CHAPTER V

Chapter V

Vegetation structure, regeneration, woody biomass and productivity

5.1. Introduction

The Himalayan chain is a unique storehouse of precious biotic and abiotic reserves that stretches from Indus to Bhramaputra (Sahu 1986). It is not only mammoth of cultural symbol but also an important determinant in shaping our economy, milieu and climate (Pant 1980). India endows most of the Himalayan region with bounties of nature and culture evolved and preserved through process of civilisation, and contains some of the most restricted and threatened ecological systems on earth. Most of the spectacular and rugged mountain range of the Himalaya is biologically unexplored, thus the biological diversity of entire Himalaya is not properly known. The Himalaya offers an array of forest types with high biodiversity below the timberline, and is the cradle of major rivers of India. Most of these areas are now very much in the gamut of developmental process. Heavy demographic pressure with ever increasing demand for agriculture lands, firewood, fodder and cattle grazing and with developmental schemes like hydro-electric projects and extension of roads into hitherto trackless areas, have committed ecological aggression against environment. These activities have been leading to substantial reduction of forest cover, which in turn leading to serious ecological disasters such as soil erosion, landslides, loss of soil fertility and catastrophic floods (Saxena & Singh 1982b).

Extensive studies of Himalayan forest structure have been made by several authors (Tewari & Singh 1981, Ralhan *et al.* 1982, Saxena & Singh 1982a, 1982b, Saxena *et al* 1982, Singh & Ramakrishnan 1982, Shukla & Ramakrishnan 1984, Khan *et al.* 1986, Khan & Tripathi 1987, Sundriyal & Bist 1988, Ramakrishnan 1991, Singh & Singh 1992, Metz 1997). As the forest efficiency depends on the type, quality and stratification of vegetation, a qualitative evaluation of vegetation is a pre-requisite (Saxena & Singh 1982a). A detail description of canopy profile is also important for the study of forest condition because canopy organisation acts as a platform of interaction between forest and atmosphere for model of light interception (Anderson 1966, Miller 1967), photosynthetic capacity (Schulze *et al.* 1977) and evaporation (Lindroth & Haldin 1986). The product of interaction determines the quality of forest ecosystem.

Sikkim is widely acknowledged as India's most significant biodiversity *Hot Spot* (Kumar 1993, Shenga 1994) and one of the world's most critical centre of biodiversity (Myers 1990, WCMC 1992) with 550 species of orchids (95 genera), 36 species of rhododendrons (45 varieties), 4000 species of flowering plants, 9 species of conifers, 300 species of ferns and allies (WII 1997), and 175 species of Wild edible plants (Sundriyal & Rai 1996, Sundriyal 1999). In the last few decades there have been a continuous decline of species composition and density of plants at certain locations in Sikkim (Sundriyal *et al.* 1994). Urban development, tourism impact, profitable and non-profitable forest produce collections are the primary threats to biodiversity in the Sikkim Himalaya (Sharma *et al.* 1992, Sundriyal *et al.* 1994, Sundriyal & Sharma 1996, Rai & Sundriyal 1997). Now emphasis has been given for conservation of biodiversity in most of the areas in the Himalaya (Rao 1995).

However, very few studies have been undertaken on natural resources in the Sikkim Himalaya (Sundriyal *et al.* 1994, Sundriyal & Sharma 1996). The tree species, their density, productivity and vegetation complexity and resource exploitation patterns have a direct impact on the wildlife (Willson 1974, Maratha & Louis 1998, Bland, 1993). The present chapter provides the information obtained from the investigation on vegetation structure and biomass productivity in two (open and closed) forest types along the popular Yuksam-Dzongri trekking trail in west Sikkim. The relationship of some structural components of forests to the bird and butterfly community will be dealt with in Chapters VI, VII and VIII.

5.2. Methods

Depending on elevation the trekking corridor forests have been divided into two zones namely lower forest ranging from 1780–2350 m amsl (LF) and upper forest ranging from 2350–3500 m amsl (UF). The resources from LF is utilised by the communities, particularly of Yuksam for their daily requirements and some are also used for tourism purposes by non-residents. The hydro-power project labourers also used these forests until 1997 when the project was scrapped. On the other hand, at UF, Tshoka community and tourism related enterprises depend for various resources, either for recreation or for utilisation.

The study of vegetation parameters was undertaken in closed canopy (CC) and open canopy (OC) forests with respect to their canopy cover percentage. Based on the resources extraction intensity the OC forest was designated for utilized or CC forest as less utilized. Furthermore, OC having <40% canopy cover and CC having >40% canopy cover were considered based on mapping following IRS-IA LISS II satellite data of 1988. Rectangular plots of forest with topographical homogeneity were used (Sundriyal *et al.* 1994, Sundriyal & Sharma 1996, Metz 1997). Sampling stands with permanent plots measuring 30 m x 40 m were laid in both LF (CC = 4, and OC= 5) and UF (CC= 4, OC = 6) between 1780 m and 3400 m asml. Total number of permanent sample plots laid were 19 all along the trail. Trees in each plot were identified, marked at 1.3 m as diameter at breast height (DBH) for annual increment measurement. The DBH was measured using specific diameter tape. Height of the trees was estimated using clinometer. Stems having >10 cm diameter at 1.3 m height from the ground were considered as trees, stems <10 cm but >2.5 cm diameter as saplings and <2.5 cm diameter stems as seedlings. Saplings and seedlings were recorded in 5 m x 5 m subplots numbering five in each stand.

All tree species listed from the stands were used for calculating an importance value index (IVI), which was the sum of relative abundance, relative frequency and relative dominance. Shannon-Wiener's index of species diversity and concentration of dominance were estimated following Hayek & Buzas (1997). The ratio of abundance/frequency (A/F) was used to interpret distribution pattern of the species (Whitford, 1949). If A/F ratio was < 0.025, the distribution was regular, between 0.025-0.05 it was random and if > 0.05, it was contagious (Curtis & Cottam, 1956). Canopy depth of all trees was estimated by subtracting first branch height from the total height.

In forests, vertical and horizontal architecture of canopy structures were assessed non-destructively, with ground level observation. Sampling of forest structural profile was made on each of the above-mentioned four forest conditions. In order to include maximum number of dominant species in the diagram, a 30 m line stripe was found sufficient to have three sections of 30 m each except for one forest with two 30 m stripes and one with 40 m. Samplings were undertaken at gentle slope (<20°), medium slope (20-30°) and steep slope (>30°) of the site. A rough sketch of the tree profile was made at the field. Depending on the tree dimensions like tree height, crown depth and crown area, a final profile diagram was sketched for two forest zones considering both the forest types of each zone from the corridor. Canopy depth of all trees was estimated by subtracting first branch height from the total height. Canopy index for tree layers were calculated by dividing sum of canopy area of each stratum by total sampled area. Height and canopy depths of shrub were excluded as no measurement was made. The quotient of slenderness (SG) for canopy trees (top canopy tree A_1 and under canopy tree A_2) in each stand was calculated by formulae given by Brunig and Heuveldop (1976).

