Tropical Ecology **48**(2): 209-225, 2007 ISSN 0564-3295

www.tropecol.com

Tree species gap phase performance in the buffer zone area of Namdapha National Park, Eastern Himalaya, India

PANNA DEB[1] & R.C. SUNDRIYAL[2*]

[1]*G.B. Pant Institute of Himalayan Environment and Development, North East Unit, Vivek Vihar, Itanagar, Arunachal Pradesh, 791113, India*

[2]*G.B. Pant Institute of Himalayan Environment and Development, Kosi-Katarmal, Almora, Uttarakhand, 263643 India*

Abstract: The Namdapha National Park located in the Eastern Himalayan region is among the most diverse patches of biodiversity in India. The buffer zone area of the park that comprised tropical wet evergreen *(Dipterocarpus)* forests, was investigated for tree regeneration (seedlings and saplings) in gaps as well as in understorey (close-canopy) areas. The forest comprised mainly the small size gaps (area < 70 m^2) that were created by natural processes, through fall of single or multiple trees, and branches or crown breakage. The species composition varied in gaps and understorey, however, the density was nearly same. The species richness was slightly higher in understorey area than the gaps (45 and 39 tree species, respectively), which may be because of less number of gaps found in the forest. The mid-canopy species, which were better adapted to the shady condition, contributed maximum to species richness and density in the understorey areas. The overall regeneration for gap and understorey areas was recorded 7025 individuals ha^{-1} and 7323 individuals ha^{-1}, respectively, which is well comparable with other tropical forests. The study revealed that the small and medium size gaps had limited impacts on the species composition; such gaps, however, are crucial for regeneration of top canopy and pioneer species thus important for maintaining species diversity. As the gaps showed difference in species composition, it clearly illustrated that the plant species behavior in low-land tropical forest is independent of gap size and it mainly governed by availability of seeds at the time of creation of gaps. The information on the tree species gap performance has implications for the management of the forest stand.

Resumen: El Parque Nacional Namdapha, ubicado en el este de la región de los Himalaya, está entre los parches con mayor biodiversidad en la India. Se estudió la regeneración de árboles (plántulas y juveniles o brinzales) en claros y en el sotobosque (áreas de dosel cerrado) en la zona de amortiguamiento que contiene bosques tropicales húmedos perennifolios (*Dipterocarpus*). El bosque incluyó principalmente claros de tamaño pequeño (área < 70 m^2) creados por procesos naturales, a través de la caída de uno o varios árboles, y ramas o rompimiento de las copas. La composición de especies varió entre los claros y el sotobosque, pero la densidad fue casi la misma. La riqueza de especies fue ligeramente mayor en el área de sotobosque que en los claros (45 y 39 especies de árboles, respectivamente), lo cual puede deberse al bajo número de claros hallados en el bosque. Las especies del dosel medio, las cuales estuvieron mejor adaptadas a la condición de sombra, hicieron la mayor contribución a la riqueza de especies y a la densidad en las áreas de sotobosque. Para la regeneración general en claros y en áreas de sotobosque se registraron 7025 individuos ha^{-1} y 7323 individuos ha^{-1},

[*] *Corresponding Author*; e-mail: sundriyalrc@yahoo.com

respectivamente, lo cual es bastante similar a datos de otros bosques tropicales. El estudio mostró que los claros de tamaño pequeño y mediano tienen impactos limitados sobre la composición de especies; dichos claros, sin embargo, son cruciales para la regeneración de las especies del dosel superior y las pioneras, y por lo tanto importantes para el mantenimiento de la diversidad de especies. Como los claros mostraron diferencias en la composición específica, quedó claramente ilustrado que el comportamiento de las especies vegetales en el bosque tropical de tierra baja es independiente del tamaño de claro y que está determinada principalmente por la disponibilidad de semillas en el momento de la creación de los claros. La información sobre el desempeño de las especies arbóreas tiene implicaciones para el manejo del rodal de bosque.

Resumo: O Parque Nacional Namdapha, localizado na região oriental dos Himalaias, está entre os parques com maior biodiversidade na Índia. Estudou-se a regeneração de árvores (plântulas e juvenis) em clareiras e no sub-coberto (em áreas de copado fechado) na zona tampão que continha florestas tropicais húmidas sempre verdes (*Dipterocarpus*). A floresta incluía principalmente pequenas clareiras (área < $70m^2$) criadas por processos naturais em resultado da queda de uma ou várias árvores, ramos ou quebras da copa. A composição das espécies variou entre as clareiras e o sub-coberto se bem que a densidade fosse quase a mesma. A riqueza específica foi ligeiramente maior na área do sub-coberto em comparação com os clareiras (45 e 39 espécies arbóreas, respectivamente), a qual pode dever-se a um baixo número de clareiras encontradas na floresta. As espécies do dossel médio, que se encontravam mais adaptadas às condições de sombreamento, foram as principais contribuintes para a riqueza específica e densidade nas áreas de sub-coberto. A regeneração geral registada para clareiras e sub-coberto foi de 7025 e 7323 árvores ha^{-1}, respectivamente, valores estes que são bastante comparáveis aos dados de outras florestas tropicais. O estudo mostrou que as clareiras pequenas ou medianas têm impactos limitados sobre a composição das espécies; e que, entretanto, estas clareiras são cruciais para a regeneração das espécies do andar superior dominante e das pioneiras da floresta e, por isso, importantes na manutenção da biodiversidade. Como as clareiras apresentaram diferenças na composição específica ficou claramente mostrado que o comportamento das espécies nas florestas tropicais das terras baixas é independente da dimensão da clareira e que a mesma é governada, principalmente, pela disponibilidade de sementes na altura da formação da clareira. A informação sobre o desempenho das espécies arbóreas nas clareiras tem implicações sobre a gestão da parcela florestal.

Key words: Forest gaps, species regeneration, species richness, tropical rainforests, understorey vegetation.

Introduction

The future composition of forests depends on potential regenerative status of tree species within a forest stand (Ayyapan & Parthasarthy 1999; Henle *et al.* 2004), therefore, an understanding of the processes that affect regeneration of forest species is of crucial importance to both ecologists and forest managers (Slik *et al.* 2003). Disturbances determine forest species composition, structure and processes as it facilitate changes in resource fluxes and lead to some form of reorganization of the disturbed patch or gap that may be similar or dissimilar to predisturbance levels over temporal and spatial scales (Grubb 1977; Slik *et al.* 2003). A large number of canopy species are dependent upon the gaps for their regeneration (Hartshorn 1980) and an understanding of gap dynamics offers an insight into the patterns and processes within the forest ecosystem. As tree fall gaps play an important role in maintaining species richness of a given forest, a study of such regimes along with tree replacement processes would provide a better insight into the dynamics of closed canopy communities where these openings are the only means for tree regeneration (Hubbell & Foster 1986). Much of the available information on gap phase dynamics of the tropical forest ecosystem are reported from the Latin American (Brokaw 1985) and southeast Asian countries (Ashton *et al.* 2001) though in India it is restricted to a few forest areas only (Barik *et al.* 1992; Chandrashekara & Ramakrishnan 1994; Khan & Tripathi 1991; Ramakrishnan 1991; Rao 1992; Tripathi & Khan 1990). Namdapha National Park is well known for its species richness and habitat diversity (Chauhan *et al.* 1996; Deb 2006; Deb & Sundriyal 2005).

The present study analyses the regeneration status and gap phase performance of tree species along with the microsite heterogeneity and selected physical attributes of tree fall gaps in the lowland tropical rainforests of Namdapha National Park.

