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Tree structure, regeneration and woody biomass removal in a sub-tropical forest of Mamlay watershed in the Sikkim Himalaya

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Abstract

This paper reports on the tree structure, tree dimension relationships and woody biomass production and removal of a sub-tropical natural forest in the Mamlay watershed of the Sikkim Himalaya. The forest provides fuel, fodder and timber to four villages. Only 11 tree species were found growing in the tree stratum despite the high diversity in the stand (32 tree species). The forest shows good regeneration potential with 5474 seedlings/ha and 1776 saplings/ha, but the population structure revealed a marked paucity of trees of higher diameter classes due to removal of trees of lower diameters. Standing wood biomass of 362 Mg/ha is mainly shared by 4 dominating species in the stand. The boles are removed mainly for timber and fuel purposes and about 22 Mg/ha wood biomass was removed in between 1987–1991. Net Primary productivity of woody biomass of the forest is recorded to be 18 Mg/ha/year. 3.85 Mg/ha of annual woody biomass production was removed in the form of tree boles apart from lopping of branches.

Introduction

Sikkim is a part of the eastern Himalaya and comprises of about 36% of its total geographical area (7096 sq km) under forest cover. Records show that the physical area under forest remained nearly the same in Sikkim for the last 2–3 decades. However, the density of trees in these forests has declined remarkably. In the Himalaya, management of most of the forests is hindered due to limited information available on forest and watershed characteristics. Most of the watersheds in the Himalaya are experiencing a decline in forest cover, and agricultural landuse has become a major component of the landscape.

Studies of population structure and dynamics of woody vegetation in the Himalaya are a few (Saxena & Singh 1982, 1984; Khan *et al.* 1986; Khan & Tripathi 1987; Ramakrishnan 1991; Shukla & Ramakrishnan 1984; Singh & Ramakrishnan 1982; Sundriyal & Bisht 1988). Such studies are not at all available for the forests of Sikkim where they are under increasing biotic pressure for last few decades especially in the sub-tropical region. Considering this the present study was undertaken to determine the tree structure, tree dimension relationships, regeneration, the extent of biomass removal and productivity of a sub-tropical natural forest in the Mamlay watershed of the Sikkim Himalaya.

Study area and vegetation

The forest under investigation is located within the Mamlay watershed (27° 12′N and 88° 21′E) in the south district of Sikkim. The Mamlay watershed is the catchment area of the river Rangeet and has a wide range of elevations from 300 m to 2550 m above msl. Two important forest types are recognized in the watershed, namely (i) sub-tropical natural forest and (ii) temperate natural forest. Sub-tropical natural forest located at lower Kamrang (elevation 400–1050 m above msl) has been worked out in the present study. The annual rainfall is 1400 (at 400 m elevation) to 1700 mm (at 1200 m elevation), and the average daily temperature ranged from 8 to 25 °C, as recorded in the nearest station at Namchi (elevation 1400 m).

Soils of the forest are blackish-brown and clay-loam in texture. The pH of top 30 cm soil depth ranges between 4.9–6.0. Rock formations are of the Daling and Gondwana series, which consist of metasedimentary rocks.

People of four villages (about 35 households) exclusively use the produce of this forest for fuel, fodder and timber purposes. The stall-feeding of cattle is practiced in the surrounding villages and the forest bears medium to high levels of fodder collection pressure, mainly during the winter and early summer months. The ground flora of the forest mainly consists of ferns, and herbs such as *Hedychium gardnerianum* Wall., *Eupatorium* Linn., *Cautleya lutea* Royle, *Bidens pilosa* Linn., *Viola tricolor* Linn., and *Debregeasia* Gaud. A few climbers, namely *Piper betle* Linn., *Smilax* Linn., and *Hedyotis scandens* Roxb. are also present. Among graminoides, species of *Thysanolaena* Nees., *Pogonantherum* and *Cyperus* are common. *Maesa chisia* D. Don, *Poinsettia pulcherrima* R. Grah., *Viburnum* Linn., *Rhus insignis* HK.f., *Premna bengalensis* Clarke, and *Sterculia alata* Roxb. are common shrubs of the study area.

Methods

The structural analysis of the forest was done using 10×10 m quadrats (n=24). The trees occuring in each quadrat were listed. Diameter at breast height (DBH at 1.3 m above ground level) and at bottom of the bole was measured for all tree species with DBH >10.0 cm. Importance values were calculated for each tree species as a sum of percentage density and percentage basal cover (Beatty 1984). The ratio of abundance to frequency (A/F) was used to interpret distribution pattern of the species (Whitford 1949) and if A/F ratio is <0.025, the distribution is regular, if between 0.025–0.05 it is random and if the ratio is >0.05 it is contagious (Curtis & Cottam 1956). All the individuals <10 cm DBH were considered as regenerating individuals (Beatty 1984; Saxena *et al.* 1984; Khan *et al.* 1987; Sundriyal & Bisht 1988). Regeneration potential (i.e. number of seedlings plus saplings) was estimated for the forest. All the species of the stand were grouped into 4 dominating species and 'other species' (excluding dominant species) category.

