narrow in the upper reaches and abruptly widens in the lower reaches, creating a funnel shaped orography. The river banks are inundated during peak monsoon (June–September).

The vegetation type of the study area has been categorized as Assam Valley Tropical Evergreen Forests (Champion and Seth, 1968). The emergent species were *Tetrameles nudiflora* and *Altingia excelsa*. The forests were dominated by evergreen trees of Lauraceae, Elaeocarpaceae and Euphorbiaceae with only a few deciduous species. The predominant species were *Talauma hodgsonii* and *Pterospermum acerifolium*. This forest was a matrix of treefall gaps and closed patches rich in lianas and climbers. The undergrowth was about 1.5 m high in the treefall gaps and 0.5 m high in the closed canopy areas. Logged forests had large openings in the canopy and were characterized by dense, impenetrable undergrowth about 2 m high.

2.2. Logging history

Prior to the declaration of Pakhui Wildlife Sanctuary in 1977, the low-lying forests on either side of the river were managed under a single forest division. The forests on the eastern banks were protected naturally because the river restricted the movement of people for six months a year (April–October). The forests of Doimara Reserve forest on the eastern bank were logged under the 'selection system' where trees were selectively felled and allowed to regenerate naturally (Sen, 1978). The history of selective logging in this area is unclear and it is suspected that this practice may have started in the late 1960s and continued until 1996 when there was a ban on tree felling by the Supreme Court of India. Prior to this ban, sawmills and plywood mills operated in this area and mill contractors extracted about 1670 m^3 of wood every year from an area of 216 km^2 (Datta and Goyal, 1997). About 60 species of trees were felled and girth classes above 350 cm were sawn while trees of girth 150–240 cm were removed for the manufacture of plywood. The estimated extraction rate was 7 trees per hectare (Datta and Goyal, 1997). The major species exploited were *A. excelsa*, *Ailanthus grandis*, *Artocarpus chaplasha*, *Canarium resiniferum*, *Castonopsis* spp., *Chukrasia tabularis*, *Duabanga grandiflora*, *Mesua ferrea*, *Morus laevigata*, *Terminalia myriocarpa* and *Phoebe goalparensis* (Datta and Goyal, 1997).

3. Methods

The selectively logged, unlogged forests with treefall gaps and closed forests were sampled using stratified random sampling. The minimum distance between two plots within a stratum was 150–200 m. The treefall gaps varied in size and shape depending on the crown structure and whether the tree was a part of the general canopy layer or the emergent layer. In each of these three habitats, four quadrats each of size 25×25 m were laid. Within these plots host characteristics, epiphyte abundance and environmental parameters were quantified.

3.1. Sampling of epiphytes

Within the study plots in each habitat, all tree species more than 5 m high and above 30 cm girth were considered for sampling epiphytes. Each host tree was divided into three-meter vertical zones. Bamboo poles were used to an approximate height of 12 m and higher zones were further delineated trigonometrically by measuring angle of elevation and ground distances. As only one half of the tree is visible from any point, estimation of epiphytic cover was done at two different aspects to cover the entire circumference. Individual species of epiphyte was estimated using binoculars (8×40) in each three-meter zone. Since vascular epiphytes are a composite group and most of them are modular in nature, it was difficult to count the individuals within a clump. The simplest method of quantification was ocular estimation of the percentage cover (projection of epiphytes on the bark surface) of the epiphytes on the trees. Epiphytic cover was quantified for the entire trunk, roughly 50% of primary branches and 20% of secondary branches. Since ocular estimates are subjective and prone to biases, data collection was standardized during the initial phase of the project. The surface-area of each cylindrical zone of the tree was calculated. The effective sampling area from each observation point was half of the circumference of the tree. The effective sample area was half of the surface area calculated. The area occupied by a paper square of size 25 cm^2 pasted within this zone was further estimated. By means of comparative proportions, the probable area occupied by an epiphyte was deduced. It was found that this estimate did not largely differ from the ocular estimate of percentage epiphyte cover even in the higher zones. Tertiary branches were not considered for sampling owing to poor visibility from the ground. These percentages were then converted to Braun–Blanquet's cover classes (Mueller-Dombois and Ellenberg, 1974) for analysis.