In order to have a better understanding of the forest, foliage profile structure of four forest conditions were drawn for eight height classes of woody tree species. Trees were categorised into eight height classes and their abundance was considered for the abundance profile drawing following Sankar Raman (1995) and Javed (1996) with certain modifications.

Woody biomass of standing trees were calculated by tallying DBH with height and using allometric relationships of different species from Sikkim (Sundriyal *et al.* 1994, Sundriyal & Sharma 1996) (Table 5.1). Woody biomass removal was estimated from 10 random 20 m x 20 m plots from each representative condition. Girth at the base of each stump was measured and converted to DBH; the tree height class was derived by matching its calculated DBH to the mean height of similar-sized trees as measured in the permanent plots. Biomass of all the removed trees was calculated from allometric relationship following Sundriyal *et al.* (1994) and Sundriyal and Sharma (1996). These data were compared with the estimates of firewood extraction and consumption which again, were done through systematic household interviews. Annual increments on DBH and heights of the trees were recorded for two successive years (1998-1999). Since some of the trees were removed in the marked plots, net primary productivity (NPP) was calculated considering the standing and removed biomass. However, for net ecosystem productivity (NEP) removed biomass was subtracted and productivity of only standing trees was calculated (Binkley & Arthur 1993, Sundriyal & Sharma 1996).

Stands were identified with the help of local community and all the trees were marked on 3rd to 5th January 1997 in the LF and 19th to 23rd April 97 in UF. The stand regeneration status, ground vegetation and shrub data were collected during April and May for summer and during November for the winter. The annual increment in the DBH was measured on 19-21st January in 1998 and 23-25th January 99 for LF and during April 98 and April 99 in UF.

5.3. Results

5.3.1. Vegetation structure

5.3.1.1. Diversity

Species diversity, species richness and concentration of dominance of woody vegetation are presented in Table 5. 2. In the LF, tree species diversity was greater in the OC (H′=5.5) than in the CC (H′=2.04), whereas at the UF, it was higher in the CC (H′=2.8) compared to that of OC (H′=2.5). Values of species richness were greater at OC both the lower and upper forests. The values of concentration of dominance varied at different sites and were greater in the sites dominated by a few species.

5.3.1.2. Regeneration

Out of 56 species only twenty species of trees were found regenerating at the LF accounting 43% of the total species at the closed and 47% at the open canopy forest (Table 5.3.1). Nineteen out of 32 species were found regenerating in the UF accounting 56% of the total species at the closed and 58% at the open canopy forest (Table 5.3.2). Number of regenerating individuals markedly declined in the open forests at both LF and UF showing poor regeneration of canopy trees. The secondary species like *Symplocos* spp and *Eurya acuminata* occurred with higher densities of seedlings and saplings at almost all sites. Comparatively, regeneration of *Quercus lamellosa* and other commonly used species was relatively higher in the closed canopy forest at the LF. Similarly, *Rhododendron falconeri* and *R. arboreum* showed relatively higher regeneration in closed canopy forest at the UF. Interestingly, *Abies densa,* the dominant species of the UF, was regenerating poorly at both closed canopy and open canopy forests.

5.3.1.3. Woody tree species composition and distribution pattern

Comparative values of woody tree abundance, abundance by frequency ratio, density of woody trees, basal area and the importance value index (IVI) are given in the Tables 5.4.1, 5.4.2, 5.4.3 and 5.4.4. The open canopy forest of the LF showed markedly reduced IVI values and basal area for the species with high firewood preference compared to those of the close canopy forest (Tables 5.4.1 & 5.4.2). The species like *Quercus lamellosa, Q. lineata* and *Castanopsis* spp. had lower IVI values in the open forest. The species like *Cinnamomum impressinervium* and *Beilschmiedia sikkimensis* were totally absent in the open canopy forest. It appeared that many fodder tree species (*Leucosceptum canum, Sterculia villosa,* and *Acrocarpus fraxinifolius*) were left safely at the stands for annual extraction of fodder. At the UF, the IVI and basal area values of used species were also low. The species like *A. densa, Acer papilio, R. grande* and *L. elongata* showed low values of basal area and IVI in the open forest compared to those of closed canopy forest. *C. impressinervium* and *R. falconeri* were absent in the open forest of the UF (Tables 5.4.3 & 5.4.4). Densities of trees reduced from 435 trees ha^{-1} in the closed canopy forest to 206 trees ha^{-1} in the open canopy forest at the LF. Likewise, at the UF it reduced from 319 trees ha^{-1} in the closed canopy forest to 222 trees ha^{-1} in the open forest. The basal area of the tree species was also reduced from 59 m^2ha^{-1} in the closed canopy forest to 23 m^2ha^{-1} in the open forest at the LF, and from 50 m^2ha^{-1} in the closed canopy forest to 40 m^2ha^{-1} in the open forest at the UF.

The analysis of distribution pattern using A/F ratio indicated that three species namely *Quercus spicata, Elaeocarpus sikkimensis* and *Engelhardtia spicata* showed regular distribution in the closed canopy at the LF. Among the rest of the species, 12 showed random and 15 contagious distribution. The open canopy forest of the LF showed five species (*Symplocos ramisissima, Eurya acuminata, Quercus spicata, Glochidion acuminataum* and *Pantapanax leschenaulti*) having regular distribution, 21 random and 17 contagious. The distribution pattern of species in the UF under the closed canopy showed six species having random distribution, 17 contagious and none for regular distribution. In the open canopy forest of the UF only one species was found with random distribution, 23 contagious and none in regular distribution catagory.

Density of DBH classes showed L shaped distribution for the closed canopy forests at both the LF and UF indicating good regeneration and structural strata of different sized trees. The distribution pattern was skewed for the open canopy forest at both the LF and UF (Figs 5.1.1 & 5.1.2) as they showed fewer small DBH class trees. Tree population structure of the most dominant canopy and sub canopy species are presented in Figs 5.2.1 and 5.2.2. At the open canopy forest, *Q. lamellosa* showed higher density with bigger trees compared to the closed canopy forest. The species showed almost uniform distribution of all the stage classes, but proportionate numbers of seedlings and saplings have decreased in closed canopy. In case of open canopy forest, proportionate distribution of *Q. lamellose* showed upright pyramid except for small class trees. Similarly under closed canopy, in the case of *Machilus edulis* small class tree density reduced indicating distortion and consequence threat (Fig. 5.2.1). All dominant and "other species" also showed substantial reduction in the density of higher tree stage classes in the open canopy forest. Notably, the densities of small and large trees were markedly reduced at the open canopy forests of both the LF and UF. Density of total species in different stage classes formed an upright pyramid showing proportionate distribution in both close and open canopy forests. Density of large trees in the open canopy decreased compared to closed canopy that could be a sign of caution. At the UF, small sized trees of *A. densa* were almost missing in both the closed canopy and open canopy forests, which appeared as a worrying factor. At the LF, only 39% and 12% attained sapling and tree stages respectively under the closed canopy, and 45% and 10% at the open canopy forest. Similarly at the UF, 23% and 9% at closed canopy, and 28% and 10% in the open canopy forest reached sapling and tree stages, respectively.