Individuals of tree species were separated into 4 size classes: (a) seedlings (height <20 cm), (b) saplings (height >20 cm but DBH <10 cm), (c) small tree (DBH >10 cm but <30 cm), and (d) big tree (DBH >30 cm). Species diversity (Shannon & Wiener's index) was calculated using the method given by Mueller-Dombois & Ellenberg (1974).

On the basis of the tree diameter at breast height, 7 diameter classes (10–20 cm to 70–80 cm) of trees for all species were presented. Average heights of standing trees were measured using bamboo sticks. The density of the trees of each species in each diameter class was recorded.

Trees of different species, representing different diameter classes, were randomly selected for biomass estimation. The volume of the standing tree bole and branches was measured, and wood biomass of each tree was estimated as a product of the volume and the specific wood density (Ruark *et al.* 1987; Anderson & Ingram 1989). Allometric relationships of wood biomass (bole and branches) of different species were developed using tree dimensions and specific wood density (Table 1). The estimation of wood biomass of trees of the studied quadrats were extrapolated to stand values using the above relationships.

The number of trees removed in five years (1987–91) was recorded on the basis of stumps left behind. The basal diameter of each stump was measured and converted to diameter at breast height and tree height based on the relative dimensions of standing trees. Wood biomass of the removed trees was predicted from the allometric relationship specific to each species (Table 1) using the predicted relative diameter at breast height and tree height. Annual woody biomass productivity was measured by marking (February 1992) 30×30 m area size quadrats (n=3) for different dominant canopy covers. The annual increment in the tree diameters at breast and tree heights were measured in February 1993. Using regression given in Table 1, biomass for each quadrat was extrapolated and productivity was calculated. Net primary productivity (NPP) was calculated considering the standing as well as removed biomass in the marked plots, while in calculating net ecosystem productivity (NEP) removed biomass was excluded (Grier & Logan 1977; Aber & Melillo 1991; Binkley & Arthur 1993).

Table 1. Regressions relating wood biomass with tree dimensions and specific wood density of dominant and other species in the sub-tropical natural forest of the Mamlay watershed.

Species	Regression equation*	n	r	p<
C. indica	$y = exp[0.204 + 0.769ln(D^2H)]$	52	0.906	0.001
C. tribuloides	$y = exp[0.511 + 0.763ln(D^2H)]$	12	0.940	0.001
S. robusta	$y = exp[-1.768 + 0.945ln(D^2H)]$	26	0.904	0.001
S. wallichii	$y = exp[-1.064 + 0.888ln(D^2H)]$	32	0.960	0.001
Other species	$y = exp[-0.277 + 0.906ln(D^2H)]$	13	0.618	0.050
Total species	$y = exp[1.741 + 0.615ln(D^2HS)]$	135	0.615	0.001

* y=wood biomass including branch and bole (kg); D= diameter at breast height (cm); H= height (m); and S= specific wood density (Mg/m^3); exp= exponential.

Results

Tree structure

A total of 11 tree species were found in the tree stratum having DBH >10 cm. The forest stand showed a dominance of 4 tree species viz. *Shorea robusta* Gaertn., *Castanopsis indica* A. DC., *C. tribuloides* A. DC. and *Schima wallichii* Chois.

The highest density and importance was recorded for *C. indica*, followed by *S. wallichii*, *S. robusta* and *C. tribuloides* (Table 2). The density of the forest stand is 562 trees/ha, and is within the range reported in other broad leaved temperate Himalayan forests (Saxena & Singh 1982; Rawat & Singh 1988; Sundriyal *et al.* 1986; Sharma & Ambasht 1991). However, the density of this forest is lower than the values reported for the tropical forests (Foster & Reiners 1983). Basal cover is highest in *C. indica*, closely followed by *S. robusta* which relegates that establishment of these two species might have been simultaneous in the long past. Tree basal cover for the forest stand is 52.3 m^2/ha, which is comparable to other Himalayan forests (Saxena & Singh 1982; Sundriyal & Bisht 1988; Sharma & Ambasht 1991). The analysis of distribution pattern of various species indicated that only *S. wallichii* has the regular distribution, whereas *C. indica* and *C. tribuloides* have shown random distribution. All other species showed contagious distribution. The Shannon-Wiener index of diversity ($\overline{H}$= 2.29) indicates that the richness is mainly attributable to a few species.

The relationship between tree diameter size (DBH in cm) and density varied among species and the forest stand had a dominance of lower diameters (up to 40 cm DBH). Since the DBH can be measured easily and more directly related to commercial value than age (Leak 1964), DBH structure of all species will be stressed in interpreting population dynamics. Only a few individuals of *C. indica, C. tribuloides, S. robusta* and *S. wallichii* could reach to a diameter of >40 cm and none of the individuals of the other species group was larger than 40 cm DBH (Fig. 1). The higher frequency of lower DBH indicated that the stand came under pressure a few decades ago.