Material and methods

Study area

Namdapha National Park (27°23'30"- 27°39'40" N to 96°15'2" - 96°58'33" E) is located in the Changlang district of Arunachal Pradesh state. It covers an area of about 1985 km^2 with 177 km^2 in buffer zone and 1808 km^2 in core zone. The park is wedged between the Dapha Bum range of Mishmee Hills, an outspur at the tail end of North Eastern Himalaya and the Patkai range with an elevational variance of 200-4571 m asl. Geologically, the park is of recent origin and owes its formation to the upheaval of the Himalaya in Pleiocene period of the tertiary age (Chauhan *et al.* 1996). The topography is rugged with numerous steep hills and narrow valleys intersected by several rivers. Biogeographically, the area falls under the Eastern Himalaya (2D) biogeographic province of the Indian origin, which covers the Paleartic and the Indo-Malayan (Oriental) realms (Rodgers & Panwar 1988). The soils of Namdapha

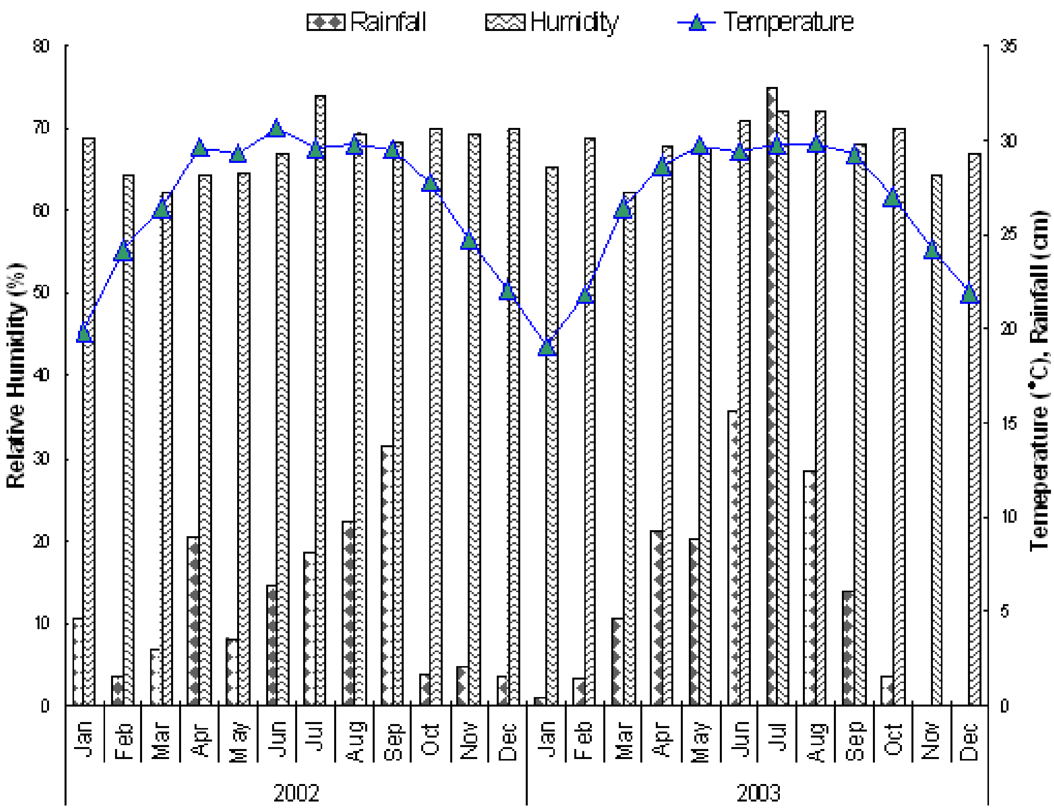

Fig. 1. Temperature, rainfall and humidity at Deban Range of the Namdapha National Park during 2002 and 2003.

National Park are characterized by deep layer of sandy loam soil, rich in vegetative matter that is also found in the lower and gentle slopes of the hills which supports the best fully stocked *Dipterocarpus* forests. The present study was confined to the buffer zone area comprising the lowland tropical wet evergreen forests, which is also called as South bank Tropical Wet Evergreen (*Dipterocarpus*) Forests (Kaul & Haridasan 1987). The study area exhibits tropical climate having typical monsoon pattern with rainy season extending from May to September with a total annual rainfall of 2500-3000 mm. At times the rainy season prolongs to 9 months in a year. Occasional off-season showers are also not uncommon. The temperature and relative humidity remains high throughout the year (Fig. 1). The park is reported to harbour 1119 species of plants belonging to 639 genera and 215 families (Chauhan *et al*. 1996). The park also exhibits high faunal diversity with over 1399 species that includes a large variety of mammals and wide diversity of invertebrates (Ghosh 1987). Local ethnic groups such as Lisu, Lama and Chakma communities live in and around the park (Deb & Sundriyal 2005).

Sampling methods

Natural regeneration and gap phase performance of species was studied during November 2003 to May 2004 (covering winter, summer, rainy and post-monsoon seasons). Sampling was performed in the physiognomically identified forest patches of the lowland evergreen forest in Namdapha National Park, which is categorized as the South Bank Tropical Wet-Evergreen (*Dipterocarpus*) forest. The selection of the forest patch was based on considering the broad features, viz. canopy covers, climax vegetation, and species composition of the forest stand. The details of the forest stands including species composition, tree structure, species richness, species diversity and biomass-productivity was reported by Deb (2006).

For analyzing tree species gap-phase regeneration status, a total of 13 gaps were identified that have originated from either single or multiple tree and branch falls. A gap was considered as an opening in the forest canopy extending through all foliage levels to an average height of 2 m above ground (Brokaw 1985). All the gap areas were mapped to scale by measuring the distances and angles from the gap center to the gap margin or edge of each gap in at least eight directions (usually every 45°) and then summed the area of all the triangles so formed (Pinzon *et al.* 2003). The size of the gap was further confirmed by measuring the scaled drawing of the gap areas with a digital planimeter. Causes of the gap formation were ascertained through field verification and discussion with the field staff of the National Park. Gaps less than 70 m^2 area were considered small size gaps, while >70 m^2 area considered as medium size gaps. Large size gap was not recorded and gap area less than 25 m^2 were not considered in the present study. On the basis of remnants of fallen trees and branches and the degree of decomposition incurred and successional stages of vegetation in the gaps, all gaps in the study area were broadly grouped in two classes, viz., < 2 years and > 2 years old, i.e. if the felled trees which caused the gap had intact or dried foliage, the age of the gap was considered less than two years (Chandrashekara & Ramakrishnan 1994; Ramakrishnan 1992; Rao 1992). An architectural analysis of the tree saplings in the gap area was also used to tentatively identify the age of the gap formation using local knowledge that people acquire over the years, and such an approach has been successfully applied in some places (Ramakrishnan 1992). The tree species regeneration in all the gaps was studied by random quadrat sampling. All individuals <31.5 cm cbh were considered regenerating individuals, comprising seedlings and saplings (Singh & Singh 1987; Sundriyal & Sharma 1996; Sundriyal *et al.* 1994). The regenerating individuals were further categorized into saplings (individuals with > 20 cm height and < 31.5 cbh) and seedlings (individuals < 20 cm height) (Sundriyal *et al.* 1994). The quadrat size was 5x5 m for sapling analysis (n=100) and 2x2 m for seedlings analysis (n=125). Samples of all plant species were collected and identified to species level. The species composition and density of the regenerating individuals (tree saplings and seedlings) occurring in the gaps was enumerated. The data were collected separately for gaps as well as for understorey areas. Similarity among gaps was measured using presence/absence data according to Sorensen's similarity index (Sorensen 1948). Species diversity of gaps and understorey have been discussed on the basis of α-diversity (Brokaw & Scheiner 1989; Whittaker 1972), which refers to the mean number of species per gap. These indices were also calculated for understorey vegetation adjacent to each gap.