3.2. Quantification of habitat variables

The following characteristics of the host trees were noted: height estimated using a clinometer, girth measured at breast height, bark texture (http://www.botfeatures/index.html) (The Mildred E. Mathias, 2000) and tree-architecture after Halle et al. (1978). Temperature (°C) and relative humidity (%) were measured at two heights: 0.5 m and 15–16 m to capture the variation in the environmental variables on the vertical plane and establish relationships with species diversity and composition. Data loggers (Hobo Pro Series$^{\text{TM}}$) for recording temperature and relative humidity (recording interval – 30 min) were placed in these height zones on trees for a minimum of 4 days and a maximum of 10 days in each plot. Light intensity was measured at all these heights using the luxmeter between 9 a.m. and 10 a.m. A temperature and humidity data logger of the same type was placed outside the forests, on an open river bank, as a standard. This was done to account for seasonal variations in the environmental parameters. Therefore, the absolute values of temperature and relative humidity in the open riverbank for a particular date and time were subtracted from the corresponding values in different habitats. Similarly, the ambient light intensities were recorded outside the forests in open riverbank and these values were subtracted from the readings taken in the forests.

3.3. Data analyses

The epiphytic assemblage was divided into pteridophytes, orchids and other angiosperm epiphytes. The epiphytic abundance was calculated as the sum of Braun–Blanquet cover classes for a given epiphyte species in each three-metre zone on the tree. The species composition of different epiphytic groups is the relative abundance of individual species in that group. The variation in epiphytic abundance was compared across habitats using the Kruskal–Wallis test (Zar, 1984). The indices of diversity (Magurran, 1988), rarified species richness and Bray–Curtis coefficient of similarity based on species composition (Krebs, 1989), were calculated using the software Biodiversity Pro (1997). Rarified species richness is a measure of species diversity, which is robust to sample size effects, permitting comparison between communities where, for example, densities of organisms are very different.

$$E(\mathrm{S}) = \sum \left\{ 1 - \left(\binom{N - N_i}{n} \Big/ \binom{N}{n} \right) \right\},$$

where $E(\mathrm{S})$ is the expected number of species, n the standardized sample size, N the total number of individuals recorded, N_i the number of individuals of the ith species.

Log series index of species diversity,

$$\alpha = \frac{N(1-x)}{x},$$

where α is the index of diversity, N the total number of individuals, $0.9 > x > 1$.

Similarity between sites based on species composition was given by 1−B, where

$$B = \frac{\sum_{i=1}^{n} |X_{ij} - X_{ik}|}{\sum_{i=1}^{n} (X_{ij} + X_{ik})},$$

where B is the Bray–Curtis measure of similarity, X_{ij}, X_{ik} the no. of individuals in species i in each sample, n the number of species.

All the habitat variables were tested for normality. The differences in habitat conditions were tested using one-way parametric ANOVA. Suitable multiple range tests were done to test differences across habitats based on the presence or absence of homogeneity of variances. All habitat variables were then correlated with the calculated richness and abundances of the three epiphytic groups to find out the species environment relationships. Triangular matrices of similarities in habitat variables and species composition were calculated and correlations were derived between these matrices using Mantel's randomization test (Manly, 1997).

4. Results

Of the 173 trees sampled for vascular epiphytes in all habitat types, 132 trees (76%) supported at least one vascular epiphyte. The proportion of trees colonized by epiphytes differed across habitats. About 82% of trees in closed forests and 75% of trees in the treefall gaps were colonized by vascular epiphytes, while only 69% of trees in the logged forests had vascular epiphytes.

4.1. Epiphyte composition in different habitats

The epiphytic assemblages of unlogged forests with gaps and closed forest were similar (Fig. 1). Closed forest and treefall gap habitats were represented by 9 and 11 families, respectively. A total of 50 species of epiphytes belonging to 26 genera and 11 families were recorded within the lowland old growth forest. There were 46 species of holo-epiphytes (species that do not have any contact with the ground) and four species of hemi-epiphytes (species that spend part of their life as epiphytes) in the sampling area. Orchidaceae was the most species rich family (52% of the total) but its abundance was only 10% of the total. Gesneriaceae and Aspleniaceae were found to be abundant (24%) represented by three and two species respectively. The epiphytic assemblage was represented by five pteridophyte, four dicot and two monocot families.