Regeneration

A total of 32 tree species were found to be regenerating as seedlings and saplings (Table 3). The number of regenerating species is much higher than the total number of species (11) which attained tree stratum. The total number of seedlings and saplings were 5474/ha and 1776/ha, respectively. Of all the species, *C. indica* showed highest regeneration potential followed by *C. tribuloides, S. robusta, Litsaea polyantha* Juss., *S. wallichii* and *Gynocardia odorata* R.Br. Excluding the four dominant species, only a few individuals of *G. odorata* attained tree stratum, whereas not a single tree of *L. polyantha* was found in spite of good regeneration through stumps and root sprouts. The number of seedlings and saplings in the forest stand may also express a relationship with total basal cover of the trees. Saplings have shown negative relation with total basal cover (r= -0.564, p <0.01), whereas, seedlings have indicated a positive relationship which is not significant.

Table 2. Density, basal cover and importance of tree species in the sub-tropical forest of Mamlay watershed.

Species	Density (per ha)	Basal cover (m^2/ha)	Importance*
Castanopsis indica	217	15.002	67.31
Schima wallichii	133	11.884	46.39
Shorea robusta	108	14.889	47.70
Castanopsis tribuloides	50	7.915	24.04
Gynocardia odorata	13	0.541	3.34
Engelhardtia spicata	13	0.488	3.24
Pavetta indica	8	0.462	2.30
Terminalia chebula	8	0.194	1.80
Walsura tubulata	4	0.386	1.45
Cinnamomum cecidodaphne	4	0.299	1.28
Symingtonia populnea	4	0.212	1.13

* Sum of percentage density and percentage basal cover (Beatty 1984)

Table 3. Natural regeneration of the seedlings (height < 20 cm) and saplings (height > 20 cm, diameter < 10 cm) of tree species in the sub-tropical forest of the Mamlay watershed.

Species	Seedlings (per ha)	Saplings (per ha)
Albizzia odoratissima Benth.	21	46
Castanopsis indica A. DC.	1194	399
C. tribuloides A. DC.	786	270
Emblica officinalis Gaertn.	25	54
Engelhardtia spicata Bl.	92	21
Ficus hirta Vahl.	12	71
Grewia vestita Wall.	154	12
Gynocardia odorata R. Br.	304	50
Litsaea polyantha Juss.	416	46
Machilus gammieana King.	316	41
Meliosma simplicifolia Walp.	67	–
Mimosa himalayana Gamble	175	12
Neonauclea griffithii HK.f.	37	41
Phoebe lanceolata Nees.	187	–
Rhus succedanea L.	146	50
Schima wallichii Chois.	279	112
Shorea robusta Gaertn.	636	237
Walsura tubulata Heirn.	145	96
Others (14 species)	202	172

Tree population structure

The population structure of the four dominant tree species showed that *S. wallichii* and *C. indica* are represented by all the life stage classes. However, the percentage density decreased progressively from seedling to large tree stage (Fig. 2). In a forest stand, generally most dominant species are represented by all diameter classes (Khan *et al.* 1987; Sundriyal & Bisht 1988). In the cases of *C. tribuloides* and *S. robusta*, only a few individuals are in the small tree class. Similarly for the 'other species group', both small and large trees are very low. This can be ascribed to higher stress on small trees, and also to the removal of regenerating individuals before they achieve tree status and thus resulting into very little chances to go into a large tree stage.

Biotic pressure in the forest is increasing and at least 95 trees/ha were found removed in 5 years (between 1987–1991), besides lopping of branches of the standing trees. In terms of species, *S. wallichii* was removed the most (37 stumps/ha), followed by *C. indica* (17 stumps/ha), *C. tribuloides* (12 stumps/ha) and *S. robusta* (12 stumps/ha). At least 17 stumps/ha were recorded removed of the 'other species group'. *S. wallichii* is mainly used for fuel and also as timber in spite of its low quality. *C. indica, C. tribuloides* and *S. robusta* are good timber trees. Most species of the 'other species group' are good either for fodder or fuel.

