Vegetation Change During Recovery of Shifting Cultivation (*Jhum*) Fallows in a Subtropical Evergreen Forest Ecosystem of North-Eastern India

R.S. Tripathi[1], S.D. Prabhu[2], H.N. Pandey[3] and S.K. Barik[3,4]*

[1]CSIR-National Botanical Research Institute, Lucknow-226001, INDIA; [2]Bombay Natural History Society, Shaheed Bhagat Singh Road, Mumbai-400001, INDIA; [3]Department of Botany, North-Eastern Hill University, Shillong-793022, INDIA; [4]Present address: Department of Botany, University of Delhi, Delhi-110007, INDIA

***Corresponding Author:** Prof. S.K. Barik, Department of Botany, North-Eastern Hill University, Shillong-793022, India, Fax: +91 364 2550108, Email: sarojkbarik@gmail.com

Abstract

An understanding of vegetation change on *jhum* fallows undergoing recovery following shifting cultivation is vital for developing a rehabilitation strategy for shifting cultivation areas. However, the pattern of vegetation change during the recovery of shifting cultivation fallows is not well-studied. Therefore, the present study was carried out in a subtropical forest ecosystem in the buffer zone of Nokrek Biosphere Reserve in north-eastern India where shifting cultivation is being practiced extensively. The species composition and other plant community attributes were studied in 1-year, 3-year, 6-year and 12-year old shifting cultivation (*jhum*) fallows and were compared with an undisturbed forest in the adjoining core zone of the Biosphere Reserve. The rate of recovery of various community attributes such as species dominance and diversity, tree species population structure, stratification and life form spectrum was, in general, slow. The young fallows exhibited high dominance and low equitably which slowly progressed towards high equitability as recovery progressed with increasing age of the fallows. The number of species recorded in the 12th year of fallow represented about 86% of the total species in the undisturbed forest. Other community attributes of the forest regrowth on the 12-year old fallow reached up to 70-80% of the values recorded in the undisturbed forest community indicating that there was good recovery of species richness and other community attributes on the 12-year old fallows if there was no disturbance.

Key words: Biosphere reserve, Plant community profile, Plant diversity, Shifting cultivation, Fallow land succession, Undisturbed forest.

1. Introduction

The humid tropical and montane sub-tropical forests of Eastern Himalaya and north-eastern India harbour at least 5,000 endemic plant species and are rich in plant diversity (Olson *et al*., 1998). Hooker (1872-1897), Kanjilal *et al*. (1934-1940), Rao and Panigrahi (1961), Rao (1969, 1970, 1974, 1977), Balakrishnan (1981-1983), and Haridasan and Rao (1985-1987) have enumerated the taxonomic richness of these forests during their botanical explorations in different parts of north-eastern India. In the state of Meghalaya, quantification of plant diversity, and ecological implications of disturbances on forest communities have been analyzed by Khan *et al*. (1987), Barik *et al*. (1992), Rao *et al*. (1990), Jamir and Pandey (2003) and Upadhaya *et al*. (2003). All these studies are mostly confined to the forested areas in Khasi and Jaintia hills of the state. The forest vegetation in Garo hills of Meghalaya has not been studied.

Shifting cultivation is the predominant means of subsistence for a majority of the people of all the north-eastern states of India except Sikkim (Tripathi and Barik, 2003). In addition to northeast India, substantial portion of tribal population in the states of Odisha, Andhra Pradesh, Chhatisgarh, Jharkhand and Biharalso depends on shifting cultivation for their sustenance. Shifting cultivation has been blamed for large-scale forest and land degradation and loss of wild biodiversity in north-eastern India and in other states of the country where such type of cultivation is prevalent. With increasing population pressure, and due to shortage of agricultural land, the fallow period in tropics has been shortened excessively and the period of cultivation has been extended for too long (Whitmore, 1998) causing severe degradation of the land. Shifting cultivation with at least 10 years of fallow period has been argued to be sustainable (Barik, 2007). However, due to the increasing population pressure, the intervening fallow period between two successive cropping has now been reduced to 2 years in most areas of north-eastern India leaving insufficient time for the shifting cultivation (locally called *jhum*) land to naturally recover. Unless the *jhum* fallow land (the land undergoing recovery beginning from the period of post-crop abandoning under 1st cycle to slashing for cropping again under the 2nd cycle on the same piece of land) is managed effectively, the reduced fallow period could convert the large tract of forest areas into degraded lands. In fact, most forest areas in north-eastern India are communally owned, and they represent a mosaic of forest patches of different ages developed on recovering shifting cultivation fallows of varying ages. Except a few undisturbed natural forest patches most forest areas are affected by shifting cultivation.

An understanding of species and vegetation recovery following shifting cultivation is vital for developing a rehabilitation strategy for shifting cultivation areas. The pattern of vegetation change during recovery of shifting cultivation fallows is not well-studied. Therefore, the present study was carried out in a subtropical forest ecosystem in the buffer zone of Nokrek Biosphere Reserve in north-eastern India where shifting cultivation is being practiced extensively. The species composition and other community attributes of the vegetation were studied in 1-year, 3-year, 6-year and 12-year old shifting cultivation fallows and were compared with an undisturbed forest in the adjoining core zone of the Biosphere Reserve. The recovery rates of plant diversity and various other community attributes were quantified to understand the secondary successional process on shifting cultivation fallows. An understanding of the vegetation recovery pattern during secondary succession is important for proper management of protected areas that are exposed to different anthropogenic disturbances.

2. Materials and Methods

2.1. Study area

Nokrek Biosphere Reserve (NBR) is spread over an area of 820 sq km covering parts of East Garo Hills, West Garo Hills and South Garo Hills districts in Meghalaya. It lies between 90°13’ E and 90°35’ E longitudes and 25°20’ N and 25°29’N latitudes (Fig. 1). It is a part of Tura ranges of mountain system with altitude ranging from 200 to 1415 m asl. The core zone of the NBR, which has also been designated as Nokrek National Park, covers 47.48 sq km area of the ridge of Nokrek Hills, spread in east-west direction. The northern aspect of the National Park has gentle slope while the southern aspect has very steep to moderate slope. The core zone of the Biosphere Reserve (BR) represents undisturbed vegetation of Meghalaya. The major rivers of the Garo Hills viz., Simsang, Dedari, Dareng and Ganol, originate from the Nokrek BR. The area surrounding the core zone is the buffer zone, covering 772.52 sq km area.

Nokrek BR is a reservoir of a large variety of wild relatives of *Citrus* species cultivated throughout the north-eastern India. In order to conserve *Citrus* germplasm, the area was designated as a National Park (NP) in 1986. Considering various anthropogenic stresses which are posing serious threat to conservation and management of Nokrek NP, and the importance of Nokrek NP from the biodiversity point of view, the Nokrek NP was notified as a Biosphere Reserve by Ministry of Environment and Forests, Government of India, with an objective to strike a balance between conserving biodiversity, and encouraging economic, cultural and social development of the local people. The buffer zone of this biosphere reserve is subjected to various anthropogenic activities especially shifting cultivation and mining of coal and limestone, causing serious threat to plant diversity of the BR. The total land area under shifting cultivation within buffer zone of the BR is ca. 31400 ha (38% of the total land area). The observed period of cultivation on a given piece of land after slashing and burning of forest vegetation is 2 to 3 years, after which the *jhum* land is abandoned and left as fallow to regenerate naturally. This fallow period varies from 7-15 years depending on the area available with the villages.

The undisturbed forests of Nokrek BR represented five major forest types viz., subtropical evergreen, tropical evergreen, tropical semi-evergreen, tropical moist deciduous and riverain forests. Out of these, the subtropical evergreen forests also described as Khasi subtropical wet hill forests under the subgroup montane sub-tropical broadleaved hill forests (Champion and Seth, 1968) are spread between 1000-1415 m altitude and are confined to the core zone of the BR constituting 30.54 sq km area, which is 63% of the total core zone. The tropical evergreen forest covers a very small portion of the core zone, but it occurs widely in the buffer zone. The area covered by this forest is 137.71 sq km, which is 16.79% of the total area of the BR. The riverain forests are located in the buffer zone of the NBR and are found in small patches fringing along the banks of the rivers, which too are predominantly evergreen in nature. Abandoned *jhum* fallows are mostly present in the northern part of the buffer zone occupying ca. 314 sq km i.e. 38% of the total land area of the BR (IIRS, 2002).