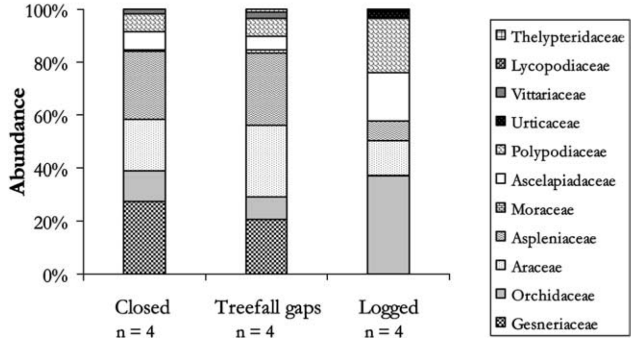

Fig. 1. Epiphyte assemblages in different habitats. Proportional abundance of epiphytic families in different habitats. Note the prominent absence of Family Gesneriaceae in the logged forest.

Thirty-one species of epiphytes belonging to seven families were found in logged forests. Two big trees of more than 3 m girth contributed 30% of epiphyte species in this habitat. The epiphytic assemblage in the logged forest was dominated by Orchidaceae in species richness (54.8%) and abundance (36.7%). Families Gesneriaceae, Moraceae, Lycopodiaceae and Thelypteridaceae were not represented in this habitat. Three species, *Dendrobium anceps*, *Dendrobium aphyllum* and *Phalaenopsis manii* were found only in the logged forest.

4.2. Species abundance and richness across habitats

Pteridophytes and angiosperm epiphytes other than orchids were found in higher abundances in the closed forests and treefall gaps when compared to logged forests (Table 1, Kruskal–Wallis test, Pteridophytes, $\chi^2 = 7.42$, $p < 0.05$, other angiosperm epiphytes $\chi^2 = 7.76$, $p < 0.05$). Orchid abundances did not differ across habitats.

The alpha diversity and rarified species richness of different epiphyte groups were higher in the unlogged forests (Fig. 2). The difference was marginal for orchids and pteridophytes across habitats. The rarefaction curve of species richness for pteridophytes for the logged forests (Fig. 2(a)), seem to flatten out faster than the unlogged forests indicating fewer rare species.

4.3. Similarity in epiphyte species composition across habitats

The magnitude of similarity across different habitats varied for the three epiphyte groups. Closed forests and treefall gaps showed greater similarities in overall epiphytic species composition when compared to logged

Table 1
Epiphyte abundance (Mean ± SE) per plot[a] across habitats

Habitats	Orchids	Pteridophytes	Non-orchid angiosperm epiphytes
Closed forests	43.88 ± 21.44	128.50 ± 29.36	207.88 ± 39.01
Treefall gaps	28.25 ± 4.70	120.75 ± 20.94	170.00 ± 37.24
Logged forests	35.13 ± 11.30	27.75 ± 6.97	32.75 ± 14.09

[a] The size of the plot is 25 m × 25 m.