5.3.2 *Forest canopy structure and woody plant dominance profile*

Foliage height profile of open canopy forest at LF showed a pattern with remarkably low abundance at 11-15 m height class. Sequence of abundance was the highest in the height class of 1-5 m followed by 6-10 m and 26-30 m (Fig. 5.3a). Above 15 m, the height classes showed disproportionate abundance. The data supported the general concept that the rise in altitude, the abundance decreased. At closed canopy, the profile showed similar pattern with high abundance of low height class trees except the class 11-15 m height class (Fig. 5.3b). The entire profile showed a disproportionate distribution and the values were remarkably low in open canopy compared to those of closed canopy forest.

Foliage profile abundance of open canopy at UF revealed that trees of 6-10 m height were more abundant compared to 1-5 m class. The profile showed disproportionate distribution among the height classes like the LF at open canopy. Trees with 1-5 m height were less abundant and had disproportionate distribution among the other height classes (Fig. 5.4a). Interestingly, height class of 36-40 m was relatively high in this stand. The data of closed canopy from the UF showed that 6-10 m height class was abundant in the stand (Fig. 5.4b). Overall abundance was remarkably low for this stand.

The data on canopy dimensions are presented in Table 5.5. Canopy depth at close canopy of LF was the highest at steep slope for the strata A_2 and A_1. The highest canopy index was found at gentle slope for the stratum A_2 and at steep slope for the stratum A_1. Total canopy index was in the descending order of steep slope>gentle slope>medium slope. The highest SG value was recorded at medium slope followed by steep slope and gentle slope. At open canopy, index of stratum A_1 was higher at all three positions. Combined canopy index was recorded the highest at medium slope for both the strata. The total combined canopy index was the highest at steep slope followed by gentle slope and medium slope. On the other hand, the value of tree stability was highest at medium slope followed by steep slope and gentle slope.

Comparatively high canopy depth for the stratum A_2 was recorded at steep slope at close canopy of UF and that of the stratum A_1 in gentle slope. Canopy indices were found highest at medium slope for the strata A_2 and also A_1 at close canopy of UF. Combined total canopy index was also highest at medium slope followed by steep slope and gentle slope. Quotient of slenderness was found high at gentle slope followed by medium slope and steep slope. At open canopy of UF, total combined canopy index was the highest at gentle slope followed by steep slope and medium slope. Canopy was sparse at gentle and medium slopes but closed at the steep slope. Tree stability value was in the order of steep slope>medium slope>gentle slope.

5.3.3. *Standing woody biomass, productivity and extraction*

Woody biomass standing state, net primary woody biomass productivity, extraction and net ecosystem productivity are presented in Table 5.6.1 and 5.6.2. *Q. lamellosa* shared 37-40% of the standing woody biomass and 18-28% net primary productivity (NPP) of the stands in both the closed and open canopy forests. The standing woody biomass were 704 Mg ha^{-1} and 399 Mg ha^{-1} in the close and open canopy forests respectively at the LF, and 382

Mg ha^{-1} and 306 Mg ha^{-1} in the closed and open canopy forests at the UF. The NPP of woody biomass was greater (16.26 Mg ha^{-1} $year^{-1}$) at the open canopy forest compared to the closed canopy forest (11.35 Mg ha^{-1} $year^{-1}$) at the LF. The NPP of the UF showed a contrasting result showing greater (13.5 Mg ha^{-1} $year^{-1}$) value in the closed compared to open canopy forest (11.3 Mg ha^{-1} $year^{-1}$).

Annual extraction of nearly 50% of the NPP was recorded from both closed canopy and open canopy of the LF. In the UF, 46% of NPP removal was recorded from the open canopy and 21% from the closed canopy forest. Extraction of *Q. lamellosa* was the highest in both the closed and open canopy forests followed by *B. sikkimensis, A. laevigatum* and *Quercus* sp (Table 5.6.1). Extraction of woody biomass was the highest (7.8 Mg ha^{-1} $year^{-1}$) in the open canopy of the LF followed by the open canopy forest of the UF (5.2 Mg ha^{-1} $year^{-1}$) and least from the closed canopy forest of the UF (2.8 Mg ha^{-1} $year^{-}$). Distributions of woody biomass in different DBH classes were found to have uneven pattern (Figs. 5.6.1 & 5.6.2). In the closed canopy at the LF, the highest biomass value of 73 Mg ha^{-1} was recorded for 60-70 cm DBH class and the lowest value of 4.3 Mg ha^{-1} was recorded for 90-100 cm DBH class. Likewise in the open canopy forest of the LF, the highest biomass value of 201 Mg ha^{-1} was recorded for >100 cm DBH class and the lowest value of 7 Mg ha^{-1} for 60-70 cm DBH class. In the closed canopy forest of UF, the highest biomass value of 66 Mg ha^{-1} was found for 10-20 DBH class and the lowest value of 14.4 Mg ha^{-1} for 90-100 cm DBH class. Similarly, in the open forest 93 Mg ha^{-1} was found as the highest in >100 cm class and 5 Mg ha^{-1} was recorded in 20-30 cm DBH class at the UF.

5.4. Discussion

Yuksam-Dzongi trekking corridor forest showed a high woody tree species diversity with a range of 2.04-5.52. High diversity and species richness in the open forest at LF may be due to invasion by new species in the resultant canopy gaps as emphasised by Hobbs and Huenneke (1998) or due to disturbances during intermediate stage of succession, which favours the secondary species to develop (Fox 1979). Many secondary species were recorded in open canopy forest at the LF.