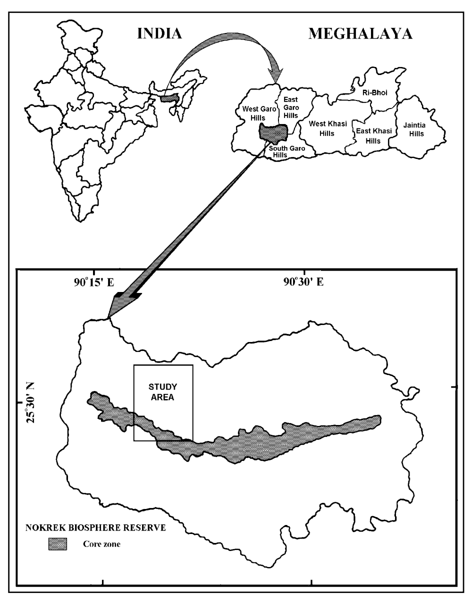

Fig. 1: Map showing the location of study sites in the Nokrek Biosphere Reserve in Meghalaya

2.1.1. Climate

The BR enjoys tropical climate with high rainfall, high humidity, mildly warm summers and moderately cold winters. Monsoon rains are received from April to October; occasional rainfall is also received during November to March. March and April represent mild and relatively dry summer. The rainy season extending from May to October is quite wet and warm. The highest rainfall is received during June to August. The winter season extends from November to February. Temperature varies from place to place depending on aspect, altitude and vegetation. The southern part of the BR is relatively warmer than the northern part. The northern aspect of the BR is the coldest area of the Garo Hills.

Soil is sandy to loamy sand, and red, brown to dark brown in colour. It is acidic in nature throughout the core zone. The core zone soils are rich in organic matter and nutrients (N, P, K) compared to the buffer zone soils.

2.2. Methods

2.2.1. Site selection for detailed study

Based on the field observations, different ecosystems were identified within the BR. More than 300 sq km area of the buffer zone of the BR is affected by shifting cultivation. The original vegetation of the BR has been converted into patches of secondary forests of different growing stages due to shifting cultivation.

In order to understand the pattern of vegetation recovery after cropping period under the shifting cultivation, the floristic composition, community characteristics and plant diversity were studied in selected ecosystem types viz., *jhum* fallows of 10 to 12 years age (J12), 6 to 8 years age (J6), 3 to 4 years age (J3), and of one year age (J1). In the *jhum* fallows of 3-4 years, 6-8 years and 10-12 years of age, all the trees, shrubs and herbs were enumerated for vegetation analysis. In case of one-year-old *jhum* fallows only herbaceous component was considered for community analysis. However, seedlings and saplings of the tree and shrub species were considered for analysis of life forms. Since all these fallows were located in the same altitudinal range of the core zone (i.e. 1000-1400 m), the subtropical evergreen forest type in the core zone representing the undisturbed forest, was selected as the control site.

An attempt was made to select the sites as wide-spread as possible to capture the variation among all the identified ecosystems in the northern as well as southern part of the BR (Fig. 1). Two sites selected from the core area of the BR, (SEF-a at 1412 m altitude and SEF-b at 1300 m altitude) were from the northwestern region. The shifting cultivation fallows of different ages, which were common in the northern region of the buffer zone of the BR, were grouped under four age groups; 10-12 years old, 6-8 years old, 3-4 years old and 1 year old fallows. Each of these four groups was studied by selecting two sites each (J12a-b, J6a-b, J3a-b, J1a-b) (Fig. 2, Table 1).

At each site, ten quadrats of 10 x 10m were laid randomly to sample all the woody individuals including trees, shrubs and lianas with circumference at breast height (CBH)≥ 5 cm. The height of the trees was measured using a calibrated bamboo stick as well as a clinometer, wherever suitable and CBH of each individual was recorded at 1.37 m from the ground level. Shrub species were enumerated separately from these quadrats. Similarly, for the ground cover twenty quadrats of 1x1 m size were laid randomly at each site in two different seasons i.e. dry and wet seasons.

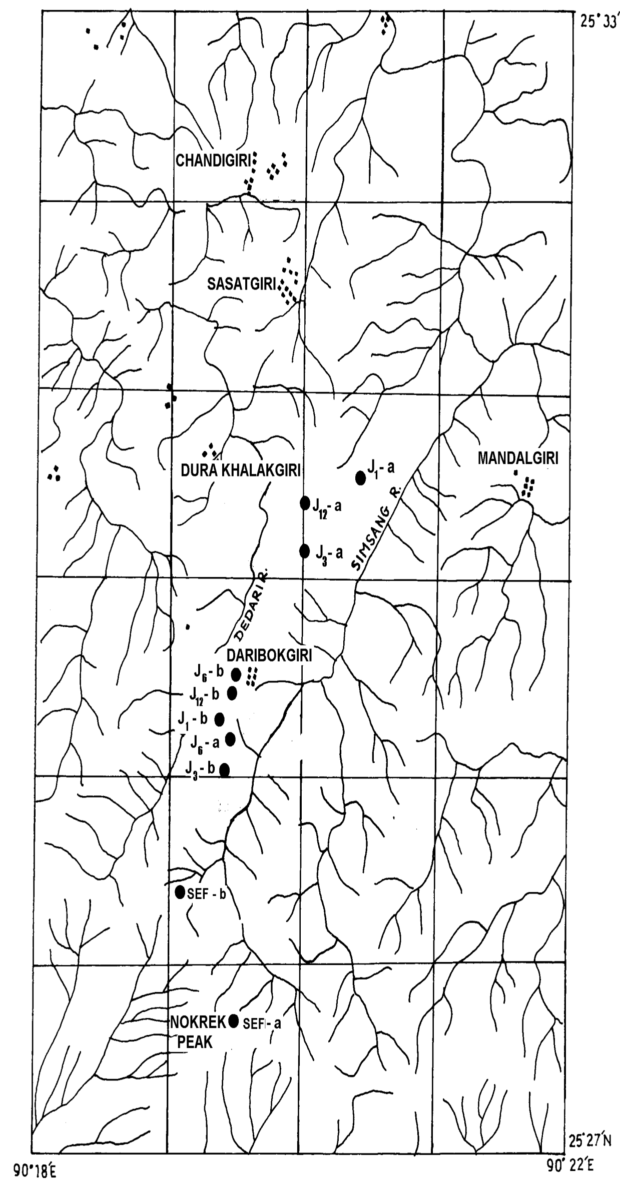

Fig. 2: Map showing the locations of the study sites within the Nokrek BR (● - sites studied)

Table 1: Details of sites representing different ecosystems selected for the study within the BR

Ecosystems	Sites	Altitude (m)	Sampled area (ha)
Subtropical Evergreen forest in the core zone	SEF-a	1412	0.1
	SEF-b	1300	0.1
Jhum fallows (12-yr old)	J12-a	1100	0.1
	J12-b	1228	0.1
Jhum fallows (6-yr old)	J6-a	1078	0.1
	J6-b	1133	0.1
Jhum fallows (3-yr old)	J3-a	1226	0.1
	J3-b	1005	0.1
Jhum fallows (1-yr old)	J1-a	1120	0.1
	J1-b	1291	0.1
Total			**1.0**

2.2.2. Analysis of biodiversity

Analysis of biodiversity was carried out by calculating Shannon Diversity Index (H′), Simpson Dominance Index (D) and Pielou's Evenness Index (E). These indices were adopted for their low sensitivity to the sample size (Magurran, 1988). α diversity (D) was calculated according to Whittaker (1960).

2.2.3. Analysis of community structure

Quantitative community characters were studied by determining density, frequency, basal cover and IVI of each species in the selected communities following the methods given by Müeller-Dombois and Ellenberg (1974). Horizontal structure of selected communities was analysed by the formula outlined by Whitford (1948). Vertical structure of selected communities was analysed with the help of life form spectra and profile diagrams. All the species encountered in the study area were identified and classified under different life forms as per the Raunkiaer's classification (1934). Profile diagrams of the selected communities dominated by tree components were prepared to illustrate the details in vertical spacing of the species. A transect of 30-60x5.0 m was established in each of these stands. The dominant individuals were drawn to the scale on a graph paper indicating their position, height, bole height and crown cover. The ground vegetation including herbs, seedlings and saplings was not considered for profile diagram.

2.2.4. Comparison of stands

The qualitative comparison between the pair of sites representing same or different communities was carried out by calculating Sorensen Index (Magurran, 1988), whereas, the quantitative similarity between the stands representing different ecosystems was worked out following Morisita-Horn index (C_{MH}).

3. Results

3.1. Taxonomic diversity

A total of 546 species belonging to 371 genera and 128 families including 532 angiosperms, 3 gymnosperms and 11 pteridophytes were recorded from the sampled 1 ha area. Out of these, 392 species were recorded from the undisturbed subtropical evergreen forest (SEF) alone. It had several tropical as well as temperate elements. The important tropical species were *Dysoxylum gobara, Mesua ferrea, Elaeocarpus* spp. and *Cinnamomum* spp. A few temperate species such as *Betula alnoides*, *Castanopsis indica*, *Euonymus lawsonii, Viburnum coriaceum* etc. were also abundant in the community. It was rich in primitive taxa such as *Actinodaphnae angustifolia*, *A. obovata, Beilschmiedia assamica, B. roxburghiana, Betula alnoides, Dillenia scabrella, Fissistigma verrucosum, Goniothalamus simonsii, Helicia excelsa, Helicia nilagirica, Holboellia latifolia, Houttuynia cordata, Knema angustifolia, Michelia oblonga, Myrica esculenta, Paramichelia baillonii, Polyalthia cerrasoides, Sarcandra glabra* and *Talauma hodgsonii.* Out of 115 families recorded in the SEF, Rubiaceae was the most dominant family contributing 22 species and 17 genera, whereas Lauraceae (22 species, 9 genera), Euphorbiaceae (19 species, 14 genera) and Orchidaceae (14 species, 11 genera) were the co-dominant families. Forty eight families were represented by only one species and 19 families by two species.