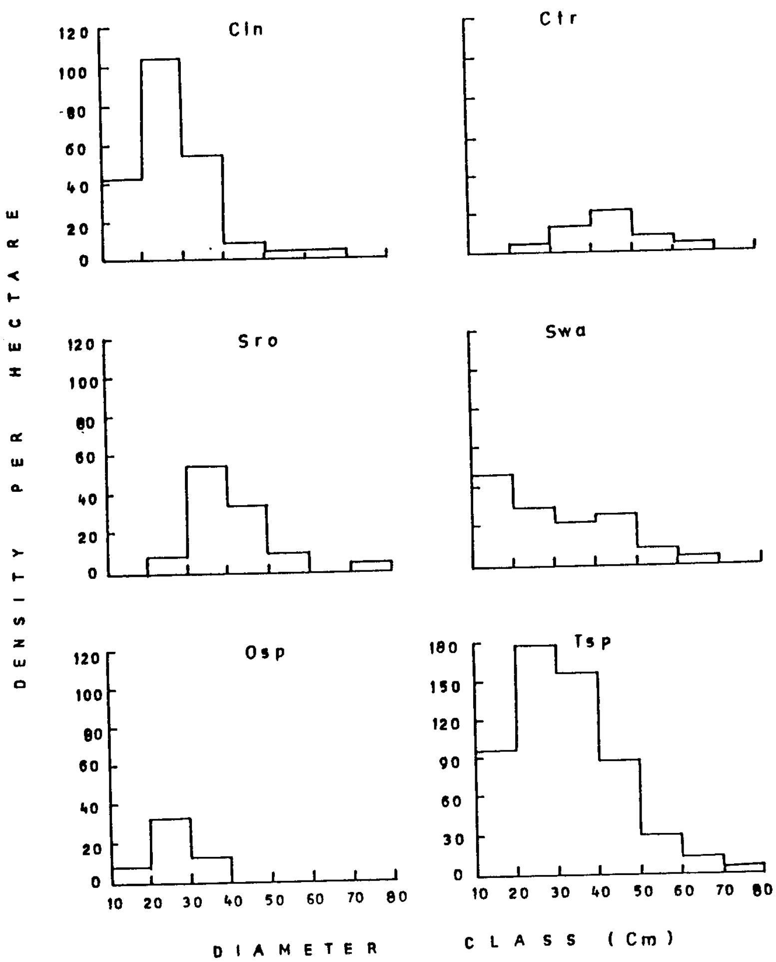

Fig. 1. Diameter class distribution of tree species (Cin=*Castanopsis indica*; Ctr=*C. tribuloides*; Sro=*Shorea robusta*; Swa=*Schima wallichii*; Osp=Other species; Tsp= Total species) of the sub-tropical forest in the Mamlay watershed.

Figure 3 shows the diameters of the removed trees (stumps) and standing trees. Individuals of 10–20 cm and 20–30 cm diameter classes are mainly removed from the stand.

Standing and removed biomass, and productivity

Distribution of standing and removed wood biomass in different diameter classes is presented in Fig. 4. Trees less than 40–50 cm diameter classes are contributing >70% of the total standing biomass. *S. robusta* accounts for the maximum biomass (30%), followed by *C. indica* (28%), *S. wallichii* (19%), *C. tribuloides* (17%) and 'other species' (6%) of the total forest standing wood biomass of 362 Mg/ha (Table 4). The woody biomass value of this forest is higher than certain tropical forests (Ovington & Olson 1970; Johnson & Risser 1974; Golley *et al.* 1975; Grubb & Edwards 1982; Singh & Ramakrishnan 1982). It is within the range of 100–500 Mg/ha for a broad range of temperate deciduous forests (Rodin & Bazilevich 1967) and close to 221–458 Mg/ha range for temperate pine and oak forests of the Himalaya (Negi *et al.* 1983; Chaturvedi & Singh 1987; Rawat & Singh 1988). Approximately 86% of the total standing wood biomass in the stand is in the tree boles and another 14% in the branches. This relative contribution of tree bole to standing wood biomass is higher than those of other forests