The gaps were also analyzed for their microenvironment at the center of the gaps in comparison to nearby forest understorey areas at five points within 5 -10 m away from the gap-edge by recording air and soil temperatures, relative humidity, light intensity, litter depth and soil moisture at 1200 h on sampling days. The photon flux density was measured at ground level using a Lux meter (LX-101-Lutron). The relative humidity and air temperature were measured at ground level using a humidity-temperature meter (Lutron, HT-3004). Soil temperature was measured down to 10 cm depth using soil multi-thermometer and soil moisture content was estimated using dry weight method. The litter accumulation was determined by assessing the depth in various places with the help of a hand held meter tape. Soil was collected from different locations of all the gaps and understorey areas that were subsequently analyzed in the laboratory for pH, total nitrogen, total phosphorous and organic carbon. The total nitrogen was determined using auto-analyzer (Kel Plus KES 20L), organic carbon was estimated by colorimetric method, while total phosphorous was determined through vanadate molybdate yellow method (Anderson & Ingram 1993).

The statistical analysis (ANOVA and Correlation) for regenerating individuals among the plots within a stand as well as between different stands, and correlation were performed using SYSTAT computer package (Wilkinson 1986).

Results

Causes of gap formation, and size and shapes of gaps

A total of 13 gaps have been identified that were investigated in detail (Table 1). An assessment of the causes for tree gaps formation revealed that the branch fall, crown fall, standing dead trees, and single or multiple tree fall were major reasons for gap creation in the studied forest (Table 1). Among the factors responsible for creating gaps in all the thirteen gap locations, tree fall accounted for 53.85% of the gap formation, branch fall for 15.38%, snapping off of the bole accounted for 7.69%, and both tree and branch falls together accounted for 21% of the gaps.

Table 1. Physical features and microsite heterogeneity of the tree fall gaps in the tropical evergreen forest of Namdapha National Park.

Gap No.	Gap Age (Years)	Area (m^2)	No. of tree fall	Causes of gap formation	Topography	Microsite heterogeneity
1	<1	77.1	Multiple	Tree fall	Level surface	Broken stump and branches
2	1	27.08	Nil	Branch fall	Level surface	Old debris
3	5	30.42	One	Tree fall	Level surface	Decaying log and soil mould
4	5	55.42	One	Tree and Branch fall	Level surface	Decaying log
5	2	61.99	Nil	Branch fall	Level surface	debris
6	1	117.13	Multiple	Tree fall	Level surface	Broken stump and root mats
7	3	45.74	One	Tree and branch fall	Level surface	Old debris
8	6	156.94	Multiple	Tree fall	Level surface	Very old debris
9	6	25.00	One	Tree fall	Level surface	Very old debris and decaying log
10	2	44.09	One	Tree fall and Branch fall	Level surface	Broken stump
11	5	62.18	Multiple	Tree fall and Branch fall	Level surface	Old debris
12	4	33.38	One	Tree fall	Level surface	Decaying log
13	2	47.95	One	Tree fall	Slight slope	Broken stump

Multiple tree falls accounted for 30.77% of the gaps created, while single tree fall accounted for 53.85% of the gaps created (Table 1). The smaller gaps were more frequent than middle sized gaps in the study area. The gap size varied from 25 to 157 m^2. Majority of the gaps were created during the rainy season compared to the dry winter season. The microsite heterogeneity of the gap areas comprised of broken stumps and branches, wood debris, soil moulds, decaying logs and root mats. About 77% gaps were small (size < 70 m^2) while remaining 23% were medium sized. The age of the gaps varied from 1 year to > 6 years (Table 1). The shape of the gaps varied from dumbbell (gap numbers 3, 5, 8, 11, 12 and 13) to hexagonal (gap numbers 4 and 9), elliptical (gap numbers 1, 2, 6 and 9) and to quadrangular shaped (gap number 10) (Fig. 2).

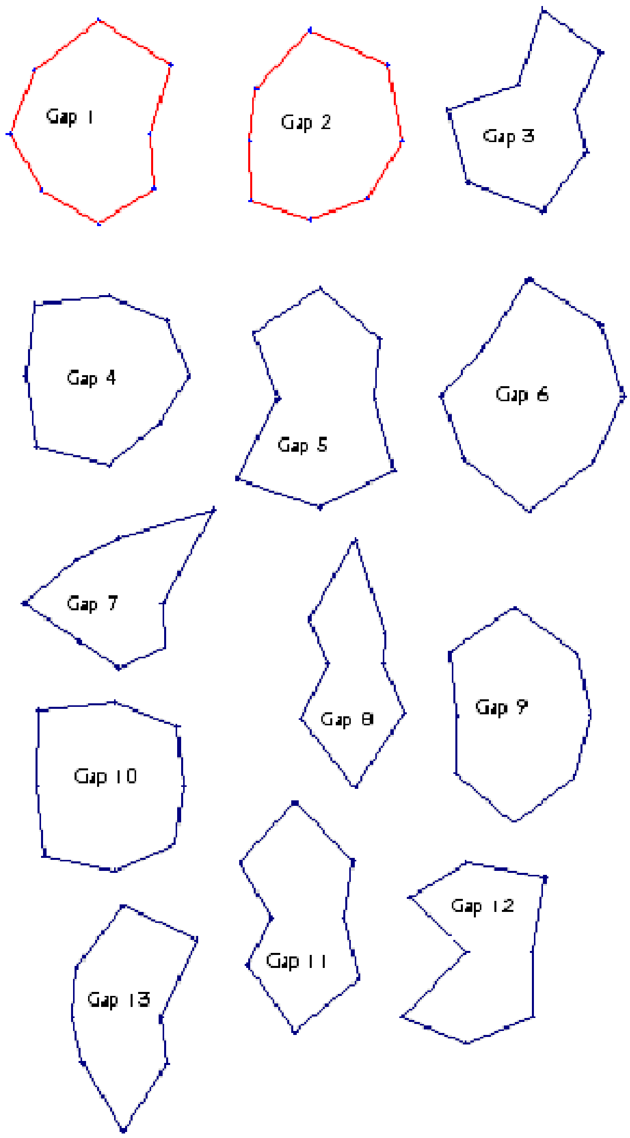

Fig. 2. Different type of gaps found in the lowland tropical wet evergreen forest stands in the buffer zone area of Namdapha National Park.

Microenvironment in the gaps and the understorey

The climatic and the edaphic variables in the gaps and the forest understorey are shown in Table 2. Photon flux, the light intensity in the gaps was significantly higher (range 220-4350 lx) as compared to the understorey areas (100-352 lx). The average air temperature in the gaps was slightly higher, recorded as 17.15°C (range 15.6-19.9°C) than the nearby understorey areas of 16.82°C (range 14.2-20.2°C). For the gaps, the size of the gap showed significant positive correlation with litter depth ($r=0.485$, $P<0.05$) and soil moisture ($r=0.600$, $P<0.05$). Air temperature showed positive relationship only with soil temperature ($r=0.814$, $P<0.001$). In the understorey, relative humidity showed positive correlation with soil temperature ($r=0.789$, $P<0.001$) and negative correlation with soil moisture ($r=0.597$, $P<0.05$).