In the successional communities on *jhum* fallows, 323 species representing 239 genera distributed under 102 families were recorded. Poaceae (24 species), Euphorbiaceae (16 species), Asteraceae (16 species) and Rubiaceae (15 species) were the dominant families in these communities. *Macaranga indica, Calicarpa vestita*, *Eurya japonica* and *Saurauia* spp. were the important tree species of these communities.

3.2. Species richness

Tree species richness per 0.2 ha decreased significantly from 88 species in the SEF to 25, 32, 58 species in J3, J6 and J12, respectively. Similarly, shrub species richness per 0.2 ha was lowest (20) in J3 showing gradual increase with age of the fallows and was highest (36) in J12.

However, herbaceous species-richness was lowest in SEF (49 species) and did not show any significant change with increase in the age of the communities on the *jhum* fallows (Table 2).

Species richness of woody species per 100 m^2 varied from 7 to 26 species in the SEF, 2 to 10 in the young stands (J3 and J6) and from 7 to 14 species in the old stand (J12). The frequency of plots (100 m^2) for different species richness classes, revealed highly patchy nature of SEF stands, where 55% of the plots possessed 11-15 species, 27% of the plots had 5-10 species and 23% of the plots had 15-20 species (Fig. 3). On the other hand, species richness was more evenly distributed in case of *jhum* fallows with average of 0-10 species per plot in J3 and J6, and 5-15 species in J12.

Species richness distribution of tree species within the different girth classes showed similar pattern in all the fourstands (Fig. 4). It was highest in the lowermost GBH class, and decreased gradually in the higher girth classes except SEF which showed 22 species in the girth class >95 cm (probably due to accumulation of upper girth classes present in this stand).

3.3. Stratification

The SEF stands showed four layers viz., (i) canopy, (ii) subcanopy, (iii) undercanopy and (iv) ground vegetation. The first three layers were composed of trees, lianas and shrubs, while ground vegetation was composed of herbs, and seedlings and saplings of the tree and shrub species. In all, 38 individuals representing 28 species were recorded. The average canopy height was 30 m. Seven species comprised this layer, which also included emergent trees like *Celtis trimorensis*, *Betula alnoides* and *Syzygium grandis*. Other species forming this layer were *Mesua ferrea*, *Calophyllum polyanthum*, *Aesculus assamica* and *Gynocardia odorata.* One liana species, *Tetrastigma rumicispermum* was also present in this layer. The sub-canopy layer had more number of species (11 species), and also was more continuous than the canopy layer. *Dysoxylum gobara*, *Macropanax dispermus* and *Litsea salicifolia* were the most dominant species of this layer. The lowermost stratum of undercanopy trees and shrubs was composed of 9 species (Fig. 5).

The secondary successional forest on the fallows of 10-12 years age had three distinct strata. A total of 18 species was recorded from this forest stand which was composed of such species as *Pittosporum podocarpum*, *Lindera reticulata* and *Saurauia nepaulensis*. The lowermost layer was composed of shrubs and saplings (Fig. 6).

Table 2: Number of species, genera, families, density, basal cover and diversity indices of tree, shrub and herb species of the undisturbed SEF and communities on *jhum* fallows of different ages in the Nokek BR

Trees	**M**	**J_{12}**	**J_6**	**J_3**	
No. of species	88	58	32	25	
No. of genera	64	43	27	22	
No. of families	35	31	20	16	
Density (ha^{-1})	2580	5000	8520	9773	
Basal area (m^2ha^{-1})	45.74	18.78	14.62	5.82	
Shannon Diversity Index	3.818	2.431	1.97	1.881	
Pielou Evenness Index	0.846	0.599	0.568	0.584	
Simpson Dominance Index	0.039	0.166	0.269	0.244	
S/logN	14.56	8.25	5.39	4	
Shrubs	**M**	**J_{12}**	**J_6**	**J_3**	
No. of species	31	36	23	20	
No. of genera	25	27	17	17	
No. of families	16	20	15	14	
Density (ha^{-1})	37250	86000	94500	101500	
Shannon Diversity Index	2.993	3.143	2.575	2.482	
Pielou Evenness Index	0.872	0.884	0.821	0.828	
Simpson Dominance Index	0.074	0.056	0.116	0.110	
S/logN	6.195	6.8	4.39	3.76	
Herbs	**M**	**J_{12}**	**J_6**	**J_3**	**J_1**
No. of species	49	64	65	66	69
No. of genera	45	59	59	60	62
No. of families	29	28	35	31	32
Density (ha^{-1})	115250	209500	279500	449000	840500
Shannon Diversity Index	4.241	3.140	3.192	3.317	3.164
Pielou Evenness Index	1.090	0.755	0.754	0.792	0.747
Simpson Dominance Index	0.099	0.074	0.081	0.060	0.078
S/logN	7.99	9.51	9.26	8.81	8.5

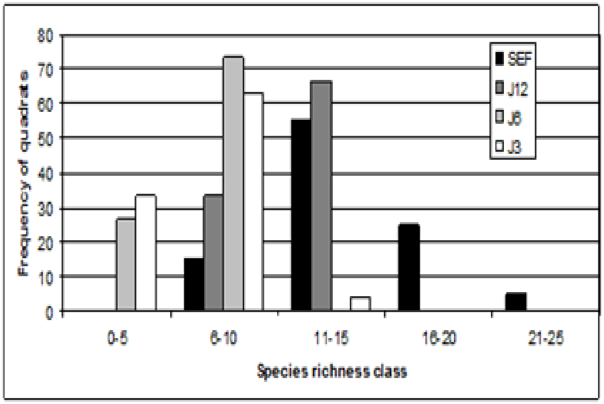

Fig. 3: Distribution of species richness per quadrat (100m^2) of tree species in the undisturbed SEF and *jhum* fallows of different ages in the Nokrek BR

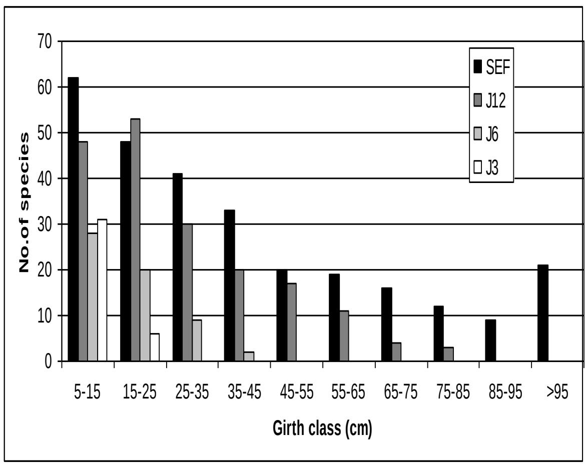

Fig. 4: Distribution of species richness of tree species in different girth classes in the undisturbed SEF and *jhum* fallows of different ages in the Nokrek BR

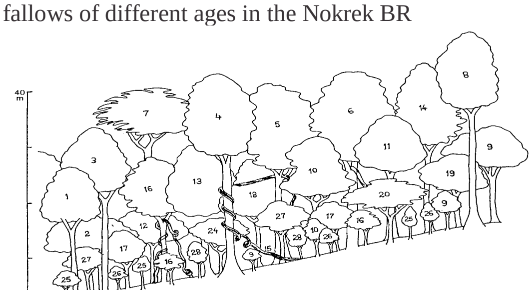

Fig. 5: Profile diagram of a site (altitude 1250 m) in SEF.
1-Dysoxylum gobara, 2-Phoebe lanceolata, 3-Mesua ferrea, 4-Syzygium grandis, 5-Calophyllum polyanthum, 6-Betula alnoides, 7- Celtistimorensis, 8-Gynocardia odorata, 9-Macropanax dispermus, 10-Litsea laeta, 11-Sarcosperma griffithii, 12-Drimycarpus racemosus, 13-Toona ciliata,14-Aesculus assamica, 15-Tetrastigma rumicispermum, 16-Garcinia cowa, 17-Miliusa roxburghiana, 18-Ficus nervosa, 19-Litsea salicifolia, 20-Grewia disperma, 21-Saprosma ternatum, 22-Dendrocnide sinuate, 23-Neolitsea cassia, 24-Glycosmis arborea, 25-Capparis acutifolia, 26-Ardisia pedunculosa, 27-Lindera reticulata, 28-Clerodendrum wallichii