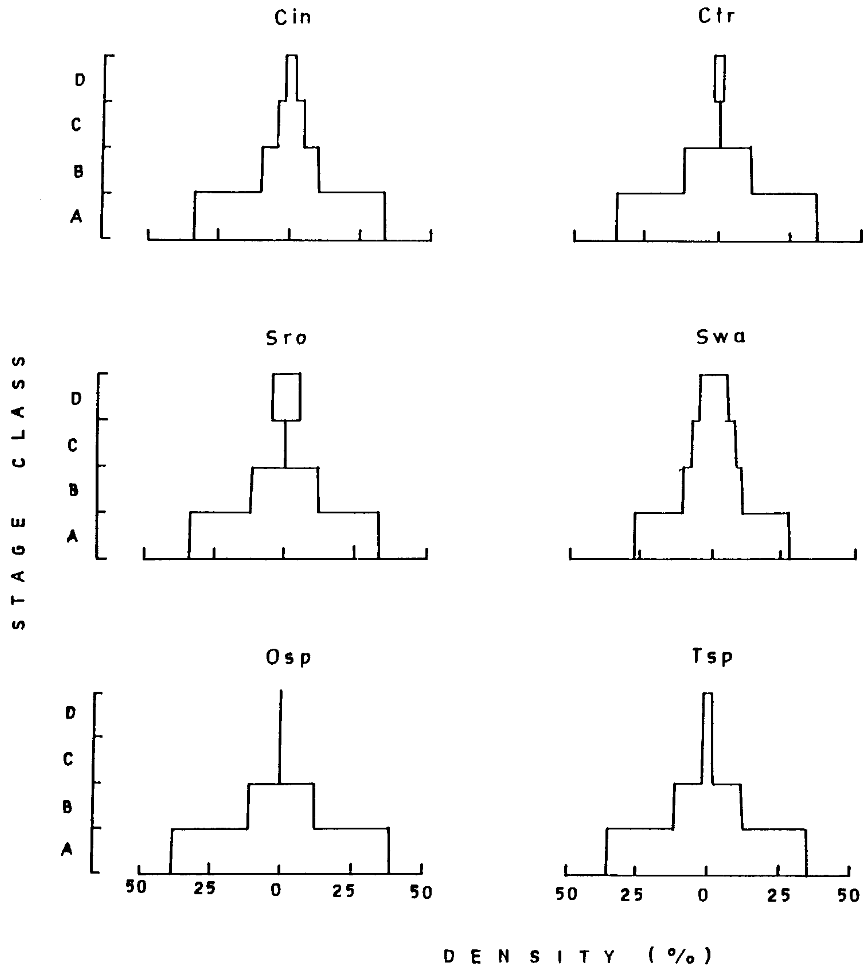

Fig. 2. Density (%) of tree species, in different stage classes (A= seedlings, height <20 cm; B= saplings, height >20 cm but diameter <10 cm; C= small trees, diameter >10 cm but <30 cm; D= large trees, diameter >30 cm) in the sub-tropical forest. Cin= *Castanopsis indica*; Ctr= *C. tribuloides*; Sro= *Shorea robusta*; Swa= *Schima wallichii*; Osp= other species; Tsp= total species.

(Rodin & Bazilevich 1967; Johnson & Risser 1974; Shukla & Ramakrishnan 1984; Rawat & Singh 1988). The removed biomass, estimated on the basis of standing wood biomass, was highest for *C. indica* which can be attributed to its dominance and demand for fuel as well as timber. *S. wallichii, S. robusta* and *C. tribuloides* were also widely extracted during 5 years. The relative contribution of species to total removed biomass was 41% in *C. indica*, 25% in *S. robusta*, 16% in *C. tribuloides*, 16% in *S. wallichii* and 1% in 'other species group' (Table 4).

Net primary productivity of 17.83 Mg/ha/year for woody biomass was recorded, while the net ecosystem productivity was 13.98 Mg/ha/year.

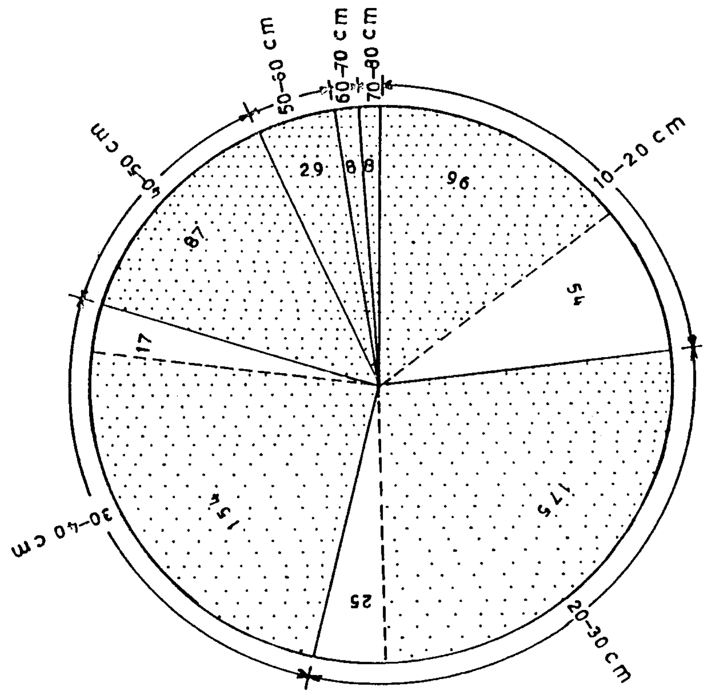

Fig. 3. Diameter and density (per ha) of standing trees (shaded) and stumps (blank) of removed trees in five years (1987–1991) of seven diameter classes (10–20 cm to 70–80 cm) in the sub-tropical forest.

Discussion

Three distinct types of canopy covers are visualized in the studied forest i.e. *Shorea robusta* dominated at lower elevations, *Castanopsis indica* at middle slopes and mixed canopy cover (shared by *C. indica, Castanopsis tribuloides* and *Schima wallichii*) at top of the stand. The forest stand have shown a good diversity and regeneration, though just 24% and 8% of total seedlings could reach to sapling and tree stratum stages, respectively. Only *S. wallichii* is showing regular distribution and performing well at canopy gaps, a behaviour of early successional species (Shukla & Ramakrishnan 1984). Seedlings of *S. robusta* and *C. indica* were evenly distributed in shade as well as in open areas and thus showing the status of late successional species. It is reported that late successional species are adapted to grow under low light regime where resources are often limiting, but they can equally grow under open situation such as opening in the forest canopy (Boojh & Ramakrishnan 1982). A few other species like *Litsaea polyantha, Ficus hirta* and *Grewia vestita* showed good regeneration through coppicing/sprouts but not a single individual of these species was recorded in tree stratum showing great stress on them. The overall relationship of tree saplings with total basal cover was negative indicating the light loving nature of saplings (Saxena *et al.* 1984; Khan *et al.* 1986).