Regeneration determines the future quality of the forest (Veblen 1992). The two forest sites along the corridor show poor regeneration and the quality of forest has been degrading slowly but steadily. High regeneration of secondary species indicates that the area will be slowly taken over by them. At the LF, the highest number of seedlings and saplings of secondary species have been recorded in both the closed and open canopy forests. Regeneration of secondary species such as *E. acuminata, S. ramosissima* and *V.*

cordifolia has been abundant. *S. ramosissima* has regenerated in both open and closed canopy conditions, thereby has been dominating in areas between the elevation of 2400 and 2700 m. Canopy opening or canopy species death leads to *S. ramisissima* domination (Metz 1997). "Other species" group had comparatively lesser number of seedlings and saplings. Regeneration of *Q. lamellosa* and a few other commonly used species were observed good at certain patches in closed canopy forest. The regeneration of *R. falconeri, R. arboreum* and *Magnolia campbellii* have been fairly good in the closed canopy of UF. At this forest, extraction pressures on the forest-based resources were comparatively low resulting in better regeneration.

Interestingly, *A. densa*, the dominant species of the UF has shown very poor regeneration along the trail and even in some relatively untouched areas. This may be due to specific niche microsite conditions that are not suitable for the regeneration of this species. A possible reason for the poor survival of species may be due to higher slope and lower water holding capacity as gentle slope experiences lesser soil washout and favours survival of seedlings. Sampled plots have shown a mean slope of 49°, which is regarded as steep, and also high trampling that possibly has reduced the water holding capacity. Steep slope and poor water holding capacity of the sites attributed to poor regeneration of *A.*

densa. Although seedling number has been high for most of the species at all the sites, the sapling survival has been substantially low. Consequently the number of small and large trees has also reduced causing irregular distribution. This indicates that forest along the trail suffers from instability of plant species population (Veblen 1992). The reason for such instability may be due to selective harvesting of lower DBH class trees and high intensity of grazing and trampling along the trail causing continued disturbances (Singh *et al.* 1997, Singh 1998).

Density of trees in the close canopy forest has been within the range reported for other broad-leafed temperate Himalayan forests. But in the open forest, the density has been lower (Saxena & Singh 1982, Rawat & Singh 1988, Sharma & Ambasht 1991, Sundriyal & Sharma 1996, Bhandari *et al.* 1997, Metz, 1997). However, overall density in the present study is lower than that reported for tropical forests (Foster & Reiner 1983). Basal areas of these forests are also comparable to other Himalayan forests (Saxena & Singh 1982a, 1982b, Rawat & Singh 1988, Sundriyal *et al.* 1986, Sharma & Ambasht 1991, Sundriyal & Sharma 1996, Bhandari *et al.* 1997, Metz 1997).

Present study reveals that the open forest cover has been extensive at lower forest area suggesting that excessive pressure have caused this situation. The forests remained denser at steeper slopes and canopy opening is more pronounced at gentler slopes. On the other hand, canopy structure has been more disturbed near the human habitations or campsites with sparsely distributed shrubs and seedlings. Canopy cover in medium slopes were poor at open conditions. The structure of forest varies from stand to stand. Such inter-stand variation in tree structure, crown geometry and canopy architecture are quite common (Anderson 1961, Brunig & Heuveldop 1976, Saxena & Singh 1982). Moreover, from the figures 5.3 and 5.4, it is revealed that the effective area due to inclination could be responsible for low density of woody trees in steep slope than in gentle slope (Sharma & Ambasht 1982).

Almost at all the stands, there was no distinct stratification of height layers due to presence of wide range of tree with different heights. The closed canopy architecture with well marked strata of different forests and positions acts as filtering layer as it intercepts light, precipitation and reduces the momentum of large particles such as rain dropping from remarkable heights (Parker *et al* 1989). From the field observation it has been revealed that lower forest has been subjected to intense human pressure. As a result, the tree structure and canopy architecture has been disturbed at gentle slopes. Poor development of herbaceous plants in some stands may be because of the tendency of inverse relationship between the canopy cover (of tree and shrub layer) and development of herb layer (Smith 1956, Zobel *et al.* 1976, Killingbeck & Wali 1978).

The canopy index, a relative measure of canopy cover of both the tree strata has been the highest at steep slope of UF at closed canopy forest and least at medium slope at open canopy forest. There has been no definite trend in the canopy cover index at the upper and lower forests and also at the open and closed canopy forests. The average canopy depth (across position and forest types) for A_1 stratum is the highest in the medium slope of LF open canopy forest and lowest in the steep slope of the closed canopy forest at UF.

Well-developed canopies of closed canopy forest influence the soil condition of the site as it is directly related to canopy cover (Packer 1951). These forest conditions reduce the terminal velocity of the raindrops dropping from top canopy trees and ultimately check the soil erosion (Lull 1964, Trimble & Weitzman 1954, Rai & Sharma 1998). Thus a forest having multilayered canopy with a high canopy index and a well stratified forest as found at closed canopy forests have a greater protective value as compared to a forest with fewer layers and low canopy index observed at open canopy forest (Kittredge 1948). Data on the quotient of slenderness (SG) indicates the stability of trees; lower the SG values higher was the stability (Brunig & Heuveldop 1976). From the present study, all the areas, especially the gentle slope are stable except at the upper closed canopy forest where the value at the steep slope was lower than the two other slope gradients.

Due to extensive lopping of middle height class trees, abundance of 11-15 m height class trees have been remarkably reduced even at the closed canopy at LF. This is obvious due to preference of smaller trees for firewood by the local people. At UF, 6-10 m height class trees have been abundant at both the closed and open canopy forests. However, abundance value of 1-5 m class has been comparatively high at the closed canopy forest. The low value of 26-30 m height class at upper forest attributes to suitable size of utilization of *Abies* for timber. High abundance value of 36-40 m class at the upper closed canopy forest was a result of abundant *Abies* trees, which are the only tree, attaining this gigantic height class.

The effects of the human intervention on forest biomass have shown a marked decline in accessible forest areas as also reported by Andrews (1961), FAO (1969), and Brown *et al.* (1991). Lesser number of stems with smaller DBH classes reflect the reduction of biomass in the open forests resulted by chopping and lopping of trees. A few large DBH class trees mainly have accounted for the most of the woody biomass of the open forest in contrast to more number of smaller trees (<50 cm DBH) in closed canopy forest. In fact, the medium sized trees are usually harvested illicitly. High extraction attributed to greater annual demand of firewood in the study area and is described in chapter III. Thus, huge demand of firewood caused deforestation that has accelerated soil erosion process and reduced soil fertility and productivity (Rai & Sharma 1998). The standing biomass of the LF under the closed canopy was much higher than that of the open. The present standing biomass values are comparable to those of temperate deciduous forest (Rodin & Bazilvich 1967) and that of the closed forest was higher than the standing biomass of certain forests in tropical areas (Ovington & Olson 1970, Johnson & Riser 1974, Singh & Ramakrishnan 1982, Sundriyal *et al.* 1994, Sundriyal & Sharma 1996). The woody biomass values of UF are comparable to those of temperate pine and oak forest of the Himalaya (Negi *et al.* 1983, Chaturvedi & Singh 1987, Rawat & Singh 1988).