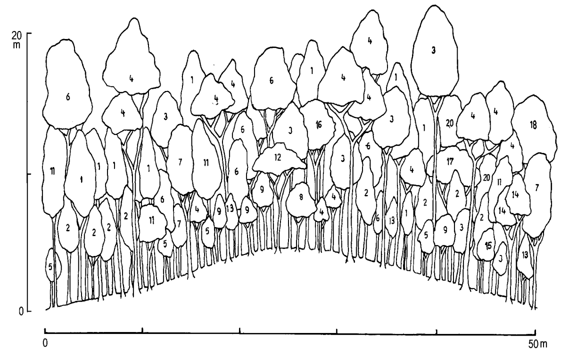

Fig. 6: Profile diagram of a forest stand growing on a 10-12 year old *jhum* fallow.
1-Macaranga indica, 2-Saurauia punduana, 3-Eurya acuminata, 4-Saurauia roxburghii, 5-Pittosporum podocarpum, 6-Callicarpa vestita, 7-Symplocos hookeri, 8-Saurauia napaulensis, 9-Lindera reticulata, 10-Callicarpa arborea, 11-Ostodes paniculata, 12-Litsea lancifolia, 13-Phoebe lanceolata, 14-Gleditsia assamica, 15-Glochidion assamicum, 16-Castanopsis tribuloides, 17-Oreocnide integrifolia, 18-Schima wallichii

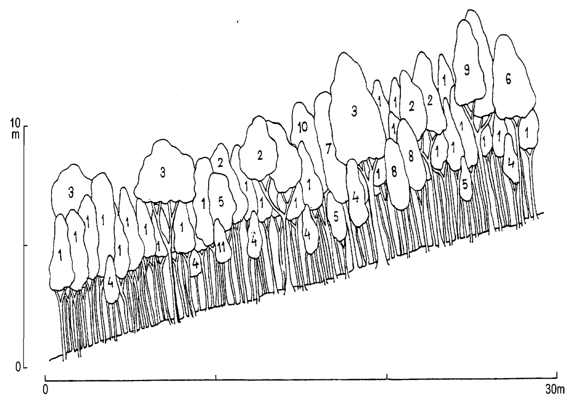

Fig. 7: Profile diagram of a forest stand growing on a 6-8 yr old *jhum* fallow.
1-Macaranga indica, 2-Saurauia punduana, 3-Callicarpa vestita, 4-Eurya acuminata, 5-Rhus javanica, 6-Securinega virosa, 7-Castanopsis tribuloides, 8-Pithecellobium heterophyllum, 9-Saurauia roxburghii, 10-Alangium chinense, 11-Miliusa roxburghiana

In the *jhum* fallows of 6-8 years age, the canopy attained 6-8 m height. In all, 11 species were recorded from this stand. Here the species were distributed in two strata; the canopy layer, which was composed of trees, and the understorey, which was composed of shrubs and saplings of trees. In this stand too, canopy layer was dominated by *Macaranga indica* followed by *Callicarpa vestita* (Fig. 7).

Jhum fallows of 3-4 years age hardly showed any stratification. A total of 11 species was recorded from these stands, dominated by *Macaranga indica* saplings. Along with some other shrub species *M. indica* formed a more or less homogeneous stand with even canopy. The average height of the canopy was 3-3.5 m, although saplings of a few other tree species such as *Eurya acuminata*, *Callicarpa vestita* and *Bruinsmia polysperma* emerged above the canopy layer (Fig. 8).

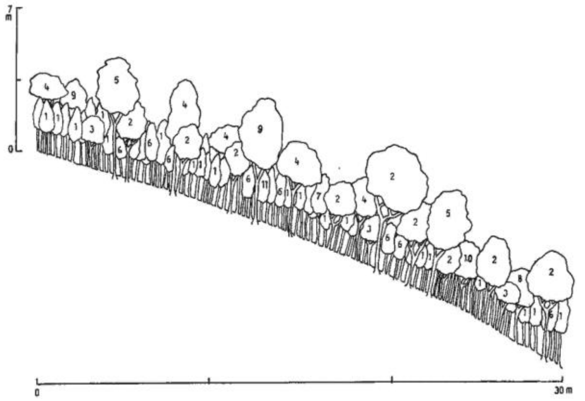

Fig. 8: Profile diagram of a forest stand growing on a 3-4 year old *jhum* fallow.
1-Macaranga indica, 2-Eurya acuminata, 3-Saurauia punduana, 4-Callicarpa vestita, 5-Bruinsmia polysperma, 6-Maesa indica, 7-Skimmia laureola, 8-Rhus javanica, 9-Saurauia roxburghii, 10-Trema cannabina, 11-Citrus medica

3.4. *Life form spectrum*

In SEF, phanerophytes constituted 63%, while the therophytes were an inconspicuous component of the community (Fig. 9). The phanerophytes were dominant in the 10-12 year old *jhum* fallows, while chamaephytes and hemicryptophytes were abundant in the young *jhum* fallows (1 year-old). There was a gradual decrease in the proportion of chamaephytes, hemicryptophytes and therophytes and increase in the proportion of lianas with the age of the fallows. The vegetation on *jhum* fallows were devoid of epiphytes.

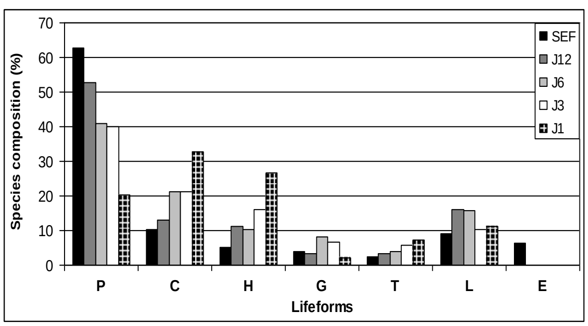

Fig. 9: Life-form spectrum of the undisturbed SEF and communities on the *jhum* fallows of different ages in the Nokrek BR. (P- Phanerophytes, C- chamaephytes, H-Hemicryptophytes, G- Geophytes, T- Therophytes, L-Lianas, and E- Epiphytes)

3.5. *Distribution of species under Raunkiaer's frequency classes*

Majority (89-95%) of the species in the undisturbed stands of SEF belonged to Raunkiaer's frequency class A, followed by a small fraction belonging to class B (7-4%) and a very small fraction belonging to class C (0-3%). Frequency classes D and E were totally absent (Fig. 10). *Gynocardia odorata*, *Saprosma ternatum*, *Glycosmis arborea* and *Dysoxylum gobara* are some of the most frequent tree species present in the classes B and C. *Pteris quadriaurita* was the most frequent herb species followed by *Elatostemma sikkimense* in SEF.

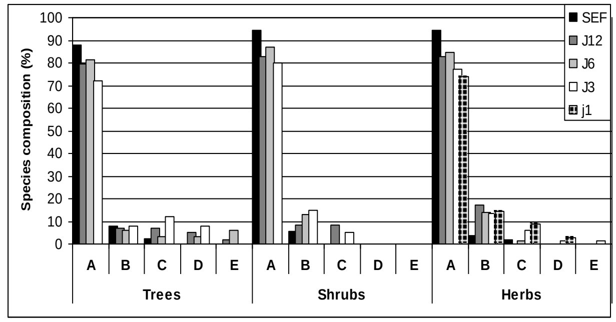

Fig. 10: Distribution of tree, shrub and herb species in different frequency classes in the undisturbed SEF and communities on the *jhum* fallows of different ages in the Nokrek BR

In the case of vegetation on *jhum* fallows, Raunkiaer's normal frequency distribution (A>B>C>/<D<E) was observed only in case of trees. *Macaranga indica, Eurya accuminata, Callicarpa vestita* were the most frequent species in all the *jhum* fallows. In addition to these, *Maesa indica* on the younger *jhum* fallows and *Saurauia roxburghii* on the 10-12 year old fallows were also frequently found. In case of the herbs, the proportion of species in class A increased with the age of *jhum* fallows.

3.6. *Spatial distribution pattern*

Majority of the tree species (87-93%) and all herb as well as shrub species in the SEF showed clumped or contiguous distribution (Fig. 11). On the *jhum* fallows, the contiguous distribution pattern was predominant (90-98%) among all the constituent species. Regular distribution was rare and observed only in trees growing on the younger *jhum* fallows. *Rhus javanica* in the 6 year-old fallows and *Callicarpa vestita* in the 3 year-old fallows showed regular distribution pattern.