Frequency of occurrence of species in gaps and understorey

A total of 62 tree species have been recorded to occur in gaps and nearby understorey areas, of which 39 species were found in gaps, while 45 species were recorded in understorey areas (Table 3). A total of 35 species were found common to both gaps and the understorey areas showing 42% similarity. Two species, *viz. Beilschmiedia assamica* and *Castanopsis* species showed widespread occurrence in both gaps and understorey areas (Table 3). Pioneer species such as *Altingia excelsa* and *Sapium baccatum* were found regenerating in the gaps only. *B. assmaica* (85%), *D. procerum* (69%), *Castonopsis indica* (85%) and *Ostodes paniculata* (54%) were most frequently occurring species in the gaps. The understorey areas adjacent to the gaps showed a dominance of the regenerating individuals of *Beilschmiedia assamica* (85%), *Saprosma ternatum* (85%), *Dysoxylum procerum* (54%) and *Syzygium macrocarpum* (46%) based on their frequency of occurrence.

Table 2. Environmental variables in the gaps and understorey (Us) in lowland evergreen forest of Namdapha National Park.

	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6		Site 7	
Variables	Gap 1	Us	Gap 2	Us	Gap 3	Us	Gap 4	Us	Gap 5	Us	Gap 6	Us	Gap 7	Us
Gap area (m^2)	77.1		27.08		30.42		55.42		61.99		117.13		45.74	
Species richness	6	11	5	8	12	13	9	14	6	10	5	9	7	7
Light intensity (Lux)	817	118	860	100	559	100	1020	352	4350	308	1328	125	760	175
Air Temperature (°C)	19	20	16.4	16	17.3	16.4	15.6	15.0	17	16.4	18	17.1	17.2	17
Relative Humidity (%)	92	96	88.2	93.7	92.8	93.1	89.6	94.2	88	92	86	95	89.7	93.5
Soil temp (°C)	16.1	15	13.7	14.1	15.3	14.7	14.7	14.5	15	14.5	15.3	15	14.5	14
Litter depth (cm)	6	6	5	5	5	8	6	6	6	10	7.5	5	7	8.5
Soil moisture (%)	30.58 ± 0.83	23.22 ± 2.56	29.50 ± 2.12	22.49 ± 1.87	23.36 ± 0.18	22.46 ± 0.34	28.15 ± 0.41	24.36 ± 0.40	26.21 ± 0.49	25.24 ± 0.20	25.63 ± 0.88	20.80 ± 0.06	25.47 ± 0.42	22.54 ± 0.49
pH	5.80 ± 0.09	5.35 ± 0.23	4.79 ± 0.07	4.50 ± 0.45	5.84 ± 0.07	6.02 ± 0.09	5.003 ± 0.13	5.49 ± 0.06	5.12 ± 0.014	5.35 ± 0.12	5.05 ± 0.19	5.43 ± 0.05	5.53 ± 0.57	5.52 ± 0.28
Nitrogen (%)	1.79 ± 0.16	0.43 ± 0.03	1.26 ± 0.63	0.44 ± 0.04	1.45 ± 0.03	0.45 ± 0.05	1.57 ± 0.054	0.41 ± 0.41	1.27 ± 0.01	0.48 ± 0.02	1.44 ± 0.55	0.44 ± 0.02	1.16 ± 0.032	0.18 ± 0.0017
Phosphorous (%)	0.71 ± 0.08	0.23 ± 0.02	0.81 ± 0.11	0.21 ± 0.014	0.63 ± 0.04	0.25 ± 0.05	0.73 ± 0.09	0.21 ± 0.02	0.59 ± 0.00	0.22 ± 0.03	0.69 ± 0.12	0.20 ± 0.02	0.53 ± 0.00	0.21 ± 0.02
Carbon (%)	2.99 ± 0.12	2.69 ± 1.00	2.32 ± 0.03	2.37 ± 0.05	2.57 ± 0.04	1.37 ± 0.04	2.48 ± 0.06	1.04 ± 0.03	1.81 ± 0.07	1.08 ± 0.19	2.69 ± 0.04	1.82 ± 0.03	2.15 ± 0.08	2.37 ± 0.05

Table 2. Continued.

	Site 8		Site 9		Site 10		Site 11		Site 12		Site 13	
Variables	Gap 8	Us	Gap 9	Us	Gap 10	Us	Gap 11	Us	Gap 12	Us	Gap 13	Us
Gap area (m^2)	156.94		19.23		44.09		62.18		33.38		47.95	
Species richness	9	8	12	9	7	8	9	6	6	8	8	4
Light intensity (Lux)	220	120	800	250	800	344	416	216	1500	180	600	297
Air Temperature (°C)	15.7	14.2	16.6	15	16.2	16.4	17.7	18	16.3	16.9	19.9	20.2
Relative Humidity (%)	90.1	96	89	96.3	95	95	83	88.2	91.2	93.3	91.9	95
Soil temp (°C)	14.2	14	14.4	13.9	14.7	14.4	15.2	15.2	14.3	14.1	15.7	16.3
Litter depth (cm)	8	6	7	7	8	8.5	4.5	6	6	7.5	5.5	5
Soil moisture (%)	33.65	29.21	25.95	22.68	26.01	22.35	27.67	20.13	26.88	20.84	26.93	20.25
pH	33.65 ± 2.15	29.21 ± 1.15	25.95 ± 0.33	22.68 ± 0.56	26.01 ± 1.19	22.35 ± 1.02	27.67 ± 1.06	20.13 ± 0.61	26.88 ± 0.36	20.84 ± 0.61	26.93 ± 0.75	20.25 ± 0.41
Nitrogen (%)	5.55 ± 0.36	5.09 ± 0.04	4.89 ± 0.03	4.61 ± 0.08	5.24 ± 0.45	5.78 ± 0.02	6.13 ± 0.16	4.39 ± 0.23	4.83 ± 0.41	4.08 ± 0.03	5.002 ± 0.03	4.82 ± 0.12
Phosphorous (%)	1.37 ± 0.032	0.13 ± 0.01	1.18 ± 0.042	0.19 ± 0.0015	0.71 ± 0.042	0.096 ± 0.052	1.29 ± 0.07	0.16 ± 0.11	1.12 ± 0.08	0.11 ± 0.08	0.34 ± 0.13	0.19 ± 0.0017
Carbon (%)	0.92 ± 0.05	0.20 ± 0.02	0.72 ± 0.11	0.19 ± 0.01	0.75 ± 0.19	0.19 ± 0.01	0.52 ± 0.04	0.24 ± 0.01	0.62 ± 0.012	0.21 ± 0.01	0.46 ± 0.05	0.25 ± 0.05
	2.52 ± 0.04	3.26 ± 0.17	2.41 ± 0.07	3.23 ± 0.28	2.36 ± 0.027	3.71 ± 0.11	2.19 ± 0.07	3.22 ± 0.54	2.12 ± 0.05	3.58 ± 0.20	2.11 ± 0.05	3.40 ± 0.22

Table 3. Frequency of occurrence (%) of different species at tree fall gaps and adjacent understorey vegetation in Namdapha National Park.