Net primary production has been higher in the open canopy forest compared to that of closed canopy at the LF. High productivity in the open forest of the warm temperate zone could be due to fast growth of species after opening of the canopy as a result of favourable temperature, higher rainfall and better illumination. The NPP values are comparable to those of temperate forests of other parts of Sikkim (Sundriyal *et al.* 1994, Sundriyal & Sharma 1996). In contrast NPP of the closed canopy forest has been higher than the open forest of the UF. The UF comprising of cool temperate and sub-alpine region does not show much difference of growth after opening of canopy. The ecosystem productivity of the present study sites is comparable with the temperate forest at the Mamlay watershed in south Sikkim (Sundriyal & Sharma 1996). Woody biomass distributions on DBH classes show higher pressure on lower classes in the open forest that matches the frequency of chopping the trees (Chapter IV, Fig. 4.3).

5.5. Conclusion

Forest based resources are the integral part of livelihood of Himalayan people. Yuksam-Dzongri trekking corridor in the Khanchendzonga Biosphere Reserve in Sikkim has been endowed with high biodiversity. Population growth and rapid increase in tourist number have caused threat to the forest resources and biodiversity. The dense forests have been reduced and degraded in most parts especially at the lower elevations where human interference is intensive. Extraction of firewood and timber for community and tourism purposes has been observed all along the trekking corridor, and it is more pronounced near the major settlement of Yuksam. Tourism related pressure on the forest has been more distinctly visible at Tshoka, the first camping site on the trail. Removal of selective canopy species for firewood and timber has changed the forest structure and also opened areas where secondary species invaded. Regeneration of canopy species has been relatively low due to invasion by secondary species, which is likely to dominate in future. Extensive disturbance, like resources extraction and livestock grazing seems to be incompatible to *Abies* forest due to impairment of normal growth and development. These disturbances may also encourage the invasion of *Rhododendron* spp. within the *Abies* zone until another disturbance allows other species to invade.

In the present study some of the highly used firewood and timber species show poor regeneration and may affect the future conditions of the forest and availability of fuelwood and timber resources of choice. Laws for the forest management and conservation exist, though these are not adequately enforced due to various technical reasons. Secondly, there was no adequate fuel alternative in the area until recently. After implementation of Sikkim Biodiversity and Ecotourism Project, people have realised the importance of resources in the corridor for sustainable tourism development. Initiation of conservation activities has been geared up and the communities have started participatory monitoring for resources and wildlife. In order to maintain biodiversity of the area, it is necessary to look for the specific niche depending on qualitative indigenous species for firewood, fodder and timber. The degraded areas need immediate attention for community management. Management of trekking corridor forests should be oriented in such a way that only the canopy species regeneration is encouraged. Compliance to the code of conduct for conservation by tourists, enterprises and communities especially on the use of alternative to firewood would enhance the restoration of natural forest condition and conservation of related biodiversity.

Table 5.1. Regression data relating wood biomass to tree dimension and specific wood density of the dominant and other species in the temperate forest at Mamlay watershed (source :Sundriyal *et. al* 1994, Sundriyal & Sharma 1996).

Species	Regression equation	df	*r*	*E*
Temperate forest				
Quercus lamellosa	$Y = \exp(-0.948 + 0.826\ ln\ D^2 H)$	27	0.947*	1.077
Castanopsis tribuloides	$Y = \exp(0.807 + 0.595\ ln\ D^2 H)$	38	0.908*	1.049
Symplocos theifolia	$Y = \exp(0.520 + 0.594\ ln\ D^2 H)$	17	0.935*	1.066
Eurya acuminata	$Y = \exp(1.165 + 0.514\ ln\ D^2 H)$	19	0.860*	1.073
Alnus nepalensis	$Y = \exp(-2.847 + 0.839\ ln\ D^2 H)$	8	.0.967*	1.030
Other species	$Y = \exp(-0.427 + 0719\ ln\ D^2 H)$	24	0.915*	1.120
Total species	$Y = \exp(- 0.427 + 0.719\ ln\ D^2 H)$	143	0.909*	1.049
Tropical forest	**Regression equation**	***n***	***r***	***P<***
Castanopsis indica	$Y = \exp(0.204 + 0.769\ ln\ D^2 H)$	52	0.906	0.001
Shorea robusta	$Y = \exp(- 1.768 + 0.945\ ln\ D^2 H)$	12	0.940	0.001
Schima wallichii	$Y = \exp(- 1.064 + 0.888\ ln\ D^2 H)$	32	0.960	0.001
Other species	$Y = \exp(- 0.277 + 0.906\ ln\ D^2 H)$	13	0.618	0.050
Total species	$Y = \exp(1.741 + 0.615\ ln\ D^2 H)$	135	0.615	0.001

Y = Woody biomass (bole and branch) (kg); D = diameter at breast height (cm); H = tree height (m); S = specific wood density (gm cm^{-3}); d.f. = degree of freedom; r = coefficient of correlation; E = relative error calculated as antilog of the standard error of the natural logarithm of the y value; * significant at $P<0.001$; exp = exponential

Table 5.2. Species diversity, stand dimensions and regeneration at lower and higher forests at Yuksam-Dzongri trail.

Species diversity and dimension	Lower forest		Upper forest	
	CC	OC	CC	OC
Shannon Weiner's diversity index (H')	2.04	5.52	2.8	2.5
Species richness [Margalef's (d)]	5.4	8.8	4.2	4.7
Concentration of dominance (cd)	0.05	0.13	0.02	0.03
Basal area (m^2 ha^{-1})	59	23	50	40
Density (tree ha^{-1})	435	206	319	222
Tree species (number $site^{-1}$)	30	43	23	24
Regenerating species (number $site^{-1}$)	13	13	13	14
Regeneration (seedlings ha^{-1})	3480	2642	3694	2100
Regeneration(saplings ha^{-1})	1360	1200	860	585

CC = closed canopy, OC = open canopy.