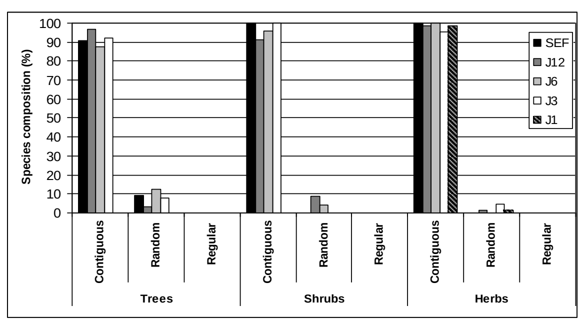

Fig. 11: Spatial distribution of the tree, shrub and herb species in the undisturbed SEF and communities on the *jhum* fallows of different ages in the Nokrek BR

3.7. *Density*

The total stand density of woody species varied considerably among all four stands. It was 2580 stems ha^{-1} in the SEF and 9773 stems ha^{-1} in the J3 (Table 2). The species with highest density in SEF were *Helicia nilagirica, Saprosma ternatum*, *Gynocardia odorata* and *Glycosmis arborea* (345, 175, 130 and 130 stems ha^{-1}, respectively). On the fallows, the tree species largely contributing to the stand density were *Macaranga indica*, *Eurya acuminata*, *Callicarpa vestita* and *Saurauia roxburghii*. Density-distribution of the tree species in different girth classes (Fig. 12) revealed that the lowest girth class (5-15 cm) constituted 35% of the total stand density in the SEF, 43% in the J12, 62% in J6 and 97% in J3. In all the three fallows, the percentage contribution to the total stand density decreased with the increasing girth class, except in SEF where the largest girth class (>95 cm) contributed significantly to the total stand density (i.e. 12%). *Rhynchotechum ellipticum*, *Piper griffithii*, *Chasalia ophioxyloides* among the shrubs and *Pteris quadriaurita* among herbs had the highest number of individuals in the SEF. The density of the herbaceous species, similar to that of tree species, decreased with the increasing age of the *jhum* fallows. *Eupatorium adenophorum* was the dominant herb in all the fallows.

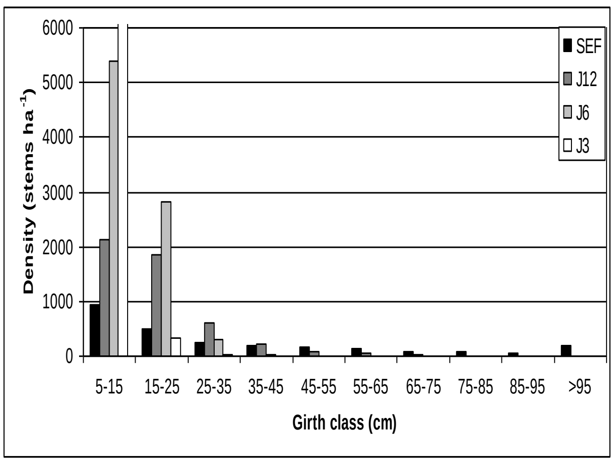

Fig. 12: Density-diameter distribution of tree species in the undisturbed SEF and communities on the *jhum* fallows of different ages in the Nokrek BR

3.8. Basal cover

Basal cover of the woody species also differed considerably in the four stands, from 45.74 m^2ha^{-1} in the SEF to 5.82 m^2ha^{-1} in J3 (Table 2). In the SEF species contributing largely to the total basal cover were *Sapium baccatum* (3.05 m^2ha^{-1}), *Helicia nilagirica* (2.24 m^2ha^{-1}), *Castanopsis indica* (2.98 m^2ha^{-1}), *Dysoxylum gobara* (2.60 m^2ha^{-1}), *Gynocardia odorata* (2.41 m^2ha^{-1}) and *Ostodes paniculata* (2.08 m^2ha^{-1}).

Macaranga indica, *Eurya acuminata* and *Callicarpa vestita* were the main contributors to the basal cover of the fallow communities. The basal cover of *Macaranga indica* varied from 0.47 m^2ha^{-1} in J3 to 4.55 m^2ha^{-1} in J12. Similarly, basal cover of *Callicarpa vestita* varied from 0.25 to 1.8 m^2ha^{-1} and that of *Eurya acuminata*, from 0.23 to 3.2 m^2ha^{-1} in young (J3) and older (J12) *jhum* fallows, respectively.

The distribution of basal area in different girth classes revealed that in SEF in spite of the highest stand density, the lowermost girth class contributed the least to the total basal cover of the stand. The contribution to the basal cover increased gradually till the girth class 55-75 cm and then decreased back in the upper girth classes except the largest girth class (>95 cm) where it contributed 46% (Fig. 13). In the pioneer community (3-4 year old fallows) young individuals (5-15 cm gbh) contributed maximum to the basal cover. In the plant community developing on 6-8 year old fallows, the individuals having 15-25 cm gbh along with younger plants (5-15 cm gbh) were main contributors, while in the plant community in 10-12 year old fallows the plants of 15-25, 25-35, 35-45 cm gbh classes became more important than other classes.

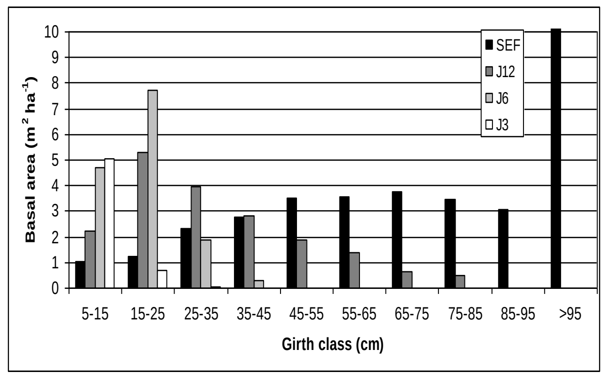

Fig. 13: Distribution of basal area of tree species in different diameter classes in the undisturbed SEF and communities on the jhum fallows of different ages in the Nokrek BR

3.9. Dominance

The undisturbed forest and fallows showed altogether different patterns of dominance based on the IVI values of the tree, shrub and herb species. In the SEF *Helicia nilagirica* (IVI 19.64) was the most dominant species and *Aphanamixis wallichii* and *Dysoxylum gobara* (IVI 15.73 and 13.47, respectively) were the co-dominant species. Among the shrub species in the SEF, *Rhynchotechum ellipticum* showed the highest values of IVI (24.60) followed by *Piper griffithii* (IVI 17.37), *Jasminum subtriplinerve* (IVI 13.76) and *Chasalia ophioxyloides* (IVI 13.76). The herbaceous component was dominated by *Pteris quadriaurita* (25.81), *Elatostemma sikkimense* (IVI 24.17), and *E. hookerianum* (IVI 14.36) in the SEF. In general, the dominance-distribution curves for the tree, shrub and herb components for all the four communities (Fig. 14) showed lognormal distribution which is a characteristic of a species-rich community (Whittaker, 1972; Magurran, 1988). The young fallows did exhibit high dominance and low equitability which slowly progressed towards high equitability as recovery progressed with increasing age of the fallows.

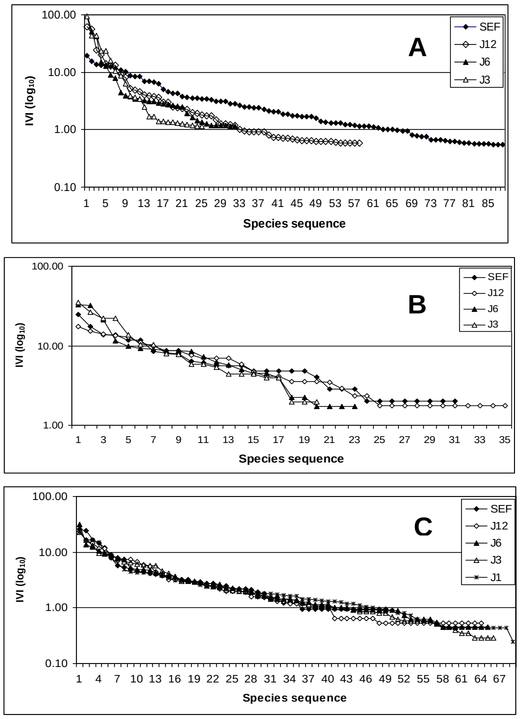

Fig. 14: Dominance-diversity curves for A) trees, B) shrubs and C) herbs in the undisturbed SEF and communities on the *jhum* fallows of different ages in the Nokrek BR

3.10. Ecological diversity

Trees and lianas showed high values for α-diversity, Shannon diversity index as well as Pielou's evenness index for SEF, which indicates high diversity, and equitability of this component in this community. This was also supported by the low values of Simpson dominance index. The herbs and the shrubs had lower values of diversity and higher values of dominance (Table 2). The α - diversity and the Shannon index increased with the age of the community on the *jhum* fallows. The number of species recovered in the 12th year of fallow represented only 86% of the total species in the undisturbed forest. Other community-attributes reached only up to 70-80% of the undisturbed community structure till 12th year of fallow recovery.

3.11. Similarity

Sørensen index of qualitative similarity indicated the maximum similarity between J12 and J6 for the shrub and herb species (Table 3). However, the quantitative similarity between and among stands as worked out by Morisita-Horn index revealed high similarity among the tree and herb components of the fallows and least similarity with SEF, the undisturbed subtropical evergreen forest (Table 4).