Species	Gaps	Understorey
Actinodaphne obovata	8	0
Allophyllus sp.	8	15
Altingia excelsa	8	0
Antidesma acuminatum	8	23
Aporosa dioica	23	0
Ardisia sp.	15	23
Artocarpus chaplasa	8	0
Baccaurea ramiflora	8	31
Beilschmiedia assamica	85	85
Beilschmieida sp.2	0	8
Camelia caudata	8	0
Canarium strictum	23	0
Castanopsis indica	85	15
Castanopsis sp.2	8	0
Chukrussia tabularis	0	8
Cinnamomum bejolghota	46	31
Dalbergia sp.	0	15
Diospyros sp.	0	8
Dipterocarpus macrocarpus	0	8
Dysoxylum procerum	69	54
Elaeocarpus sp.	15	0
Eleaocarpus aristatus	8	8
Ficus sp.	0	15
Glycosmis sp.	0	8
Griffithianthuus fuscus	8	8
Helicia robusta	0	8
Aphania rubra	0	8
Knema linifolia	0	8
Laportea crenulata	0	8
Lasianthus longicauda	8	0
Lauraceae	8	0
Leea indica	8	0
Lindera latifolia	23	23
Linociera macrophylla	8	0
Litsea salicifolia	38	38
Litsea sp.2	8	15
Macropanax dispermus	0	8
Mangifera sylvatica	8	0
Melia dubia	8	0
Mesua ferrea	15	38
Milliusa roxburghiana	8	15
Olea dentate	0	8
Ostodes paniculata	54	15
Persea sp.	0	15

Contd…

Table 3. Continued.

Species	Gaps	Understorey
Premna sp.	0	8
Pterygota alata	0	8
Quercus lamelosa	0	8
Quercus semiserrata	8	15
Rhamnaceae	0	8
Sapium baccatum	8	0
Saprosma ternatum	38	85
Shorea assamica	15	0
Sterculia sp.	0	15
Stereospermum chelonoides	0	8
Styrax serruletum	0	8
Syzygium cumini	8	0
Syzygium macrocarpum	31	46
Talauma hodgsonii	8	23
Turpinia pomifera	0	8
Vitex sp.	0	8
Xerospermum glabratum	15	0
Unidentified	8	46

Species richness, density and diversity in the gaps and the understorey

The overall species richness for the regenerating individuals was higher in the understorey areas compared to the gaps. However, the seedling richness was nearly double in the gap areas (Table 4). The total density of all regenerating individuals was 7323 ha^{-1} in the understorey areas, which was marginally higher than the gap areas (7025 individual ha^{-1}). Alpha (α) diversity was recorded highest for tree (H= 7.85) and lowest for shrubs (H= 0.54) for the gap areas. In the understorey areas as well, similar pattern of α-diversity was noticed, maximum for trees (8.62), followed by herbs (2.54) and lowest for shrubs (0.69) (Table 4). The dominant regenerating plant family was Lauraceae at both the gap and understorey sites. *Beilschmiedia assamica* was most dominating regenerating species in the both the situations (Table 4).

The regenerating individual density in the gaps for saplings was 4400 individuals ha^{-1} and for seedlings 2625 individuals ha^{-1} (Table 5). Eight top-canopy species were recorded regenerating in the gaps that comprised *Cinnamomum bejolghota* and *Shorea assamica*. Besides, two pioneering species, *viz. Altingia excelsa* and *Sapium baccatum* were also recorded regenerating in seedling stage in gaps although their respective density was very

Table 4. Comparative account of regeneration in the gaps and the understorey in the buffer zone area of Namdapha National Park, Arunachal Pradesh.

Parameters	Gaps	Understorey
Elevational range	300-600	300-600
Forest type	*South Bank Tropical Wet Evergreen (*Dipterocarpus*)	South Bank Tropical Wet Evergreen (*Dipterocarpus*)
Species richness		
Regenerating individuals	39	45
Saplings	34	41
Seedlings	31	17
Density ha^{-1}		
Regenerating individuals	7025	7323
Saplings	4400	4677
Seedlings	2625	2646
α - diversity		
Regenerating tree species	7.85 ± 2.41	8.62 ± 3.10
Shrubs	0.54 ± 0.52	0.69 ± 0.63
Herbs	2.54 ± 0.78	2.54 ± 0.97
Number of species in different canopy status		
Top	10	9
Middle	20	32
Lower	8	4
Dominant regenerating family	Lauraceae	Lauraceae
Number of regenerating family	20	25
Dominant regenerating species	*Beilschmiedia assamica* *Castanopsis* sp.	*Beilschmiedia assamica* *Saprosma ternatum*
Dominant shrub	*Strobilanthus sp.*	*Strobilanthus sp.*
Dominant herb	*Forrestia* sp.	*Forrestia* sp.

low (10 and 31 individuals ha^{-1}, respectively) (Table 5). Twenty five mid-canopy species were found regenerating in the gaps among which *Beilschmiedia assamica* with 1446 individuals ha^{-1} registered maximum density that was followed by *Castanopsis indica*. Six tree species belonging to the lower-canopy stratum were also found regenerating in the gaps among which *Ardisia* sp. and *Saprosma ternatum* were performing better than others (Table 5). A total of 28 species were recorded within 20-50 m^2 gap sizes, 19 species in 50-100 m^2, while 11 species were recorded in >100 m^2 gap sizes. The higher number of species from lower size gap areas could be attributed to more gaps found in that category.

In comparison to gaps, a total of 45 species were found regenerating in the adjacent forest understorey with 4676 saplings ha^{-1} and 2646 seedlings ha^{-1} (Table 6). Only four top canopy species were regenerating in the understorey of which *Canarium strictum* and *Cinnamomum bejolghota* were common in gaps as well as in understorey areas. *Dipterocarpus macrocarpus* and *Cinnamomum bejolghota* were the dominating regenerating species in understorey areas. *Altingia excelsa,* the most dominating tree species of the stand was not recorded regenerating in the understorey areas. A total of 36 regenerating species represented mid-canopy species, which clearly shows their role in the forest stand diversity. *Beilschmiedia assamica* showed highest regeneration among mid-canopy species. *Saprosma ternatum* recorded highest regeneration among the lower-canopy species (Table 6).

Analysis of similarity of species among the different gap sizes showed variable trends (Table 7). Highest similarity was observed between gap no. 5 and 11 (67%), while it was minimum between gap 3 and 9 (11%) (Table 7). There was no similarity between gap nos 2 and 9, 9 and 12, and 9 and 13. There was 38% species similarity recorded between the small and the mid size gaps showing that the species composition varied with gaps (Table 7).

Table 5. Density of the regenerating tree saplings and seedlings (ha^{-1}) in the gaps in Namdapha National Park.

Species	Canopy status	Saplings ha^{-1}	Seedlings ha^{-1}	Total regenerating individuals (individuals ha^{-1})
Antidesma acuminatum	Lower	30.77	0	30.77
Ardisia sp.	Lower	307.69	30.77	338.46
Baccaurea ramiflora	Lower	30.77	0	30.77
Leea indica	Lower	30.77	0	30.77
Milliusa roxburghii	Lower	30.77	0	30.77
Saprosma ternatum	Lower	215.38	30.77	246.15
Actinodaphne obovata	Lower	30.77	0	30.77
Allophyllus sp.	Lower	30.77	0	30.77
Camelia caudata	Lower	30.77	0	30.77
Lasianthus longicauda	Lower	30.77	0	30.77
Aporosa dioica	Middle	123.08	0	123.08
Beilschmiedia assamica	Middle	676.92	769.23	1446.15
Castanopsis indica	Middle	769.23	184.62	953.85
Castanopsis sp.2	Middle	30.77	0	30.77
Dysoxylum procerum	Middle	461.54	246.15	707.69
Elaeocarpus sp.	Middle	30.77	30.77	61.54
Eleaocarpus aristatus	Middle	61.54	0	61.54
Griffithianthuus fuscus	Middle	61.54	0	61.54
Lauraceae	Middle	30.77	0	30.77
Lindera latifolia	Middle	61.54	61.54	123.08
Linociera macrophylla	Middle	30.77	0	30.77
Litsea salicifolia	Middle	246.15	61.54	307.69
Litsea sp.2	Middle	0.00	30.77	30.77
Melia dubia	Middle	30.77	0	30.77
Mesua ferrea	Middle	61.54	0	61.54
Ostodes paniculata	Middle	153.85	307.69	461.54
Quercus sp.	Middle	0.00	61.54	61.54
Syzygium macrocarpum	Middle	61.54	430.77	492.31
Talauma hodgsonii	Middle	30.77	0	30.77
Xerospermum glabratum	Middle	92.31	0	92.31
Artocarpus chaplasa	Top	30.77	0	30.77
Altingia excelsa	Top	0.00	10	10
Canarium strictum	Top	61.54	30.77	92.31
Cinnamomum bejolghota	Top	246.15	61.54	307.69
Mangifera sylvatica	Top	92.31	0	92.31
Sapium baccatum	Top	0.00	30.77	30.77
Shorea assamica	Top	123.08	184.62	307.69
Syzygium cumini	Top	0.00	61.54	61.54
Unidentified 1	-	61.54	0	61.54
Total		**4400.00**	**2625.40**	**7025.41**