Table 5.3.1. Regeneration status (ha^{-1}) of some widespread tree species in the lower forest of Yuksam-Dzongri trekking corridor

Species (local name)	Closed canopy		Open canopy	
	Seedling	Sapling	Seedling	Sapling
Eurya acuminata (Jhiguni)	840	440	480	176
Symplocos ramisissima (Kharane)	460	240	352	272
Cinnamomum impressinervium (Malagiri)	420	40	-	-
Quercus lineata (Phalant)	380	80	-	-
Neonaucleo griffithi (Pahenli)	320	180	272	64
Viburnum cordifolia (Asare)	260	100	464	128
Castanopsis tribuloides (Musre katus)	240	80	48	-
Machilus edulis (Ghew kaulo)	180	60	224	112
Beilschmiedia sikkimensis (Tarsing)	100	40	-	-
Acer oblongum (Phirphire)	80	40	-	-
Quercus spicata (Arkhaulo)	80	20	-	-
Betula cylindrostachys (Saur)	80	20	-	-
Quercus lamellosa (Bajrant)	40	20	96	80
Engelhardtia spicata (Mahuwa)	-	-	320	16
Castanopsis hystrix (Jat katus)	-	-	224	144
Sterculia villosa (Odal)	-	-	130	
Alnus nepalensis (Uttis)	-	-	80	48
Mahonia sikkimensis (Chuletro)	-	-	80	48
Prunus nepaulensis (Arupate)	-	-	80	32
Andromeida elliptica (Angeri)	-	-	16	80

Table 5.3.2. Regeneration status (ha^{-1}) of some widespread tree species in the upper forest of Yuksam-Dzongri trekking corridor

Species (local name)	Closed canopy		Open canopy	
	Seedling	Sapling	Seedling	Sapling
Eurya acuminata (Jhiguni)	80	60	373	80
Quercus lineata (Phalant)	120	40	-	-
Machilus edulis (Ghew kaula)	-	-	227	40
Quercus spicata (Arkaulo)	-	-	27	-
Mahonia sikkimensis (Chuletro)	-	-	200	40
Prunus nepaulensis (Arupate)	-	-	133	53
Andromeda elliptica (Angeri)	60	20	-	-
Rhododendron falconeri (Korling)	880	180	67	26
R. grande (Patle korling)	520	60	40	40
R. arboreum (Lali guras)	520	180	253	67
Magnolia campbellii (Ghogen chanp)	400	40	400	80
R. barbatum (Lal chimal)	380	40	147	80
Litsaea elongata (Pahenli)	280	60	-	
Acer thomsoni (Kapase)	240	60	-	13
Sorbus sp. (Pansi)	120	40	-	-
Betula alnoides (Saur)	67	40	140	13
Abes densa (Gobre salla)	27	40	80	13
Acer laevigatum (Putli)	-	-	53	13
Quescus sp. (Ainte)	-	-	67	27

Table 5.4.1. Values of abundance (AB), abundance frequency ratio (A/F), density (DN, ha^{-1}), basal area (BA, $m^2\ ha^{-1}$) and importance value index (IVI out of 300) of tree species in close canopy condition at Lower Forest along the Yuksam-Dzongri corridor

Species	AB	A/F ratio	DN	BA	IVI
Quercus lamellosa	5	0.067	31	22.2	51.6
Cinnamomum impressinervium	11	0.151	71	1.7	25.5
Beilscmiedia sikkimensis	14	0.270	56	4.2	24.3
Quercus lineata	14	0.280	58	2.2	21.4
Symplocos ramosissima	5	0.071	33	0.6	15.5
Eurya acuminata	3	0.040	21	1	12.9
Machilus edulis	3	0.050	10	3.6	12.8
Litsae elongata	5	0.090	19	2.4	12.6
Machilus odoratissima	4	0.070	15	2.5	11.9
Viburnum cordifolia	15	0.600	31	0.4	10.0
Quercus sp.	1	0.040	2	2.8	7.4
Engelhadtia spicata	1	0.010	2	1.5	7.3
Quercus spicata	1	0.020	4	1.2	7.3
Symplocos theifolia	9	0.360	19	0.4	7.1
Elaeocarpus sikkimensis	1	0.020	4	1	7.0
Ficus nemoralis	2	0.040	8	0.3	6.6
Castanopsis tribuloides	5	0.200	10	1	6.2
Nneonaucleo griffithi	2	0.080	4	1.7	6.0
Alnus nepalensis	1	0.040	2	2	5.0
Acer thompsoni	1	0.040	2	1.7	5.5
Prunus nepaulensis	1	0.040	2	1.2	4.7
Betula cylindrostachys	1	0.040	2	1.2	4.6
Michelia exelsa	2	0.080	4	0.5	3.9
Anthocephalus indicus	3	0.120	5	0.2	3.8
Rhododendron arboreum	2	0.080	4	0.2	3.4
Acer oblongum	2	0.080	4	0.1	3.3
Walchura tubulata	2	0.080	4	0.1	3.2
Unidentified (Chedang)	1	0.040	2	0.2	3.0
Quercus lanceafolia	1	0.040	2	0.3	3.0
Ilex sikkimemsis	1	0.040	2	0.06	2.7
Prunus nepaulensis	1	0.050	2	0.2	3.5
Total			**435**	**58.7**	**300**

Table 5.4.2. Values of abundance (AB), abundance frequency ratio (A/F), density (DN, ha^{-1}), basal area (BA, m^2 ha^{-1}) and importance value index (IVI out of 300) of tree species in open canopy condition at Lower Forest along the Yuksam-Dzongri corridor

Species	AB	A/F ratio	DN	BA	IVI
Quercus lamellosa	5	0.059	32	6	49.5
Castanopsis sp.	5	0.113	15	3	24.4
Nyssa javanica	3	0.075	10	1.5	15
Eurya acuminata	2	0.019	10	0.4	13.2
Machilus edulis	3	0.063	8	0.7	10.3
Quercus sp.	3	0.150	5	1.3	10.2
Betula cylindrostachys	3	0.063	8	0.6	9.9
Engelhardtia spicata	2	0.050	7	0.6	9.1
Castanopsis hystrix	2	0.050	7	0.6	9.1
Acrocarpus fraxinifolius	2	0.100	3	1	7.8
Symplocos ramosissima	1	0.017	5	0.1	7.6
Neonaucleo griffithi	2	0.050	7	0.1	7.3
Gaguga gamblei	2	0.100	3	0.8	7.0
Cinnamomum sp.	2	0.380	5	0.2	6.9
Drypetes lancifolia	2	0.038	5	0.2	6.9
Machilus odoratissima	1	0.050	2	0.9	6.4
Cinnamomum cecidodaphne	3	0.150	5	0.5	6.2
Prunus nepualensis	2	0.100	3	0.6	6
Viburnum cordifolia	2	0.038	5	0.1	5.9
Mahonia sikkimensis	2	0.038	5	0.1	5.9
Glochidion acuminatum	1	0.025	3	0.2	5.7
Rhododendron arboreum	1	0.050	2	0.6	5.3
Pantapanax leschenaulti	1	0.025	3	0.1	5.2
Boemeria platyphylla	3	0.150	5	0.2	5.1
Quercus lineata	2	0.100	3	0.3	4.5
Andromeda elliptica	3	0.150	5	0.1	4.5
Castanopsis tribuloides	1	0.050	2	0.3	3.6
Sterculia villosa	2	0.100	3	0.1	3.6
Ficus nemoralis	2	0.100	3	0.3	3.5
Michelia exelsa	1	0.050	2	0.2	3.5
Alnus nepalensis	1	0.050	2	0.2	3.4
Caeseria glomerata	2	0.100	3	0	3.4
Macropanax undulatum	1	0.050	2	0.1	2.8