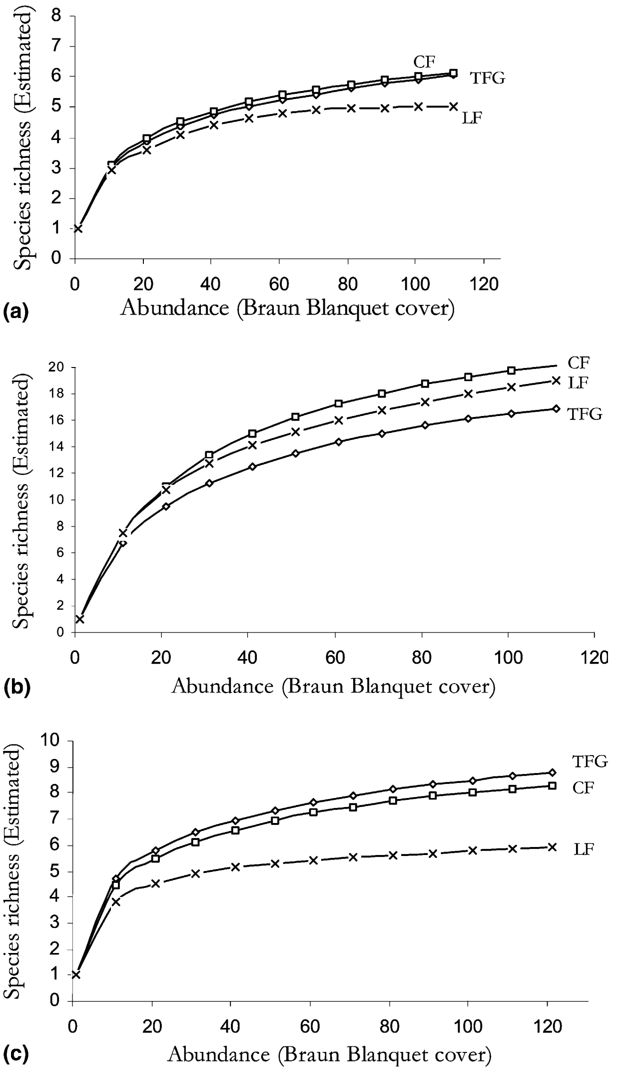

Fig. 2. Species accumulation curves of epiphytes in different habitats, shown separately for three epiphytic groups (2a, 2b, 2c). The points in the curves are rarified species richness for a given epiphyte abundance. The habitats are represented by CF – Closed forests, LF – Logged forests, TFG – Treefall gaps.

Table 2
Epiphyte richness across habitats

Epiphyte groups	Closed forests	Treefall gaps	Logged forests
Orchids	7.08	5.56	6.38
Pteridophytes	1.35	1.36	1.08
Non-orchid angiosperm epiphytes	1.60	1.87	1.30

The richness estimates are log series alpha values for different habitats.

Table 3
Similarity in species composition of three epiphytic groups across habitats

	Treefall gaps	Logged forests	Epiphyte groups
Closed forests	93.3	33.9	Pteridophytes
Treefall gaps	*	36.5	
Closed forests	54.4	49.7	Orchids
Treefall gaps	*	39.5	
Closed forests	77.9	24.5	Non-orchid angiosperm epiphytes
Treefall gaps	*	26.1	

The values are Bray–Curtis distance coefficient of similarity.

forests (Bray–Curtis distance). While the species composition of pteridophytes and non-orchid angiosperm epiphytes was similar in treefall gaps and closed forests, it differed in the logged forests (Table 2). The species composition of orchids showed little difference across the habitats. However, the species composition of orchids in the logged forests were more similar to closed forests (49.7%) than to treefall gaps (39.4%) (Table 3).

4.4. Changes in habitat variables

In the logged forests, temperature and light intensities at all height zones were higher and the relative humidity was lower when compared to treefall gaps and closed forests (Table 4). The canopy cover, bark texture richness and architecture richness were significantly higher in the closed forests and treefall gaps than the logged forests (Table 4). While the girth was significantly higher in the logged forests when compared to the tree fall gaps and closed forests (one way ANOVA, $F_{2,9} = 4.098$, $p = 0.018$), tree height did not vary across different habitats (one way ANOVA, $F_{2,9} = 0.590$, $p = 0.556$). The greater girths are presumably because of the absence of trees of smaller girth classes in the logged forests and inclusion of the girth of an emergent tree while computing mean girth, which escalated their values. Closed forests and tree fall gaps did not show any significant differences in variation in all the habitat variables.

4.5. Relationship between habitat variables and epiphytes

The abundance of pteridophytes and non-orchid angiosperm epiphytes was positively correlated with relative humidity, canopy cover, architecture richness and bark richness, and negatively correlated with temperature (Table 5). The species richness of epiphytic pteridophytes and non-orchid angiosperms showed positive correlations only with canopy cover (Table 5). It was found that richness and abundance of orchids did not show significant correlations with any of the measured habitat variables.

When the relationship between species composition of epiphyte groups and habitat variables was examined, substrate feature emerged to be a significant influencing variable (Table 6). Habitats similar in pteridophyte communities had similar bark texture composition and