Table 6. Density of the tree saplings and seedlings in the Understorey (Close-canopy) areas in Namdapha National Park.

Species	Canopy status	Sapling ha^{-1}	Seedling ha^{-1}	Total regenerating individuals (individuals ha^{-1})
Antidesma acuminatum	Lower	92.31	0.00	92.31
Ardisia sp.	Lower	276.92	61.54	338.46
Baccaurea ramiflora	Lower	123.08	0.00	123.08
Miliusa roxburghii	Lower	92.31	0.00	92.31
Saprosma ternatum	Lower	923.08	184.62	1107.69
Allophyllus sp.	Lower	30.77	92.31	123.08
Glycosmis sp.	Lower	30.77	0.00	30.77
Helicia robusta	Lower	30.77	0.00	30.77
Beilschmisdia sp.2	Middle	30.77	0.00	30.77
Dysoxylum procerum	Middle	215.38	123.08	338.46
Dalbergia sp.	Middle	61.54	0.00	61.54
Diospyros sp.	Middle	30.77	0.00	30.77
Eleaocarpus aristatus	Middle	30.77	0.00	30.77
Ficus sp.	Middle	61.54	0.00	61.54
Griffithianthus fuscus	Middle	30.77	0.00	30.77
Catanopsis sp.	Middle	30.77	30.77	61.54
Aphania rubra	Middle	30.77	30.77	61.54
Knema linifolia	Middle	30.77	92.31	123.08
Laportea crenulata	Middle	30.77	0.00	30.77
Lindera latifolia	Middle	92.31	0.00	92.31
Litsea salicifolia	Middle	153.85	0.00	153.85
Litsea sp.2	Middle	61.54	0.00	61.54
Macropanax dispermus	Middle	30.77	0.00	30.77
Mesua ferrea	Middle	92.31	92.31	184.62
Olea dioica	Middle	30.77	0.00	30.77
Ostodes paniculata	Middle	61.54	0.00	61.54
Persea sp.	Middle	92.31	0.00	92.31
Beilschmiedia assamica	Middle	646.15	1138.46	1784.62
Premna sp.	Middle	30.77	0.00	30.77
Pterygota alata	Middle	30.77	0.00	30.77
Quercus lamellosa	Middle	30.77	0.00	30.77
Quercus sp.	Middle	61.54	0.00	61.54
Rhamnaceae	Middle	0.00	30.77	30.77
Sterculia sp.	Middle	61.54	0.00	61.54
Stereospermum chelonoides	Middle	0.00	30.77	30.77
Styrax serruletum	Middle	30.77	0.00	30.77
Syzygium sp.	Middle	276.92	0.00	276.92
Talauma hodgsonii	Middle	123.08	30.77	153.85
Turpinia pomefera	Middle	30.77	0.00	30.77
Vitex sp.	Middle	0.00	61.54	61.54
Chukrussia tabularis	Top	0.00	61.54	61.54
Canarium strictum	Top	30.77	0.00	30.77
Cinnamomum bejolghota	Top	30.77	153.85	184.62
Dipterocarpus macrocarpus	Top	307.69	61.54	369.23
Unidentified	-	184.62	369.23	553.85
Total		4676.96	2646.18	7323.14

Table 7. Similarity matrix for tree saplings and seedlings among thirteen tree fall gaps in lowland evergreen forest, Namdapha National Park.

Gap no.	1	2	3	4	5	6	7	8	9	10	11	12	13
1	100	47	33	55.6	63	63	30	38	33	38.10	47	59	38
2		100	24	36.4	50	33.3	46	43	0	28.6	40	60	43
3			100	22.2	32	31.6	30	38	11.1	28.6	24	24	29
4				100	61.5	61.5	33	40	16.7	13.3	54.6	54.6	40
5					100	57	40	50	31	37.5	67	50	38
6						100	27	35.3	15.4	25	50	50	38
7							100	59	29	47	46	46	47
8								100	13.3	33.3	57	43	44
9									100	26.7	18.2	0	0
10										100	28.6	28.6	22.2
11											100	40	43
12												100	43
13													100

Discussion

In the buffer zone area of Namdapha National Park the gaps were natural and created by tree falls and death of standing trees due to insects, diseases and winds. Similar reports are available from other tropical forests (Lugo & Scatena 1996; Maser *et al.* 1988). Heavy precipitation predominant during the rainy season in the study area for almost nine months in a year could be a major factor for gap formation in the present study area. A single or multi-tree gap may initiate a new period of recruitment depending on the presence of seed or advance reproduction and the degree to which site resources are released (Brokaw 1982). Number of gaps per hectare and per cent gap area was recorded low in this investigation as compared to the other forests (Brokaw 1985; Chandrashekara & Ramakrishnan 1994).

The data on the tree regeneration in gaps and nearby understorey areas showed that both areas exhibited high species diversity and density, which is well comparable to many other similar forests (Poorter 1998; Swaine 1996), though it differed from the species composition of the tree stratum (Deb 2006). Several tropical forest studies have shown that the floristic composition of the tree stratum to be different from that of seedling and sapling strata (Jones *et al.* 1994; Uhl *et al.* 1988). Abundant populations of juveniles in tropical forests provide an idea of the regeneration status of different species (Khan & Tripathi 1991). In the present study the juvenile composition also varied from stand to stand at different locations. The changes in species composition among the stands may be due to topography, altitude and edaphic factors. Canopy dominant late successional tree species are site specialist restricted to particular topographic positions of the rainforest (Ashton *et al.* 2001). Yearly variations among the demography of tropical tree seedlings have been reported from Australia (Connell *et al.* 1984), Costa Rioca (Li *et al.* 1996), Brazil (Sizer 1992), Panama (Garwood 1986; Lieberman 1996) and Malesian dipterocarps (Whitmore 1996).