Continued Table 5.4.2

Species	AB	A/F ratio	DN	BA	IVI
Symplocos glomerata	1	0.050	2	0.1	2.8
Symingtonia populnea	1	0.050	2	0.1	2.7
Echaenocarpus dasycarpus	1	0.050	2	0.1	2.7
Rhus insignis	1	0.050	2	0.1	2.7
Leucosceptum canum	1	0.050	2	0.1	2.7
Castanopsis indica	1	0.050	2	0	2.5
Paveta indica	1	0.050	2	0.1	2.4
Eurya symplocina	1	0.050	2	0.1	1.4
Cedrela toona	1	0.050	2	0.1	1.4
Total			**206**	**23**	**300**

Table 5.4.3. Values of abundance (AB), abundance frequency ratio (A/F), density (DN, ha^{-1}), basal area (BA, m^2 ha^{-1}) and importance of tree species in close canopy condition at higher forest along the Yuksam-Dzongri corridor.

Species	AB	A/F ratio	DN	BA	IVI
Abies densa	13	0.520	27	15.4	41.9
Acer papilio	6	0.110	23	10.2	33.7
Rhododendron falconeri	13	0.260	54	2.30	27.9
Quercus sp.	3	0.050	10	7.08	23.6
R. arboreum	4	0.580	27	1.08	20.2
R. grande	8	0.150	31	2.05	20.2
Magnolia campbelli	2	0.028	13	2.40	18.2
R. barbatum	12	0.480	25	0.49	12.0
Betula alnoides	8	0.320	17	1.30	10.9
Symplocos theifolia	9	0.360	19	0.52	10.1
Litsae elongata	5	0.200	10	1.39	9.2
Unidentified (Seto phusre)	5	0.200	10	1.33	9.1
Unidentified (Phusre)	5	0.200	10	0.58	7.6
Cinnamomum impressinervium	4	0.160	8	0.44	6.7
Sorbus sp.	3	0.120	6	0.60	6.4
Quercus lineata	1	0.040	6	0.49	6.1
Unidentified (Lalo phusre)	3	0.120	6	0.19	5.5
Unidentified (Arare kanda)	2	0.080	4	0.48	5.5
Weigtia gigantia	1	0.040	2	0.23	4.3
Magnolia sp	2	0.080	1	0.64	6.4
Lauroceracus undulatum	1	0.040	2	0.13	4.1
Prunus nepaulensis	1	0.040	2	0.15	4.2
Andromeda elliptica	3	0.120	6	0.50	6.2
Total			**319**	**49.97**	**300**

Table 5.4.4. Values of abundance (AB), abundance frequency ratio (A/F), density (DN, ha^{-1}), basal area (BA, m^2 ha^{-1}) and importance of tree species in open forest at higher forest along the Yuksam-Dzongri corridor.

Species	AB	A/F ratio	DN	BA	IVI
Rhododendron arboreum	11	0.164	61	3.24	44.7
Mangnolia campbelli	8	0.153	32	6.42	37.4
Abies densa	9	0.539	13	11.58	36.8
Prunus nepaulensis	4	0.080	17	2.698	21.4
R. barbatum	6	0.120	25	0.57	19.7
Betula alnoides	6	0.180	13	1.88	16.9
Unidentified (Arare kanda)	7	0.419	10	3.99	16.7
Quercus sp.	2	0.060	6	3.43	15.9
Acer papilio	4	0.105	10	1.05	11.8
Symplocos theifolia	1	0.260	6	0.14	10.1
R. garnde	3	0.090	8	0.19	9.0
Acer thomsoni	1	0.030	2	0.68	7.8
Machilus edulis	3	0.179	4	1.04	6.9
Quercus lineata	1	0.015	1	0.11	5.8
Litsae elongata	2	0.119	3	0.57	5.1
Michelia sp.	1	0.059	1	0.64	4.6
Prunus rufa	2	0.119	3	0.32	4.5
Beilschmiedia sikkimensis	1	0.059	1	0.47	4.2
Unidentified (Lalo phusre)	1	0.059	1	0.3	3.8
Unidentified (Sanwar)	1	0.059	1	0.32	3.8
Machilus kurji	1	0.059	1	0.29	3.6
Sorbus sp.	1	0.062	1	0.1	3.3
Erhretia wallichiana	1	0.059	1	0.03	3.1
Mahonia sikkimensis	1	0.059	1	0.01	3.1
Total			**222**	**40.07**	**300**

Table 5.5. Canopy profile, canopy index and quotient of slenderness for two forests of Yuksam-Dzongri trekking corridor. (description of A_1 and A_2 in the text)

Forest zone	Forest condition	Location	Average canopy depth (m)		Canopy index (%) Strata			(SG)
			A_2	A_1	A_2	A_1	Total	A_2
Lower forest	Open canopy forest	Gentle slope	18.3	3.5	62.8	214.5	277.3	42.88
		Medium slope	16.1	7.3	109.1	127.4	236.5	65.8
		Steep slope	17.4	5.6	85.9	152.1	237.8	53.21
	Close canopy forest	Gentle slope	18.1	2.9	114.4	125.3	239.7	41.49
		Medium slope	18.1	4.3	122.6	161.3	283.9	59.05
		Steep slope	19.2	4.6	137.5	114.2	251.6	48.61
Upper forest	Open canopy forest	Gentle slope	14.2	5.9	142.0	109.2	251.2	42.84
		Medium slope	20.4	5.8	42.8	69.6	112.4	43.87
		Steep slope	14.3	3.6	72.8	192.4	265.2	47.88
	Close canopy forest	Gentle slope	14.2	5.5	151.2	91.5	242.7	43.27
		Medium slope	16.1	3.6	60.7	288.8	349.5	42.48
		Steep slope	19.9	2.8	67.6	252.5	320.1	41.47

SG = Quotient of slenderness

Table 5.6.1. Woody biomass standing state, net primary productivity, extraction and net ecosystem productivity at the two forest conditions of lower forest of Yuksam-Dzongri trekking corridor.