The stand density decreased with an increase in the size of tree diameter classes. On the basis of different DBH sizes, the future of the forest stand may be predicted. With the existing level of pressure on the forest stand only *C. indica* and *S. wallichii* would remain dominant in near future as they are at present. Since small trees and large trees of *C. tribuloides* and *S. robusta* are being removed, trees of these species are likely to be much less abundant. Species of the 'other species group' are mostly regenerating through stump-sprouts now, therefore, they are likely to disappear in near future if the same level of pressure continues for a few more years. Similar pressure on population structure of forest communities due to various kinds of disturbances, has also been reported by Heinselman

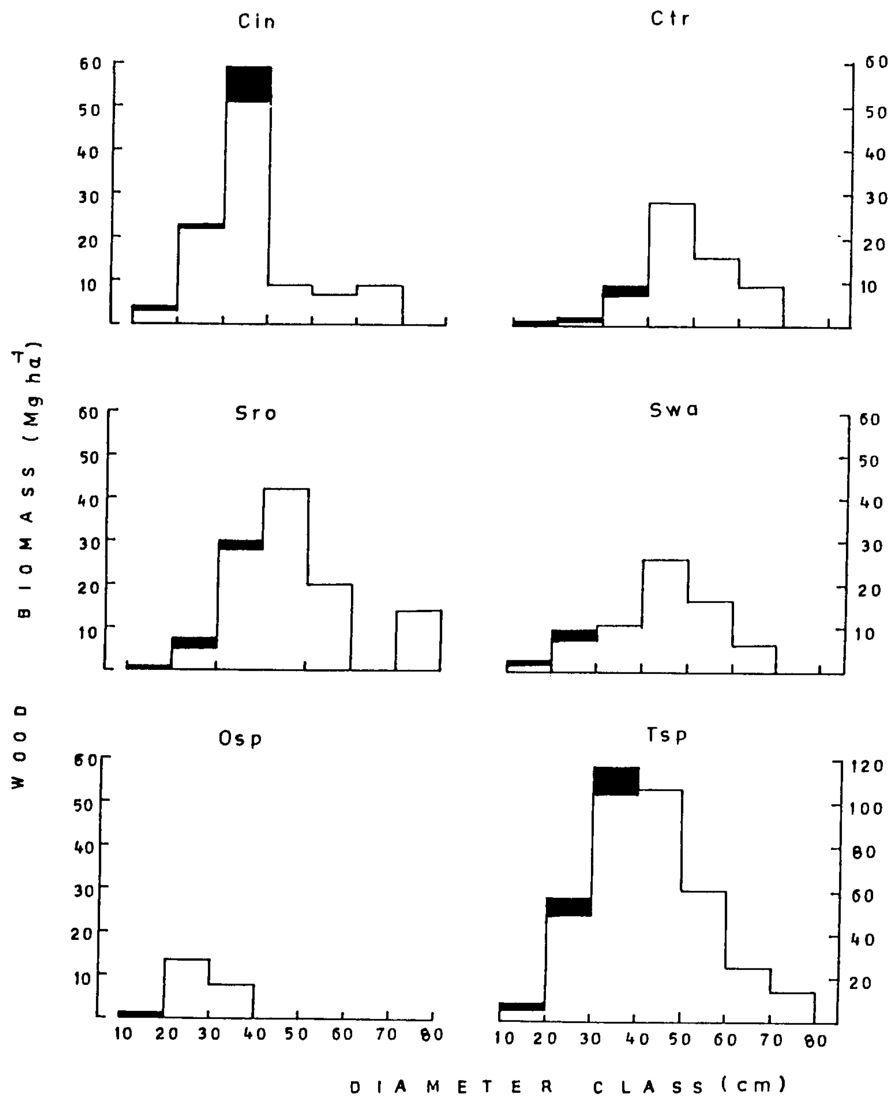

Fig. 4. Standing (hollow bar) and removed (dark bar) wood biomass of different classes of tree species (Cin= *Castanopsis indica*; Ctr= *C. tribuloides*; Sro= *Shorea robusta*; Swa= *Schima wallichii*; Osp= other species; Tsp= Total species) of the sub-tropical forest.

(1973), Foster (1980), Saxena *et al.* (1984), Primack *et al.* (1985) and Khan *et al.* (1987). Dominance of the population of small diameter individuals of *S. wallichii* in the forest stand can be ascribed to their lower to medium age, which can be correlated to their recent establishment in the forest.

In the cases of *C. tribuloides* and *S. robusta*, only a few individuals are present in the small tree class. It was observed that the tree individuals removed are mainly from the 10–20 cm and 20–30 cm diameter classes, which perhaps is due to a demand for these bole sizes in villages, although it may also be due to easy extraction on shoulders.

Field checks and interviews with locals revealed that about 35 households of four villages are exclusively dependent on this forest for their fuel and timber

Table 4. Standing and removed wood biomass of dominant and total tree species of the sub-tropical natural forest in the Mamlay watershed. Parenthetical values are percentage error for biomass.