There was no marked difference in number of seedlings and sapling between gap and understorey areas. Species richness, however, varied among them, and species richness for the seedling component in the gaps was almost double compared to the understorey areas. This could be attributed to the canopy openings and conducive-environment for the seed germination in the gaps. The higher species richness for sapling layer in the understorey areas could be attributed to the fact that many species exists in forest understorey in suppressed condition until favorable environment, which then helped them to grow to the canopy level. There was 42% species similarity between gaps and understorey. The marked difference in species composition in gaps showed that the plant species behavior in lowland tropical forest is perhaps independent of gap size and their presence mainly governed by availability of seeds at the time of creation of gaps. Maximum contribution to regeneration was from mid and lower canopy species, which are better adapted to grow in shady conditions. The poor status of pioneers could be attributed to low number of gaps and their small sizes. The difference in species composition between gaps and understorey may be attributed to micro-environmental variations at these two field conditions (gaps and understorey). Though most of the gaps encountered in the study area were small in size with only two gaps with >100 m^2, some variations in microclimatic conditions were recorded. The understorey locations showed more litter depth, low soil temperature and higher moisture content. Similar pattern was observed in sub-tropical forests of Meghalaya (Rao 1992). Soil temperature in gaps was more influenced by litter depth than by solar radiation, and no sudden air temperature change was recorded at gap edges (Ashton 1990). The variations in microclimatic conditions between gaps and close-canopy may not be sharp if gaps were of small sizes, however, with increase in gap sizes the extreme values of microclimate may change markedly (Whitmore 1996).

The pioneer species, such as *Altingia excelsa* and *Sapium baccatum* were recorded only in gaps. Such species have very small seed sizes, which hardly reaches the ground due to thick and multiple canopy layers and litter in primary forests. Therefore, pioneer and early successional species usually germinate and establish in gaps (Martinez-Ramos & Soto-Castro 1995). On the other hand, the seedlings of many shade tolerant species can establish in gaps as well as close-canopy forests (Forget 1991). The paucity of seedlings of pioneers or its complete absence as witnessed in the understorey of the present study area may be attributed to minimum forest canopy openings in buffer zone area of Namdapha. Similar reports are available for many other forest locations (Kitajima 1996; Turner 1990). Low regeneration for certain primary tree species was also reported in Kade, Ghana (Swaine & Hall 1988) and Panama forests (Hubbell & Foster 1986) where less abundant species were disproportionately represented by large trees. Even gaps differed in species composition in this investigation, which could be attributed to different location of the gap and their small size that could accommodate only a few species. Pattern of floristic change in gaps and nearby areas is affected by proximity of potential seed sources, limiting fruit production, and presence of advance regeneration at the time of disturbance or creation of gap (Lieberman 1996). The species composition of seedlings in gaps was found more closely similar to that of adjacent understorey at Omo forest, Nigeria, while difference was not recorded in seedlings diversity between large and small gaps at La Selva for 5 climax species (Barton 1984). In the present study similarity of species in gaps is perhaps governed by their closeness with the canopy cover nearby gap areas.

As the seeds of most rainforest species are recalcitrant, it is logical that high soil moisture conditions would be required for germination. Recent results on tree fall gaps in tropical forest have demonstrated that gap size has less influence than expected on tree density and floristic composition (Brown & Whitmore 1992). At Barro Colarodo Island, 79% of the species are indifferent to gaps (Welden *et al.* 1991). Uhl *et al.* (1988) found that neither the internal microhabitat, nor the size or the age of gaps produced measurable effects on plant density, establishment, or mortality, though growth rate increased with gap size. It also illuminated that tropical tree seedling may be broadly overlapping in their environmental tolerances (Lieberman 1996).

Alpha diversity for trees in the gap areas was recorded low in this investigation as compared to other species rich tropical forests (Brokaw & Scheiner 1989). It can be attributed to small area under gaps in comparison to much higher area under tree canopy. The existing microclimatic condition, perhaps, had low effect in the small canopy openings, although the regeneration of certain species is quite dependent on such small gaps. Of all the evergreen forest types in India, the lowland tropical rainforest of medium elevation dominated by Dipterocarps are the most diverse forest ecosystems (Barik *et al.* 1992; Chandrashekara & Ramakrishnan 1994; Khan & Tripathi 1991; Ramakrishnan 1991; Rao 1992). Namdapha National Park is one of the best preserved forests because of its location in northeast region that is not easily accessible. The study revealed that in this forest, creation of gaps is governed by the natural processes, which is beneficial for selected species though it is greatly dependent on the availability of seeds at the time of creation of the gaps. It also showed that creation of gaps is an essential component for maintaining tree diversity of the forest stand. It is, however, suggested that there is a further need to study survival pattern of the species in the gaps immediately after its formation so that the successional pattern of the forest could be analyzed and predicted. The analysis of the vegetation dynamics of undisturbed patches is important to understand ecosystem functioning and for the proper management of the forest system before disturbance spreads to such areas.

Acknowledgements

This study was funded by the Ministry of Environment and Forests, Government of India, New Delhi, under the Biosphere Reserve Programme (F. NO. 10/35/98-CS/BR). The authors are thankful to the Director, G. B. Pant Institute of Himalayan Environment and Development for providing institutional facilities. Thanks are due to the PCCF and Additional Principal Chief Conservator of Forest (Wildlife and Biodiversity), Department of Forests and Wildlife, Government of Arunachal Pradesh for granting permission to work in the protected area. The cooperation received during the fieldwork from the Field Director, and the Technical and Administrative Staff of the Namdapha National Park is highly appreciated. Dr. K. Haridasan, State Forest Research Institute, Itanagar helped in identification of plant specimens. Mr. Asham Mossang extended immense help during the fieldwork.

References

Anderson, J.M. & J.S.I. Ingram. 1993. *Tropical Soil Biology and Fertility. A Handbook of Methods.* 2nd edn., CAB International, Walling Ford, U.K.

Ashton, P.M.S. 1990. *Seedling Response of Shorea species Across Moisture and Light Regimes in a Sri Lankan Rainforest.* Ph.D. Dissertation, Yale University.

Ashton, P.M.S., C.V.S. Gunatilleke, B.M.P. Singhakumara & I.A.U.N. Gunatilleke. 2001. Restoration pathways for rainforest in south west Sri Lanka: A review of concepts and models. *Forest Ecology and Management* **154**: 409-430.

Ayyappan, N. & N. Parthsarathy. 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.

Barik, S.K., H. N. Pandey, R.S. Tripathi & P. Rao. 1992. Microenvironmental variability and species diversity in treefall gaps in a sub-tropical broadleaved forest. *Vegetatio* **103**: 31-41.

Barton, A.M. 1984. Neotropical pioneer and shade-tolerant species: do they partition treefall gaps? *Tropical Ecology* **25**: 196-202.

Brokaw, N.V.L. 1982. The definition of tree fall gaps and its effect on measures of forest dynamics. *Biotropica* **11**: 158-60.

Brokaw, N.V.L. 1985. Gap phase regeneration in a tropical forest. *Ecology* **66**: 682-687.

Brokaw, N.V.L. & S. Scheiner. 1989. Species composition in gaps and structure of a tropical forest. *Ecology* **70**: 538-541.

Brown, N.D. & T.C. Whitmore. 1992. Do dipterocarp seedlings really partition tropical rainforest gaps? *Philosophical Transactions of the Royal Society of London,* Series B **335**: 369-378.

Chandrashekara, U.M. & P.S. Ramakrishnan. 1994. Gap phase regeneration of tree species of differing successional status in a humid tropical forest of Kerala, India. *Journal of Biosciences* **18**: 279-290.

Chauhan, A.S., K.P. Singh & D.K. Singh. 1996. *A Contribution to the Flora of Namdapha, Arunachal Pradesh.* Botanical Survey of India, Calcutta.

Connell, J.H., J.H. Tracey & L.J. Webb. 1984. Compensatory recruitment, growth and mortality as factors maintaining rainforest tree diversity. *Ecological Monograph* **54**: 141-164.

Deb, P. 2006. *Tree Structure, Regeneration, Stand Biomass and Community Dependence in the Buffer Zone Area of Namdapha National Park, Arunachal Pradesh.* Ph.D. Thesis, Kumaun University, Nainital, Uttaranchal, India.