Table 4
Summary of habitat variables measured in different habitats

Habitat variables	Closed forests	Treefall gaps	Logged forests	*F* ratio	*p* values
Difference in Temperature from open river bank (°C)					
at 0.5 m*	−0.88 ± 0.39 ^{a}	−0.80 ± 0.15^{b}	0.11 ± 0.10^{c}	425.34	<0.001
at 15–16 m*	−1.64 ± 0.69^{a}	−1.58 ± 0.24^{b}	0.15 ± 0.12^{c}	181.76	<0.001
Differences in relative humidity from open river bank (%)					
at 0.5 m*	16.88 ± 5.31^{a}	17.39 ± 1.15^{b}	−5.28 ± 5.07^{c}	515.92	<0.001
at 15–16 m*	8.84 ± 3.69^{a}	8.60 ± 0.77^{b}	−1.30 ± 0.67^{c}	341.29	<0.001
Difference in light intensities (lux) *from open river bank*					
0.5 m *	−31964.68 ± 1719.44^{a}	−26936.02 ± 1398.86^{a}	−19218.35 ± 3351.22^{b}	15.88	<0.001
15–16 m *	−31962.52 ± 1723.98^{a}	−29301.42 ± 2190.48^{a}	−15498.50 ± 3179.77^{b}	6.16	0.003
Canopy cover (%)*	96.91 ± 0.19^{a}	93.65 ± 0.95^{a}	69.65 ± 3.56^{b}	48.810	<0.001
Girth (m)*	1.06 ± 0.08^{a}	0.95 ± 0.07^{a}	1.48 ± 0.15^{b}	4.10	0.018
Height (m)	16.39 ± 0.65^{a}	16.18 ± 0.71^{a}	18.22 ± 1.33^{a}	0.59	0.556
Bark richness*	6.25 ± 0.95^{a}	5.00 ± 0.82^{a}	3.00 ± 0.41^{b}	5.80	0.041
Architecture richness*	6.25 ± 0.95^{a}	6.75 ± 0.75^{a}	3.25 ± 0.63^{b}	4.66	0.024

a–c – Same alphabet in the superscript of the variable indicate multiple comparisons that were not significant (Tamhane's multiple range tests), $p < 0.05$, one tailed.

Table 5
Relationship between species richness and abundance of three epiphytic groups with habitat variables

Habitat variables	Richness			Abundance		
	Pteridophytes	Non-orchid angiosperm epiphytes	Orchids	Pteridophytes	Non-orchid angiosperm epiphytes	Orchids
Difference in temperature (°C)						
at 0.5 m	−0.41	−0.34	0.57	−0.76*	−0.73*	0.53
at 15–16 m	−0.4	−0.37	0.54	−0.67*	−0.68*	0.54
Difference in relative humidity (%)						
at 0.5 m	0.59	0.56	−0.3	0.71*	0.78*	−0.4
at 15–16 m	0.42	0.43	−0.53	0.78*	0.81*	−0.49
Canopy cover	0.63*	0.87*	0.04	0.77*	0.81*	0.07
Architecture richness	0.5	0.37	−0.29	0.87*	0.61	−0.01
Bark richness	0.42	0.49	−0.37	0.85*	0.74*	−0.13
Girth	−0.58	−0.49	0.31	−0.73*	−0.70*	0.33
Height	−0.48	−0.44	−0.12	−0.42	−0.33	−0.11

The values are Pearson's correlation coefficient *r*.
* Correlations significant at $p \leqslant 0.05$, two tailed.

tree species composition, while habitats similar in non-orchid angiosperm epiphyte assemblages had similar differences in relative humidity, canopy cover and tree species composition (Table 6). The similarity in species composition of orchids was related only to similarities in tree height.

5. Discussion

5.1. Species richness, abundance and composition across habitats

The responses of different epiphyte groups to logging varied with respect to their richness and abundance. With logging, non-orchid angiosperm epiphytes showed clear decline in abundance and richness (Tables 1, 2 and Fig. 2(c)). The most affected family was Gesneriaceae, with not even a single member being found in the plots of logged forest (Fig. 1) because they need a humid and shady environment for their survival and establishment.

Habitat conditions, particularly canopy cover (shade) and relative humidity, were significantly lower in the logged forests (Table 4), and the members of family Gesneriaceae appear to have responded predictably to these altered microclimatic conditions as also recorded by previous studies, for example Barthlott et al. (2001) who found that members of Gesneriaceae were not found in the secondary forests in the Venezuelan Andes.