Species	Tree component	Standing biomass (Mg/ha)	Removed biomass* (Mg/ha)
C. indica	Bole	87.448(3.50)	7.645
	Branch	14.138(0.57)	1.387
	Total	101.586(4.10)	9.032
C. tribuloides	Bole	48.020(10.4)	3.432
	Branch	13.996(3.03)	0.197
	Total	62.016(13.4)	3.629
S. robusta	Bole	97.784(12.3)	5.132
	Branch	11.737(1.50)	0.296
	Total	109.521(13.8)	5.428
S. wallichii	Bole	61.085(2.81)	3.179
	Branch	6.683(0.31)	0.432
	Total	67.768(3.12)	3.611
Other species (7 spp.)	Bole	16.517(2.79)	0.228
	Branch	4.669(0.79)	0.038
	Total	21.186(3.58)	0.266
Total species	Bole	310.854(31.8)	19.616
	Branch	51.223(6.16)	2.350
	Total	362.077(37.9)	21.966

* Biomass removed in 5 years (1987–1991)

needs. Each household on an average is composed of 6 persons and consists of 4 cattle (Sharma *et al.* 1992). The higher limit of firewood consumption per household is as much as 21 kg per day, though, a minimum of 4000 kg of dry wood per year is consumed by one family (unpublished data). This firewood is used for cooking (69%), animal feed preparation (9%), house warming (7%), water heating (7%), local wine/beer preparation (6%) and on festivals (<2%). Besides, most of the houses are made up of wood and fragmentation of families leads to construction of many new houses each year. Most of the tree sprouts as well as ground herbaceous vegetation are removed for fodder purpose. In addition, unpalatable species and leaf litter are used for animal bedding. Villagers have right to collect rotten and fallen wooden pieces from the forest. For the purpose they take permission (Patta) of Forest Department on the payment of a nominal fee. A practice of cutting tree boles in the stand, allowing to dry and then use the 'Patta' to collect the same from the site is being adopted by some families. Out of 17.03 Mg/ha/year wood biomass production 22% is removed in the form of tree bole which is in addition to the biomass removed from saplings and branches of trees. Removal of species in small girth classes leads only few individual to reach in the tree stratum. If we compare the total fuel need of the villages and wood productivity of the forest, it is clear that the stand can meet and satisfy local needs' if extracted properly. However, irregular felling of tree boles not only reduces number of tree per hectare but also decreases wood production each year. Therefore is is expected that the stand will be under great stress in years to come.

Conclusion

The study reveals that the forest stand is under increasing biotic pressure from growing population of the neighbouring villages for higher material demands of fuel, fodder and timber. Although the forest shows some advantageous characteristics for timber production, such as good basal cover and regeneration through seeds and coppice (stumps), more pressure of fuel and timber on trees and fodder on sprouts is expected to hamper their growth in near future. Diversity is an important aspect of any forest stand and it takes a long time to develop a forest with this unique diversity (32 tree species). A further increase in the surrounding human population will make the forest more desirable and approachable for exploitation. Therefore a care is needed to regulate the use of the forest resources. Better protective measures, such as, (i) proper lopping including only one-fourth removal of branches of trees, (ii) complete prohibitions on grazing even during lean period (winter) and iii) less use of timber in house construction if adopted can help in forest rejuvenation. The indiscriminate cutting should be stopped and a greater diversity need to be achieved especially by protecting the seedlings as well as stump sprouts of trees. In addition, an education programme dealing with the importance of forest and its conservation to rural masses can also help.

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References

Aber, J. D. & Melillo, J. M. 1991. Terrestrial ecosystems. Saunders, Philadelphia, Pennsylvania, USA.

Anderson, J. M. & Ingram, J. S. I. (eds.) 1989. Tropical soil biology and fertility: a handbook of methods. CAB International, Wallingford, U.K.

Beatty, S. W. 1984. Influence of microtopography and canopy species on spatial distribution of forest understorey plants. Ecology 65: 1406–19.

Binkley, D. & Arthur, M. 1993. How to count dead trees. Bull. Ecol. Soc. America 74 (1): 15–16.

Boojh, R. & Ramakrishnan, P. S. 1982. Growth strategy of trees related to successional status. I. Architecture and extension growth. For. Ecol. Manage. 4: 355–374.

Chaturvedi, O. P. & Singh, J. S. 1987. The structure and function of pine forest in central Himalaya. I. Dry matter dynamics. Ann. Bot. 60: 237–52.

Curtis, J. T. & Cottam, G. 1956. Plant ecology workbook. Laboratory field reference mannual. Burgers Publ. Co., Minnesota. 193 pp. Foster, R. B. 1980. Heterogeneity and distribution in tropical vegetation. In: M. E. Soule & S. A. Wilcoxsinauer (eds.), Conservation biology, pp. 75–92. Sunderland, Mass. U.S.A.

Foster, R. F. & Reiners, W. A. 1983. Vegetation patterns in a vergin subalpine forest at Crawford notch, white Mountains, New Hampshire. Bull. Torrey Bot. Club 110 (2): 141–153.

Golley, F. B., McGinnis, J. T., Clement, R. G., Child, G. I. & Daever, M. J. 1975. Mineral cycling in a tropical moist forest ecosystem. University of Georgia Press, Athens.