Table 3: Sorenson Index of qualitative similarity

Trees	**M**	**J_{12}**	**J_6**	**J_3**									
M	100	-	-	-									
J_{12}	31.5	100	-	-									
J_6	16.66	35.55	100	-									
J_3	10.61	38.55	52.63	100									
Shrubs					**M**	**J_{12}**	**J6**	**J3**					
M	-	-	-	-	100	-	-	-					
J_{12}	-	-	-	-	21.21	100	-	-					
J_6	-	-	-	-	11.11	**65.52**	100	-					
J_3	-	-	-	-	7.84	50.91	55.81	100					
Herbs									**M**	**J12**	**J6**	**J3**	**J1**
M	-	-	-	-	-	-	-	-	100	-	-	-	-
J_{12}	-	-	-	-	-	-	-	-	30.01	100	-	-	-
J_6	-	-	-	-	-	-	-	-	22.81	**63.57**	100	-	-
J_3	-	-	-	-	-	-	-	-	17.39	60.00	59.54	100	-
J_1	-	-	-	-	-	-	-	-	13.56	54.14	59.7	59.26	100

Table 4: Morisita-Horn Index of quantitative similarity

Trees	**M**	**J_{12}**	**J_6**	**J_3**									
M	1	-	-	-									
J_{12}	0.01	1	-	-									
J_6	0.01	**0.86**	1	-									
J_3	0	**0.82**	**0.97**	1									
Shrubs					**M**	**J_{12}**	**J_6**	**J_3**					
M	-	-	-	-	1	-	-	-					
J_{12}	-	-	-	-	0.3	1	-	-					
J_6	-	-	-	-	0.06	0.4	1	-					
J_3	-	-	-	-	0.1	0.39	0.3	1					
Herbs									**M**	**J12**	**J6**	**J3**	**J1**
M	-	-	-	-	-	-	-	-	1	-	-	-	-
J_{12}	-	-	-	-	-	-	-	-	0.07	1	-	-	-
J_6	-	-	-	-	-	-	-	-	0.04	**0.72**	1	-	-
J_3	-	-	-	-	-	-	-	-	0.05	0.63	**0.81**	1	-
J_1	-	-	-	-	-	-	-	-	0.03	0.58	**0.81**	**0.86**	1

4. Discussion

4.1. Undisturbed forest

The undisturbed forests of Nokrek Biosphere Reserve represent the flora of Manipur-Khasi province described by Takhtajan (1988), which exhibits saturation of eastern Asiatic floristic components and also shows strong ties with the florae of the eastern Himalaya, upper Burma and China. Geographic locations as well as characteristic climatic conditions appear to be the major factors contributing to the floristic richness of Nokrek BR. The prevalence of primitive species in the flora of these forests may throw light on the floral affinities of NBR. According to Takhtajan (1988), the nucleus of the flora of Khasi-Manipur Province consists of eastern Asiatic elements. In comparison with various studies enumerating floristic richness of Meghalaya (Kumar, 1984; Haridasan and Rao, 1985-1987; Tiwari *et al*., 1999; Jamir, 2000; Upadhaya *et al*., 2003), the richness of vascular species recorded from subtropical evergreen forests of Nokrek BR during the present study is worth noting. Dominance of angiosperms, richness of taxonomic families and presence of congeneric species are the characteristic features of tropical and sub-tropical moist forests as reported by many workers (Balakrishnan, 1981-1983; Kumar, 1984; Haridasan and Rao, 1985-1987; Valencia *et al*., 1994; Ayyappan and Parthasarathy, 1999; Jamir and Pandey, 2002; Upadhaya *et al*., 2003).

Biological spectrum of the forest communities revealed that the phanerophytes, lianas and epiphytes surpassed their respective proportions in the normal spectrum given by Raunkiaer (1934), while the hemicryptophytes and therophytes were much below the normal proportion. Such biological spectra could be attributed to the humid climate (Meher-Homji, 1964) of Nokrek BR.

The undisturbed forests represented a mosaic of high and low species diversity patches. This seems to be the result of the combined effect of non-extreme stable environmental conditions and gap phase dynamics within the forests (Whittaker, 1972). The majority of the species of the studied forest ecosystems exhibited clumped or contiguous distribution pattern suggesting the highly heterogeneous and patchy character of the forests. Clumping of individuals of the same species may be due to opportunity or chance of colonization/ establishment, and it is also often related to the dispersal mechanism of the species (Poore, 1968; Ashton, 1969; Hubbell, 1979).

The lower girth classes included small trees as well as saplings of the large trees and so, greater number of species was present in these classes. Small girth classes having major contribution to the species richness is also a characteristic feature of ancient climax tropical forests (Whitmore, 1970; Gentry, 1982; Condit *et al*., 1996). Abundance of young individuals in the undisturbed forest and forest regrowth on *jhum* fallows, which is a characteristic feature of vegetation on moist and infertile soil (Coomes and Grubb, 2000) indicates slow rate of seedling and sapling growth in the understorey and relatively low rate of seedling mortality. It may also be due to tree-fall gaps with environmental contrast between them favouring the trees with different regeneration requirements (Phillips *et al*., 1994).

The Shannon and the evenness indices for all the undisturbed ecosystems showed high values. Many explanations for the diversity patterns have been proposed so far, which suggest that along with the main factors such as speciation, the geological history of the site, climate and precipitation as functions of latitudinal and altitudinal position (Gentry, 1988, 1992; Lieberman *et al*., 1985; Vázquez and Givnish, 1998), and edaphic properties (Misra and Ramakrishnan, 1983; Gentry, 1988), a few other crucial factors such as competition (Huston, 1979, 1980; Tilman, 1982; Ashton, 1989), and spatial and temporal micro-niche availability also influence the diversity (Tilman and Pacala, 1993). The dominance-distribution curve showing a lognormal distribution also supports that these forests are species-rich and heterogeneous communities (Whittaker, 1972; Magurran, 1988) and represent a more complex community, ordered by a multiplicity of interactions (May, 1975).

4.2. Secondary successional communities on jhum fallows

The structure of secondary communities on the *jhum* fallows gradually became more complex with the age of the fallows indicating recovery from the impact of shifting cultivation. The young *jhum* fallows, particularly those of one-year age, were colonized by herbs, mostly the weeds, and a few tree saplings and coppices of cut trees. The weeds such as *Eupatorium adenophorum* and *Ageratum conyzoides* were dominant in the plant communities developing on fallows. The emergence and increase in the dominance of these weed species have been attributed to the light and nutrient availability and reduced competition from the neighbouring plants following shifting cultivation (Bennet and Rao, 1968; Kushwaha *et al*., 1983). The regrowth of secondary forest fallow is influenced by weed competition (Zimmerman *et al*., 2000), remnant vegetation (Finegan and Delgado, 2000; Guariguata and Ostertag, 2001), and edaphic conditions (Uhl and Jordan, 1984; Brown and Lugo, 1990). Presence of large number of herbaceous species on young fallows may be due to the strong competition offered by them to the potential woody colonists (Kellman, 1980; Holl *et al*., 2000; Ferguson *et al*., 2003; Mishra *et al*., 2004) resulting in growth suppression and mortality of the tree seedlings and saplings. This was indicated by absence of the primary forest tree species on the fallows. Highly abundant species of SEF such as *Helitia nilagirica*, *Saprosma ternatum*, *Gloghidion thomsonii* and *Gynocardia odorata* were not represented by a single individual on the fallows. Even in the case of herbs, *Balanophora dioica*, *Impatience tripetala* and *I. porecta* which are the ephemeral species and gregarious within the primary forest, were totally absent in the secondary communities. Vegetation removal, burning, soil disturbance and weeding effectively destroy the seed bank eliminating possibilities for regeneration and re-sprouting of original forest species (Uhl *et al*., 1981, 1988). Wijdeven and Kuzee (2000) found forest recovery in pastures to be strongly limited by the availability of seeds. The species that are successful in reaching open pasture sites and are capable of avoiding seed and seedling predation were generally the pioneer species, and the same could be true even for the shifting cultivation sites. Interestingly, the shrub species composition and dominance changed largely among the fallows of different ages. On abandoned agricultural lands that have experienced high intensity disturbance, the regeneration of forest is mainly dependent on seed dispersal (Uhl, 1987; Miller and Kauffman, 1998). Thus, factors that influence seed dispersal and recruitment such as, the distance to remnant primary forest and species composition of seed sources, depending on the landscape pattern around the abandoned lands (Endress and Chinea, 2001), could also influence the rate of secondary succession of forest fallow (Holl, 1999; Duncan and Duncan, 2000; Guariguata and Ostertag, 2001; Ding and Zang, 2005; Ding *et al*., 2006). The family dominance shifted from Asteraceae in one-year-old *jhum* fallow to Lauraceae in the 10-12 year old *jhum* fallow, which was also one of the dominant families in the undisturbed forests. The dominance of Lauraceae on 10-12 year old *jhum* fallows and in the undisturbed forest indicates that there could be a considerable level of recovery from shifting cultivation impact if the *jhum* fallows are allowed to regenerate naturally for somewhat longer than 12 years.