Table 6
Relationship between species composition of three epiphytic groups with habitat variables

Habitat variables	Species composition		
	Pteridophytes	Orchids	Non-orchid angiosperm epiphytes
Difference in temperature (°C)			
at 0.5 m	0.28	0.04	0.42
at 15–16 m	0.44	0.12	0.49
Differences in relative humidity (%)			
at 0.5 m	0.17	0.16	0.147
at 15–16 m	0.50*	0.09	0.59*
Difference in light intensities (lux)			
0.5m	−0.20	−0.08	0.17
15–16 m	−0.25	0.05	0.14
Canopy cover	0.28	0.01	0.40
Girth	0.24	0.27	0.11
Height	0.04	0.56*	−0.14
Bark composition	0.73*	0.48	0.48
Architecture composition	0.22	−0.15	0.51*
Tree species composition	0.57*	0.01	0.61*

The values are Mantels correlation coefficient r. The values in parentheses are p values.

* Correlations coefficients above 0.50 and also significant at $p \leqslant 0.05$.

While pteridophyte abundance was reduced by six times due to logging (Table 1), there was only a marginal reduction in species richness (Table 2). Pteridophytes proliferate in conditions of shade and high humidity (Andrade and Noble, 1997), and the general exposure they received in logged forests caused a drastic reduction in their abundance. Such a trend was not apparent in the species richness of this group due to two reasons. Some 'generalist species' occurred in a wide range of conditions; for example two species of the family Polypodiaceae are known to grow even on exposed tree trunks (Baishya and Rao, 1991). The second reason was that a few moist and shady pockets were present in logged forests making it possible for shade tolerant species of the Vittariaceae and Aspleniaceae to survive. Similar observations were made by Barthlott et al. (2001) in the secondary forests of La Carbonera of Venezuela. Species diversity of pteridophytes may therefore be maintained even in logged forests if small patches of forests are left uncut. To ensure maximum diversity of pteridophytes in these patches, they would have to be near undisturbed forests that would act as source for propagules.

There was no reduction in orchid cover and richness across habitat types. However, a single emergent tree in the logged forests contributed around 40% of the total abundance and 30% of the total species richness of orchids. The general adaptation of orchids to temporary water stress (Walter, 1971) and their ability to grow in drier and more sun-exposed areas of the upper canopy (Smith et al., 1985; Smith, 1986) irrespective of the forest types, makes them inappropriate indicators of disturbances for a study of this type. Previous studies have recorded that isolated large trees can support a considerable number of epiphytes and suggest that these trees act as nuclei for further dispersal (Freiberg, 1996; Heitz et al., 1996). However, this held well only for orchids in the present study, and retaining larger trees in logged forests would help in conserving orchids at least.

5.2. Similarity in species composition across habitats

Species composition of pteridophytes and other angiosperm epiphytes in treefall gaps and closed forests is similar, presumably because of similar habitat conditions (continuous canopy and humid understorey and substrate characteristics, Table 4), but differed in logged forests. However, the species composition of orchids was not as similar between these habitats because of the presence of many exclusive species; closed forests had 7 such species, and treefall gaps had 3. The species composition of orchids in logged forests was more similar to closed forests than to treefall gaps because in closed forests, multiple layers of trees are exposed to high light and temperature regimes resembling habitat conditions in logged forests. It can also be due to the presence of certain non-timber host species left uncut in the logged forests and in the closed forests which harboured orchids leading to similarity in orchid species composition. The natural forest with treefall gaps, perhaps, represent a different community with fewer potential host trees. Furthermore, similarities in orchid assemblages were related to tree height, a variable that did not vary across habitats (Table 6).

5.3. Relationship of epiphytes with habitat variables

From the observed trends, it is apparent that the abundance and composition of pteridophytes and non-orchid angiosperm epiphytes were related to host and environmental variables, while orchid abundance and composition were not. It becomes clear that pteridophytes and other angiosperm epiphytes would be drastically affected by large openings in the canopy and the subsequent changes in the environment and host characteristics. Orchid abundance and richness do not seem to associate with any of the measured variables and this might be attributed to the adaptations of orchids to stress and to the fact that suitable array of habitats is always available, even in logged forests. However, since orchid species composition is related to forest structure, cutting big trees would also affect them.

6. Conclusions

Changes in richness and abundance of different taxa have often been attributed to responses to disturbances (e.g. Thiollay, 1992). Abundance values do not consider the nature of species that contribute to the overall cover or the number of individuals. Similarly, richness values overlook the nature of species and give equal weight to all the species. However, abundance and richness values coupled with species composition would address the overall response to disturbance in a much better way. It is evident from this study that non-orchid angiosperms and pteridophytes are suitable indicators of disturbance caused by logging even at small scale because of their sensitivity to changes in tree species composition and relative humidity.