Grier, C. C. & Logan, R. S. 1977. Old growth *Pseudotsuga menziesii* communities of a western Oregon watershed: biomass distribution and production budget. Ecol. Monogr. 47: 373–400.

Grubb, P. J. & Edwards, P. J. 1982. Studies of mineral cycling in a montane rainforest in New Guinea. III. The distribution of mineral elements in the aboveground material. J. Ecol. 70: 623–48.

Heinselman, H. L. 1973. Fire in virgin forest of the boundary waters cance area, Minnesota. J. Quat. Res. 3: 329–382.

Johnson, F. L. & Risser, P. G. 1974. Biomass, annual primary productivity, and dynamics of six mineral elements in a post oak-blackjack oak forest. Ecology 55 (6): 1246–58.

Khan, M. L. & Tripathi, R. S. 1987. Tree regeneration in a disturbed sub-tropical wet hill forest of north-east India: Effects of stump diameter and height on sprouting of four tree species. For. Ecol. Manage. 17: 199–209.

Khan, M. L., Rai, J. P. N. & Tripathi, R. S. 1986. Regeneration and survival of tree seedlings and sprouts in tropical deciduous and sub-tropical forests of Meghalaya, India. For. Ecol. Manage. 14: 293–304.

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

Leak, W. B. 1964. An impression of diameter distribution for unbalanced, uneven-aged stands and forests. Forest Sci. 10: 39–50.

Mueller-Dombois, D. & Ellenberg, H. 1974. Aims and methods of vegetation ecology. John Wiley, New York.

Negi, K. S., Rawat, Y. S. & Singh, J. S. 1983. Estimation of biomass and nutrient storage in a Himalayan moist temperate forest. Canadian J. For. Res. 13: 1185–1196.

Ovington, J. D. & Olson J. S. 1970. Biomass and chemical content of El Verde lower montane rain forest plants. In: H. T. Odum & R. F. Piegeon (eds): A tropical rain forest. U.S. Atomic Energy Corp., Oak Ridge, Tenn.

Primack, R. S., Ashton, P. S., Chai, P. & Lee, H. S. 1985. Growth rates and population structure of moraceae trees in Sarawak, East Malaysia. Ecology 66: 577–588.

Ramakrishnan, P. S. 1991. Rain forest ecosystem function and its management in north-east India. In: A. Gomez-Pompa, T. C. Whitmore & M. Hadley (eds.): Rain forest regeneration and management, pp. 323–334. Man and Biosphere Series, UNESCO, Paris and The Pathenon Publ. Group, USA.

Rawat, Y. S. & Singh, J. S. 1988. Structure and function of oak forests in central Himalaya. I. Dry matter dynamics. Ann. Bot. 62: 397–411.

Rodin, L. E. & Bazilevich, N. I. 1967. Production and mineral cycling in terrestrial vegetation. Oliver & Boyd, Edinburgh. 288 pp.

Ruark, G. A., Martin, G. L. & Bockheim, J. G. 1987. Composition of constant and variable allometric ratios for estimating *Populus tremuloides* biomass. For. Sci. 33: 294–300.

Saxena, A. K. & Singh, J. S. 1982. A phytosociological analysis of woody species in forest communities of a part of Kumaun Himalaya. Vegetatio 50: 3–22.

Saxena, A. K. & Singh, J. S. 1984. Tree population structure of certain Himalayan forest associations and implications concerning their future composition. Vegetatio 58: 61–69.

Saxena, A. K., Singh, S. P. & Singh, J. S. 1984. Population structure of forests of Kumaun Himalaya: Implications for management. J. Envn. Manage. 19: 307–324.

Sharma, E. & Ambasht, R. S. 1991. Biomass, productivity and energetics in Himalayan alder plantations. Ann. Bot. 67: 285–293.

Sharma, E., Sundriyal, R. C., Rai, S. C., Bhatt, Y. K., Rai, L. K., Sharma, R. & Rai, Y. K. 1992. Integrated watershed management: A case study in Sikkim Himalaya. Gyanodaya Prakashan, Nainital. 120 pp.

Shukla, R. P. & Ramakrishnan, P. S. 1984. Biomass allocation strategies and productivity of tropical trees related to successional status. For. Ecol. Manage. 9: 315–324.

Singh, J. & Ramakrishnan, P. S. 1982. Structure and function of a sub-tropical humid forest of Maghalaya. I. Vegetation, biomass and its nutrients. Proc. Indian Acad. Sci. (Plant Sci.) 91: 241–253.

Sundriyal, R. C. & Bisht, N. S. 1988. Tree structure, regeneration and survival of seedlings and sprouts in high-montane forests of the Garhwal Himalayas, India. Vegetatio 75: 87–90.

Sundriyal, R. C., Joshi, A. P., Gupta, S. K. & Negi, S. S. 1986. Nagdeo forest (Pauri Garhwal): An ecological note. Indian J. Bot. 9: 99–103.

Whitford, P. B. 1949. Distribution of woodland plants in relation to succession and clonal growth. Ecology 30: 199–208.