With age, the dominant species in these communities used the major fraction of available resources of the community leaving only a small fraction to be pre-empted by other species, as depicted by the dominance-diversity curves of these communities. These communities were predominantly composed of single fast growing secondary or pioneer species such as *Macaranga indica*, *Callicarpa vestita* or *Eurya accuminata*. However, these light demanding species, which cannot regenerate or grow under the shade, can live there for only one generation as argued by Richards (1996). The observed decline in the dominance and increase in the diversity on the older *jhum* fallows support this view. Population stability is the rare phenomenon in successional habitats, where a number of environmental factors change with community development (Kushwaha *et al*., 1983). The structure of successional communities developing on the *jhum* fallows showed drastic change due to various reasons. Removal of overstorey trees during *jhum* may favour germination and seedling establishment due to increased solar radiation on the forest floor and consequent increase in surface temperature and reduced competition from trees of the upper canopy (Noble and Slatyer, 1980; Oliver, 1981; Barik *et al*., 1992). The high sapling population

(5-15 cm girth) on the young *jhum* fallow could be due to suitable microsites created by tree felling and burning of the ground vegetation. The decrease in the sapling population with the age of *jhum* fallows can be ascribed to lack of threshold light for photosynthesis due to increasing canopy cover and a thick layer of litter on the soil surface which is likely to act as mechanical barrier for seedling emergence (Grime, 1979). Thick litter layer may also influence survival of seedlings through producing allelochemics as reported by Khan *et al*. (1987).

The increase in number of strata in the vertical structure of the forest regrowth and increase in the proportion of phanerophytes in the forest vegetation on the older *jhum* fallows suggest the increasing structural complexity approaching the undisturbed forest vegetation. Decrease in the proportion of hemicryptophytes and therophytes with the age of these communities may be due to the lesser availability of light caused by the increasing canopy cover with the progress of succession (Meher-Homji, 1964; Dagar and Balakrishna, 1984; Dagar and Singh, 1999). van Gemerden *et al*. (2003) found that the basal area and plant density recovered in 5 years in logged areas and 50-60 years on the shifting cultivation sites, whereas the species richness recovery took 30-40 years after the shifting cultivation.

We could not include a fallow older than 12 years in the present study and thus have inadequate time series data to predict the period required for a vegetation recovery comparable with the original subtropical evergreen forest vegetation. However, the study clearly depicts the impact of shifting cultivation as revealed by the species composition and structure of the plant community on the one-year-old *jhum* fallows. As observed in the present study, species composition, plant diversity indices, vegetation complexity and other community attributes showed improvement with the age of the *jhum* fallows. However, even after a fallow period of twelve years, the successional vegetation does not show the extent of recovery that may make it comparable to the undisturbed primary forest vegetation. It may be mentioned that the structure of the secondary successional forest developing on 10-12 year old *jhum* fallows showed a closer resemblance to the primary undisturbed forest than does the floristic composition.

Acknowledgements

The authors are grateful to the Ministry of Environment and Forests, Govt. of India for the financial support under the Biosphere Reserve Programme (Sanction No.F.10/41/97-CS/BR dated 15.2.99). Thanks are due to the Forest Department, Govt. of Meghalaya for granting permission to undertake field study in the Biosphere Reserve. We thank the Forest Officers attached to the BR and villagers inhabiting the buffer zone of the BR for their help and cooperation. Thanks are also due to Dr. V. Ralte for her help in the field studies, and soil sampling and analysis.

References

Ashton, P.S. 1969. Speciation among tropical forest trees: Some deductions in the light of recent evidence. *Biological Journal of Linnaean Society*, London **1**:155-196.

Ashton, P.S. 1989. Species richness in tropical forests. In: Holm-Nielsen *et al*. (Eds.). *Tropical Forests*. Academic Press, London, pp. 239-251.

Ayyappan, N. and Parthasarathy, N. 1999. Biodiversity inventory of trees in a large-scale permanent plot of tropical evergreen forest at Varagalaiar, Anamalais, Western Ghats, India. *Biodiversity and Conservation* **8**:1533-1554.

Balakrishnan, N.P. 1981-1983. *Flora of Jowai and vicinity, Meghalaya*. Vol. I-II. BSI, Howrah, India.

Barik, S.K. 2007. Spatial and temporal variations in shifting cultivation in north-east India: Is sustainable land use possible with *jhum* around? In: Saxena *et al*. (Eds.) *Shifting Agriculture in Asia: Implications for Environmental Conservation and Sustainable Livelihood*. Bishen Singh Mahendra Pal Singh, Dehradun, pp. 53-64.

Barik, S.K., Tripathi, R.S., Pandey, H.N. and Rao, P. 1992. Microenvironmental variability and species diversity in tree-fall gaps in a sub-tropical broad-leaved forest. *Vegetatio* **103**:31-40.

Bennet, F.D. and Rao, V.P. 1968. Distribution of an introduced weed *Eupatorium odoratum* Linn. (Compositae) in Asia and Africa and possibilities for its biological control. *Pest Abstracts and News Summaries*, Section C **14**:277-281.

Brown, S. and Lugo, A.E. 1990. Tropical secondary forests. *Journal of Ecology* **6**:1-32.

Champion, H.G. and Seth, S.K. 1968. The forest types of India. New Delhi, India.

Condit, R., Hubbel, S.P., La Frankie, J.V., Sukumar, R., Manokaran, N., Foster, R.B. and Ashton, P.S. 1996. Species area and species individual relationships for tropical trees: A comparison of three 50-ha plots. *Journal of Ecology* **84**:549-562.

Coomes, D.A. and Grubb, P.J. 2000. Impacts of root competition in forests and woodlands: A theoretical framework and review of experiments. *Ecological Monographs* **70**:171-207.

Dagar, J.C. and Singh, N.J. 1999. *Plant resources of Andaman and Nicobar Islands*. Bishen Singh Mahendra Pal Singh Publishing Co., Dehradun, India.

Dagar, J.C. and Balakrishna, N.P. 1984. Lifeform and biological spectrum of Andaman and Nicobar Islands. *Bulletin of Botanical Survey of India* **26**:154-159.

Ding, Y. and Zang, R.G. 2005. Community characteristics of early recovery vegetation on abandoned lands of shifting cultivation in

Bawangling of Hainan Island, South China. *Journal of Integrative Plant Biology* **47**:530-538.

Ding, Y., Zang, R.G. and Jiang, Y.X. 2006. Effect of hill slope gradient on vegetation recovery on abandoned land of shifting cultivation in Hainan island, South China. *Journal of Integrative Plant Biology* **48**:642-653.

Duncan, R.S. and Duncan, V.E. 2000. Forest succession and distance from forest edge in an Afro-Tropical grassland. *Biotropica* **32**:33-41.

Endress, B. and Chinea, J.D. 2001. Landscape patterns of tropical forest recovery in the Republic of Palau. *Biotropica* **33**:555-565.

Ferguson B.G., Vandermeer, J. Morales, H. and Griffith, D.M. 2003. Post agricultural succession in El Petén, Guatemala. *Conservation Biology* **17**:818-828.

Finegan, B. and Delgado, D. 2000. Structural and floristic heterogeneity in a 30-year-old Costa Rican rain forest restored on pasture through natural secondary succession. *Restoration Ecology* **8**:380-393.

Gentry, A.H. 1982. Patterns of neotropical plant species diversity. In: Hecht *et al*. (Eds.), *Evolutionary Biology*, Vol. 15. Plenum Press, New York, pp. 1-84.

Gentry, A.H. 1988. Changes in plant diversity and floristic composition on environmental and geographical gradients. *Annuals of Missouri Botanical Garden* **75**:1-34.

Gentry, A.H. 1992. Tropical forest biodiversity: distribution patterns and their conservational significance. *Oikos* **63**:19-28.

Grime, J.P. 1979. Plant Strategies and Vegetation Processes, John Wiley, Chichester.

Guariguata, M.R. and Ostertag, R. 2001. Neotropical secondary forest succession: Changes in structural and functional characteristics. *Forest Ecology and Management* **148**:185-206.

Haridasan, K. and Rao, R.R. 1985-1987. *Forest Flora of Meghalaya*, Vols. I-II. Bishen Singh Mahendra Pal Singh, Dehradun, India.

Holl, K.D., Loik, M.E., Lin, E.H.V. and Samuels, I.A. 2000. Tropical montane forest restoration in Costa Rica: obstacles and opportunities. *Restoration Ecology* **8:**339-349.

Holl, K.D. 1999. Factors limiting tropical rain forest regeneration in abandoned pasture: Seed rain, seed germination, microclimate, and soil. *Biotropica* **31**:229-242.

Hooker, J.D. 1872-1897. *Flora of British India*. Vols. I-VII. London.

Hubbell, S.P. 1979. Tree dispersion, abundance and diversity in a tropical dry forest. *Science* **203**:1299-1309.

Huston, M.A. 1979. A general hypothesis of species diversity. *The American Naturalist* **113**:81-101.

Huston, M.A. 1980. Soil nutrients and tree species richness in Costa Rican forest. *Journal of Biogeography* **7**:147-157.

IIRS. 2002. Biodiversity Characterisation at Landscape level in North-East India using Remote Sensing and Geographical Information System. Indian Institute of Remote Sensing, Dehradun.