Logging definitely reduces species diversity in lowland forests all over the world. In the state of Arunachal Pradesh, because only 18% of the forests are protected, a considerable proportion of forests are vulnerable to commercial exploitation.

Based on the findings of this study it is suggested that varying approaches be adopted for conservation of epiphytic groups. In case of orchids, remnant larger trees within logged forests continue to ensure their survival. However, a range of age classes coupled with a variety of tree forms (e.g. emergents) is necessary to provide the structural diversity required for full representation of this group. This emphasizes the need for creation of a mosaic of timber harvest patches that are created over a much longer time scale than presently has been applied. The diversity of other vascular epiphytes can be maintained only if patches of forests are left uncut in logged areas. These patches should be in close proximity to undisturbed forests to act as source of propagules for effective recolonisation of epiphytes. Since lowland forests offer a wide range of habitats for different epiphyte groups and are constantly under threat, due to their easy accessibility, immediate attention is necessary to protect these special habitats. By adopting simple management strategies as suggested in this paper, the conservation of epiphytes and their associated life forms is possible even under conditions of selective logging.

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Appendix A

Species composition of epiphytes in different sites. ❖ - Holoepiphytes, ❖❖ - Hemiepiphytes ø, indicates presence of species

S.No.	Species	Closed forests	Treefall gaps	Logged forests	Type
	Araceae				
1	*Pothos scandens*	ø	ø		❖❖
2	*Rhaphiodophora lancifolius*	ø	ø		❖❖
	Asclepiadaceae				
3	*Dischidia raffesiana*		ø		❖
4	*Hoya fusca*	ø	ø	ø	❖
5	*Hoya lanceolata*	ø	ø	ø	❖
6	*Hoya vaccinioides*	ø	ø	ø	❖
	Aspleniaceae				
7	*Asplenium nidus*	ø	ø	ø	❖
8	*Asplenium nitidum*	ø	ø		❖
	Gesneriaceae				
9	*Aeschynanthus gracilis*	ø	ø	ø	❖
10	*Aeschynanthus macualatus*	ø	ø		❖
11	*Aeschynanthus sikkimensis*	ø	ø		❖

Appendix A (*continued*)

S.No.	Species	Closed forests	Treefall gaps	Logged forests	Type
	Lycopodiaceae				
12	*Lycopodium phlegmaria*	⌀			❖
13	*Lycopodium selago*				❖
	Moraceae				
14	*Ficus rhododendrifolia*	⌀			❖❖
15	*Ficus spp*	⌀	⌀		❖❖
	Orchidaceae				
16	*Aerides multiflorum*			⌀	❖
17	*Aerides williamsii*	⌀	⌀	⌀	❖
18	*Agrostophyllum khasianum*	⌀			❖
19	*Bulbophyllum khasianum*	⌀			❖
20	*Bulbophyllum devanagiriensis*	⌀			❖
21	*Bulbophyllum guttulatum*	⌀	⌀	⌀	❖
22	*Bulbophyllum odoratissimum*	⌀			❖
23	*Cleisocentron trichromum*			⌀	❖
24	*Cleisostoma subulatum*	⌀	⌀	⌀	❖
25	*Cymbidium aloifolium*			⌀	❖
26	*Dendrobium anceps*			⌀	❖
27	*Dendrobium aphyllum*			⌀	❖
28	*Dendrobium catcarthii*	⌀	⌀		❖
29	*Dendrobium lituiflorum*		⌀	⌀	❖
30	*Dendrobium moschatum*	⌀	⌀	⌀	❖
31	*Dendrobium nobile*	⌀			❖
32	*Eria amica*	⌀		⌀	❖
33	*Eria ferrugenia*	⌀			❖
34	*Eria flava*	⌀	⌀	⌀	❖
35	*Eria fragrans*	⌀			❖
36	*Eria pannea*	⌀	⌀	⌀	❖
37	*Eria pudica*	⌀	⌀	⌀	❖
38	*Eria stricta*	⌀	⌀	⌀	❖
39	*Flickingeria fugax*		⌀		❖
40	*Gastrochilus dasypogan*	⌀	⌀	⌀	❖
41	*Liparis plantaginea*	⌀			❖
42	*Liparis viridiflora*	⌀	⌀		❖
43	*Luisia tricorhiza*	⌀	⌀	⌀	❖
44	*Papilionanthe teres*		⌀		❖
45	*Phalaenopsis manii*			⌀	❖
46	*Pholidota imbricata*	⌀	⌀		❖
47	*Pteroceros suaveolens*	⌀		⌀	❖
48	*Thelasis longifolia*		⌀		❖
	Polypodiaceae				
49	*Drymoglossum heterophyllum*	⌀			❖
50	*Lepisorus spp*		⌀	⌀	❖
51	*Pyrossia flocculosa*	⌀	⌀	⌀	❖
52	*Pyrossia nummularia*	⌀	⌀	⌀	❖
	Thelypteridaceae				
53	*Pronephrium spp*		⌀		❖
	Urticaceae				
54	*Elatostemma rupstre*		⌀	⌀	❖
	Vittariaceae				
55	*Antrophyum plantaginea*	⌀	⌀	⌀	❖
56	*Vittaria elongata*	⌀			❖