Deb, P. & R.C. Sundriyal. 2005. Status review of Namdapha National Park: Need for strengthening community-conservation linkages. *Indian Journal of Forestry* **28:** 85-96.

Forget, P.M. 1991. Comparative recruitment patterns of two pioneer canopy tree species in French Guiana. *Oecologia* **85**: 434-439.

Garwood, N.C. 1986. Constraints on the timing of seed germination in a tropical forest. pp. 347-55. *In:* A. Estrada & T.H. Fleming (eds.) *Frugivores and Seed Dispersal.* W. Junk Publishers, Dordrecht.

Ghosh, A.K. 1987. *Qualitative Analysis of Faunal Resources of Proposed Namdapha Biosphere Reserve.* Zoological Survey of India, Calcutta, India.

Grubb, P.J. 1977. The maintenance of species richness in plant communities: the importance of the regeneration niche. *Biological Review* **52**: 107-145.

Hartshorn, G.S. 1980. Neotropical forest dynamics. *Biotropica* **12**: 23-30.

Henle, K., S. Sarre & K. Wiegand. 2004. The role of density regulation in extinction processes and population viability analysis. *Biodiversity and Conservation* **13**: 9-52.

Hubbell, S.P. & R.B. Foster. 1986. Biology, chance and history and the structure of tropical rainforest tree communities. pp. 314-329. *In*: J. Diamond & T.J. Case (eds.) *Community Ecology*. Harper and Row, New York.

Jones, R.H., R.R. Sharitz, P.M. Dixon, P.S. Segal & R.L. Schneider. 1994. Woody plant regeneration in four flood plants forests. *Ecological Monograph* **64**: 345-367.

Kaul, R.N. & K. Haridasan. 1987. Forest types of Arunachal Pradesh, a preliminary study. *Journal of Economic and Taxonomic Botany* **9**: 379-389.

Khan, M.L. & R.S. Tripathi. 1991. Seedling survival and growth of early and late successional tree species as affected by insect herbivory and pathogen attack in subtropical humid forest stands of northeast India. *Acta Oecologica* **12**: 569-579.

Kitajima, K. 1996. Ecophysiology of tropical tree seedling. pp. 559-596. *In*: S.S. Mulkey, R.L. Chazdon & A.P. Smith (eds.) *Tropical Plant Ecophysiology*. Chapman and Hall, New York.

Li, M., M. Lieberman & D. Lieberman. 1996. Seedling demography in undisturbed tropical wet forest in Costa Rica. pp. 41-58. *In:* M.D. Swaine (ed.) *Ecology of Tropical Forest Tree Seedlings*. UNESCO/Parthenon, Paris/Carnforth.

Lieberman, D. 1996. Demography of tropical tree seedlings: A review. pp.131-138. *In:* M.D. Swaine (ed.) *Ecology of Tropical Forest Tree Seedlings*. UNESCO/Parthenon, Paris/Canforth.

Lugo, A.E. & F.N. Scatena. 1996. Background and catastrophic tree mortality in tropical moist, wet and rain forests. *Biotropica* **28:** 585-599.

Martinez-Ramos, M. & A. Sato-Castro. 1995. Seedling survival of tropical tree species: Interactions of dispersal distance, light-gaps and pathogens. *Ecology* **65**: 1705-1712.

Maser, C., R.F. Tarrant, J.M. Trappe & J.F. Franklin. 1988. From the forest to the sea: A story of fallen trees. USDA Forest Service. General Technical Report PNW-GTR-229.

Pinzon, Z.S., K.C. Ewel & F.E. Putz. 2003. Gap formation and forest regeneration in a Micronesian mangrove forest. *Journal of Tropical Ecology* **19**: 143-153.

Poorter, L. 1998. *Seedling Growth of Bolivian Rainforest Tree Species in Relation to Light and Water Availability*. Ph.D. Thesis, Utrecht University, Utrecht, The Netherlands.

Ramakrishnan, P.S. 1991. Rainforest ecosystem function and its management in north east India. pp. 323-334. *In:* Gomez-Pompa, T.C. Whitmore & M. Hadley (eds.) *Rainforest Regeneration and Management*. Man and Biosphere Series, UNESCO, Paris and the Parthenon Publishing Inc. Group, USA.

Ramakrishnan, P.S. 1992. *Shifting Agriculture and Sustainable Development of North Eastern India.* UNESCO MAB Series, Paris, and Parthenon Publishing, UK.

Rao, P. 1992. *Ecology of Gap Phase Regeneration in a Subtropical Broadleaved Climax Forest of Meghalaya*. Ph.D. Thesis, North Eastern Hill University, Shillong, India.

Rodgers, W.A. & H.S. Panwar. 1988. *Planning a Wildlife Protected Area Network in India*. Wildlife Institute of India, Dehradun.

Singh, J.S. & S.P. Singh. 1987. Forest vegetation of the Himalaya. *Botanical Review* **53**: 80-192.

Sizer, N.C. 1992. *The Impact of Edge Formation on Regeneration and Litterfall in a Tropical Rainforest Fragment in Amazonia*. Ph.D. Thesis, University of Cambridge, U.K.

Slik, J.W.F., P.J.A. Kebler & P.C. van Welzen. 2003. *Macaranga* and *Mallotus* species (Euphorbiaceae) as indicators for disturbance in the mixed lowland dipterocarp forest of East Kalimantan (Indonesia). *Ecological Indicators* **2**: 311-324.

Sorensen, T. 1948. A method of establishing groups equal amplitude in plant sociology based on similarity of species content. *Det Kong Danske Vidensk, Selsk Biology Skr* (Copenhagen) **5**:1-34.

Sundriyal, R.C. & E. Sharma. 1996. Anthropogenic pressure on tree structure and biomass in temperate forest of Mamlay watershed in Sikkim. *Forest Ecology and Management* **81**: 113-134.

Sundriyal, R.C., E. Sharma, L.K. Rai & S.C. Rai. 1994. Tree structure, regeneration and woody biomass removal in a subtropical forest of Mamlay watershed in the Sikkim Himalaya. *Vegetatio* **113**: 53-63.

Swaine, M.D. (ed.). 1996. *The Ecology of Tropical Forest Tree Seedling*. Man and Biosphere Series, The Parthenon Publishing Group, UK, **17**: 340.

Swaine, M.D. & J.B. Hall. 1988. The mosaic theory of forest regeneration and the determination of forest composition in Ghana. *Journal of Tropical Ecology* **4**: 253-269.

Tripathi, R.S. & M.L. Khan. 1990. Effects of seed weight and microsite characteristics on germination and seedling fitness in two species of *Quercus* in a subtropical wet hill forest. *Oikos* **57:**289-296.

Turner, I.M. 1990. Tree seedling growth and survival in a Malaysian rainforest. *Biotropica* **22**: 146-154.

Uhl, C., K. Clark, N. Dezzeo & P. Maquiro. 1988. On the definition of ecological species groups in tropical rain forests. *Vegetatio* **75**: 81-86.

Welden, C.W., S.W. Hewett, S.P. Hubbell & R.B. Foster. 1991. Sapling survival, growth and recruitment: relationship to canopy height in a neotropical forest. *Ecology* **72**: 35-50.

Whitmore, T.C. 1996. A review of some aspects of tropical rainforest seedling ecology with suggestions for further enquiry. pp. 3-39. *In*: M.D. Swaine (ed.) *Ecology of Tropical Forest Tree Seedlings*. UNESCO/Parthenon, Paris/Canforth.

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

Wilkinson, L. 1986. *SYSTAT: A System for Statistics*. Inc. Evaston IL, USA.