Jamir, S.A. 2000. Studies on plant biodiversity, community structure and population behavior of dominant tree species of some sacred groves of Jaintia hills, Meghalaya. Ph.D. Thesis, North-Eastern Hill University, Shillong, India.

Jamir, S.A. and Pandey, H.N. 2002. Status of biodiversity in the sacred groves of Jaintia Hills, Meghalaya. *Indian Forester* **128**:738-744.

Jamir, S.A. and Pandey, H.N. 2003. Vascular plant diversity in sacred groves of Jaintia Hills in north-east India. *Biodiversity and Conservation* **12**:1497-1510.

Kanjilal, U.N., Kanjilal, P.C., De, R.N. and Das, A. 1934-1940. Flora of Assam. Government of Assam.

Kellman, M. 1980. Geographic patterning in tropical weed communities and early secondary successions. *Biotropica* **12:**34-39.

Khan, M.L., Rai, J.P.N. and Tripathi, R.S. 1987. Population structure of some tree species in disturbed and protected sub-tropical forests of north-east India. *Acta Oecologia/ Oecological Applications* **8**:247-255.

Kumar, Y. 1984. *Studies on the flora of Balphakram Wildlife Sanctuary*, Garo Hills. Ph. D. Thesis, North-Eastern Hill University, Shillong, India.

Kushwaha, S.P.S., Ramakrishnan, P.S. and Tripathi, R.S. 1983. Population dynamics of *Imperata cylindrica* (L.) Beauv. var. *major* related to slash and burn agriculture (*jhum*) in North-Eastern Hills. *Proceedings of Indian Academy of Science (Plant Science)* **92**(4):313-321.

Lieberman, M., Lieberman, D., Hartshorn, G.S. and Peralta, R. 1985. A small-scale altitudinal variation in lowland tropical forest vegetation. *Journal of Ecology* **73**:505- 516.

Magurran, A.E. 1988. *Ecological Diversity and its Measurement*. Princeton University Press, Princeton, NJ.

May, R.M. 1975. Patterns of species abundance and diversity. *Ecology and Evolution of Communities*, Harvard University Press, pp. 81-120.

Meher-Homji, V.M. 1964. Lifeform and biological spectra as edaphic criteria of eridity and humidity in tropics. *Journal of Indian Botanical Society* **43**:424-430.

Miller, P. M. and Kauffman, J.B. 1998. Seedling and sprout response to slash-and-burn agriculture in a tropical deciduous forest. *Biotropica* **30**:538-546.

Mishra, B.P., Tripathi, R.S., Tripathi, O.P. and Pandey, H.N. 2004. Effects of anthropogenic disturbance on plant diversity and community structure of a sacred grove in Meghalaya, North-east India. *Biodiversity and Conservation* **13**(2):421-426.

Misra, B.K. and Ramakrishnan, P.S. 1983. Slash and burn agriculture at higher elevations in north-eastern India. II. Soil fertility changes. *Agriculture, Ecosystems and Environment* 9:83-96.

Müeller-Dombois, D. and Ellenberg, H. 1974. *Aims and Methods of Vegetation Ecology*, John Wiley and Sons Inc, New Delhi, India.

Noble, I.R. and Slatyer, R.O. 1980. The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbances. *Vegetatio* **43**:5-21.

Oliver, C.D. 1981. Forest development in North America following major disturbances. *Forest Ecology and Management* **3**:153-168.

Olson M.D., Dinerstein, E., Mittermeier, R.A., Myers, N., Thomsen, J.B. and da Fonseca, G.A.B. 1998. Biodiversity hotspots and major tropical wilderness areas: approaches to setting conservation priorities. *Conservation Biology* **12**(3):516-520.

Phillips, O.L., Hall, P., Gentry, A.H., Sawyer, S.A. and Váquez, R. 1994. Dynamics and species richness of tropical rain forests. *Proceedings of National Academy of Sciences USA* **91**:2905-2809.

Poore, M.E.D. 1968. Studies in Malaysian rain forest. I. The forest on Triassic sediments in Jengka forest reserve. *Journal of Ecology* **56**:143-196.

Rao, P., Barik, S.K., Pandey, H.N. and Tripathi, R.S. 1990. Community composition and tree population structure in sub-tropical broad-leaved forests along a disturbance gradient. *Vegetatio* **88**:157-162.

Rao, R.S. and Panigrahi, G. 1961. Distribution of vegetational types and their dominant species in Eastern India. *Journal of Indian Botanical Society* **40**:274-285.

Rao, A.S. 1969. The vegetation of the Khasi and Jaintia Hills. *Proceedings of Pre-Congress Symposium and Field Study on Physical Geography of Eastern Himalaya and Meghalaya* (1968). Guwahati, India. pp. 92-102.

Rao, A.S. 1970. A sketch of the flora of North-eastern India, particularly Assam and Meghalaya. *In Souvenir 40th session of Central Board of Irrigation and Power*, Shillong, pp. 85-90.

Rao, A.S. 1974. The vegetation and phytogeography of Assam-Burma. In: Mani M.S. (Ed.), *Ecology and Biogeography in India*, pp. 204-205.

Rao, A.S. 1977. Floristic studies in North-eastern India (Old Assam Region). *Bulletin Botanical Survey of India* **19**:56-60.

Raunkiaer, C. 1934. The life form of plants and statistical plant geography. Being collected papers of Raunkiaer, C. Clarendon press, Oxford, London, pp. 632.

Richards, P.W. 1996. *The Tropical Rainforest*. II Edition, Cambridge University Press, Cambridge.

Takhtajan, A. 1988. *Floristic regions of the world*. Bishen Singh Mahendra Pal Singh, Dehradun, pp. 71-78.

Tilman, D. 1982. Resource competition and community structure. Princeton University Press, Princeton.

Tilman, D. and Pacala, S. 1993. The maintenance of species richness in plant communities. In: Ricklefs, R.E. and Schluter D. (Eds.) *Species Diversity in Ecological Communities*. University of Chicago Press, Chicago, pp. 13-25.

Tiwari, B.K., Barik, S.K. and Tripathi, R.S. 1999. *Sacred forests of Meghalaya*. Regional Center, National Afforestation and Ecodevelopment Board, North-Eastern Hill Universiity, Shillong, India.

Tripathi, R.S. and Barik, S.K. 2003. Shifting cultivation in North-East India. In: Bhatt *et al*. (Eds.) *Proceedings on Approaches for Increasing Agricultural Productivity in Hill and Mountain Ecosy stem*. ICAR Research Complex for NEH Region, Umiam, Meghalaya, pp. 317-322.

Uhl, C. 1987. Factors controlling succession following slash-andburn agriculture in Amazonia. *Journal of Ecology* **75**:377-407.

Uhl, C. and Jordan, C.F. 1984. Succession and nutrient dynamics following forest cutting and burning in Amazonia. *Ecology* **65**:1476-1490.

Uhl, C., Clark, K., Clark, H. and Murphy, P. 1981. Early plant succession after cutting and burning in the upper Rio Negro region of the Amazon Basin. *Journal of Ecology* **69**:631-649.

Uhl, C., Buschbacher, R. and Serrap, E.A.S. 1988. Abandoned pastures in Eastern Amazonia. I. Patterns of plant succession. *Journal of Ecology* **76**:663-681.

Upadhaya, K., Pandey, H.N., Law, P.S. and Tripathi, R.S. 2003. Tree diversity in sacred groves of the Jaintia Hills in Meghalaya, northeast India. *Biodiversity and Conservation* **12**:583-597.

Valencia, R., Balslev, H. and Mino, G.C.P.Y. 1994. High tree alpha-diversity in Amazonian Ecuador. *Biodiversity and Conservation* **3**:21-28.

van Gemerden, B.S., Shu, N.G. and Olff, H. 2003. Recovery of conservation values in Central African rain forest after logging and shifting cultivation. *Biodiversity and Conservation* **12**:1553-1570.

Vazquez, A.J.G. and Givinish, T.J. 1998. Altitudinal gradients in tropical forest composition, structure and diversity in the Sierra de Manantlán. *Journal of Ecology* **86**:999-1020.

Whitford, P.B. 1948. Distribution of woodland plants in relation to succession and clonal growth. *Ecology* **30**:199-208.

Whitmore, T.C. (Ed.) 1970. *Tree Flora of Malaya*. Vol. I. Longman, London.

Whitmore, T.C. 1998. *Tropical Rain Forests of Far East*. Oxford University Press, Oxford.

Whittaker, R.H. 1960. Vegetation of the Siskiyou mountains, Oregon and California *Ecological Monographs* **30**:279-338.

Whittaker, R.H. 1972. Evolution and measurement of species diversity. *Taxon* **21**:213-251.

Wijdeven, S.M.J. and Kuzee, M.E. 2000. Seed availability as a limiting factor in forest recovery processes in Costa Rica. *Restoration Ecology* **8:**414-424.

Zimmerman, J.K., Pascarella, J.B. and Aide, T.M. 2000. Barriers to forest regeneration in an abandoned pasture in Puerto Rico. *Restoration Ecology* **8**:350-360.