Appendix B

Tree species composition across habitats. ✓ indicates presence of species

S. No.	Species	Closed forests	Treefall gaps	Logged forests
	Magnoliaceae			
1	*Talauma hodgsonii*	✓	✓	✓
	Annonaceae			
2	*Polyalthia simiarum*	✓	✓	
	Clusiaceae			
3	*Mesua ferrea*		✓	
	Sterculiaceae			
4	*Pterospermum acerifolium*		✓	✓
5	*Pterospermum lancifolium*	✓		✓
6	*Sterculia roxburghii*	✓		✓
7	*Sterculia kingii*			✓
	Elaeocarpaceae			
8	*Echinocarpus assamicus*		✓	
9	*Elaeocarpus aristatus*	✓	✓	✓
10	*Elaeocarpus rugosus*	✓		
11	*Elaeocarpus ganitrus*	✓		
12	*Elaeocarpus prunifolius*	✓		
	Burseraceae			
13	*Canarium strictum*	✓		
14	*Canarium bengalense*	✓		
	Meliaceae			
15	*Dysoxylum binectariferum*	✓	✓	✓
16	*Chisocheton paniculatus*	✓	✓	✓
	Leeaceae			
17	*Leea indica*	✓		✓
	Staphylaceae			
18	*Turpinia pomifera*		✓	
19	*Turpinia nepalensis*	✓		
	Myrtaceae			
20	*Syzygium formosum*			✓
21	*Syzygium oblata*			✓
22	*Syzygium cumini*	✓		
23	*Syzygium syzigioides*	✓	✓	
24	*Syzygium spp1*	✓	✓	✓
25	*Syzygium spp2*	✓	✓	
	Lythraceae			
26	*Largerstroemia lanceolata*	✓		✓
	Datiscaceae			
27	*Tetrameles nudiflora*			✓
	Rubiaceae			
28	*Neonauclea griffithi*	✓		
	Bignoniaceae			
29	*Stereospermum chelonoides*			✓
30	*Vitex canescens*			✓
	Lauraceae			
31	*Actinodaphne obovata*		✓	
32	*Beilshmiedia assamica*	✓		
33	*Lindera latifolia*	✓	✓	
34	*Litsea panamonja*		✓	
35	*Litsea salicifolia*		✓	
36	*Phoebe lanceolata*	✓		

Appendix B (*continued*)

S. No.	Species	Closed forests	Treefall gaps	Logged forests
	Euphorbiaceae			
37	*Aporusa aurea*	✓		
38	*Baccaurea sapida*	✓	✓	
39	*Bischofia javanica*	✓		
40	*Bridelia assamica*	✓		
41	*Bridelia pubescens*	✓	✓	
42	*Bridelia retusa*		✓	
43	*Croton roxburghii*		✓	
44	*Ostodes paniculata*	✓	✓	
	Moraceae			
45	*Artocarpus chaplasha*			✓
46	*Ficus rhododendrifolia*			✓
47	*Ficus hookeri*	✓		
	Urticaceae			
48	*Laportea pterostigma*	✓	✓	✓
	Fagaceae			
49	*Castonopsis indica*	✓	✓	
	Anacardiaceae			
50	*Spondias pinnata*	✓		

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