Species (local name)	Standing Biomass ($Mg\ ha^{-1}$)	Net Primary Production ($Mg\ ha^{-1}\ year^{-1}$)	Extraction ($Mg\ ha^{-1}\ year^{-1}$)	Net ecosystem productivity ($Mg\ ha^{-1}\ year^{-1}$)
Close canopy				
Quercus lamellosa (Bajrant)	261.68	2.01	1.12	0.89
Beilschmiedia sikkimensis (Tarsing)	78.44	1.88	0.72	1.16
Machilus edulis (Ghew kaulo)	36.37	0.45	-	0.45
Machilus odoratissima (Lali kaulo)	34.99	0.80	-	0.80
Acer laevigatum (Putli)	24.47	0.90	0.54	0.36
Others (25)	267.84	5.31	2.38	2.93
Total	**703.79**	**11.35**	**4.76**	**6.59**
Open canopy				
Quercus lamellosa (Bajrant)	158.97	4.57	2.28	2.29
Quercus sp. (Ainte)	33.88	1.58	1.12	0.46
Castanopsis hystrix (Patle katus)	33.50	0.25	-	0.25
Nyssa javanica (Lekh chilaune)	22.44	0.08	-	0.08
Garuga gambleii	9.54	1.12	-	1.12
Others (38)	140.83	8.66	4.36	4.30
Total	**399.16**	**16.26**	**7.76**	**8.50**

Table 5.6.2. Woody biomass standing state, net primary productivity, extraction and net ecosystem productivity at the two forest conditions of upper forest of Yuksam-Dzongri trekking corridor.

Species(local name)	Standing Biomass (Mg ha^{-1})	Net Primary Production (Mg ha^{-1} $year^{-1}$)	Extraction (Mg ha^{-1} $year^{-1}$)	Net ecosystem productivity (Mg ha^{-1} $year^{-1}$)
Close canopy				
Abies densa (Gobre salla)	126.09	8.36	-	8.36
Acer papilio (Phirphire)	75.64	1.07	0.53	0.54
Quercus sp. (Ainte)	47.82	1.15	0.87	0.28
Magnolia campbellii (Ghoge champ)	22.63	0.30	-	0.30
Litsae elongata (Pahenli)	11.74	0.16	-	0.16
Others (18)	98.5	2.45	1.4	1.06
Total	**382.42**	**13.50**	**2.8**	**10.7**
Open canopy				
Abies densa (Gobre salla)	95.46	0.40	-	0.40
Magnolia campbellii (Ghoge champ)	53.13	1.06	0.63	0.43
Unidentified (Ararre kanda)	32.31	0.16	-	0.16
Quercus sp. (Ainte)	24.60	0.06	-	0.06
Betula alnoides (Saur)	16.82	0.74	0.62	0.12
Others (19)	84.04	8.91	3.93	4.98
Total	**306.36**	**11.33**	**5.18**	**6.15**

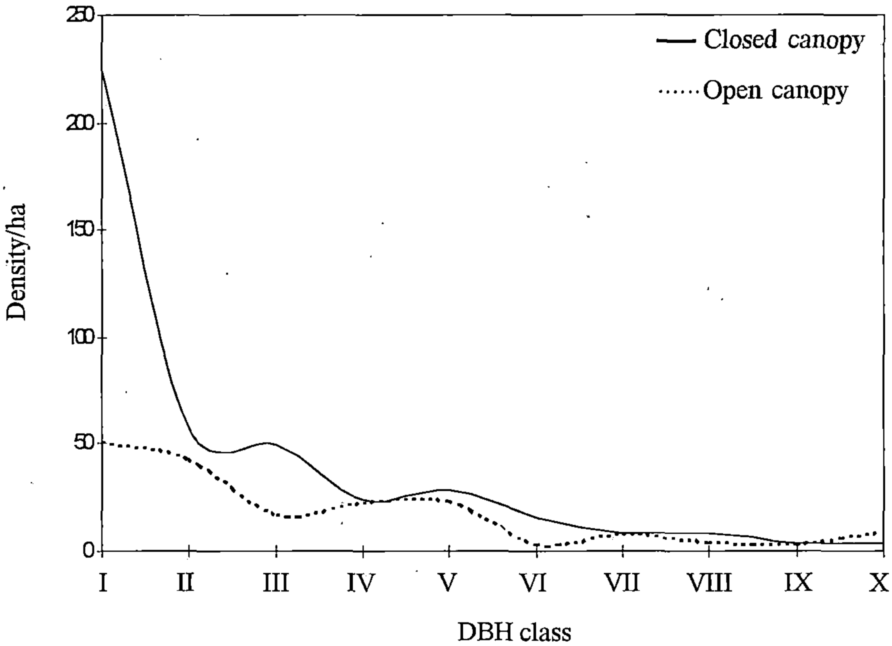

Fig. 5.1.1. Diameter class distribution of tree density in closed and open canopy conditions at lower forest along Yuksam-Dzongri trail. DBH classes (cm) I = 10-20, II = 20-30, III = 30-40, IV = 40-50, V = 50-60, VI = 60-70, VII = 70-80, VIII = 80-90, IX = 90-100 and X = >100.

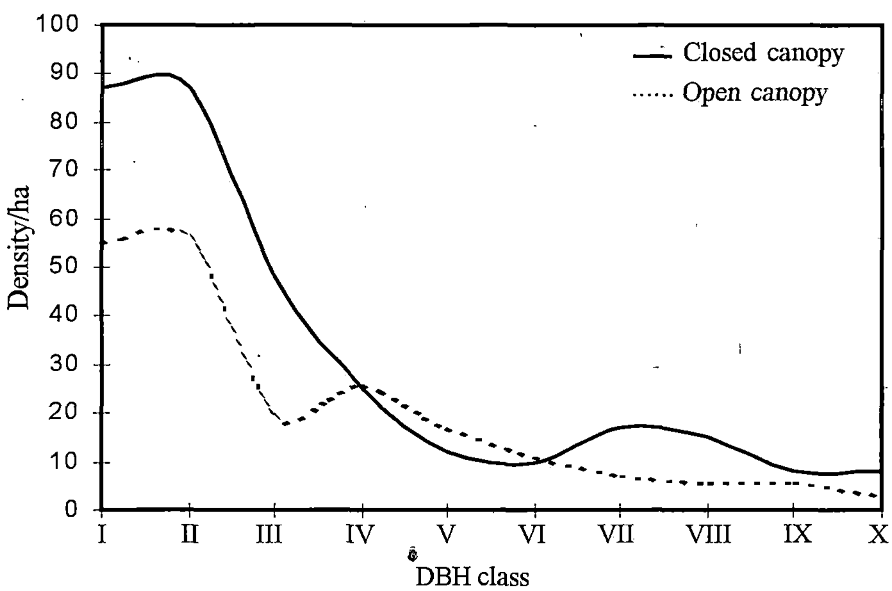

Fig. 5.1.2 Diameter class distribution of tree density in closed and open canopy conditions at upper forest along Yuksam-Dzongri trail. DBH classes (cm) I = 10-20, II = 20-30, III = 30-40, IV = 40-50, V = 50-60, VI = 60-70, VII = 70-80, VIII = 80-90, IX = 90-100 cm and X = >100.

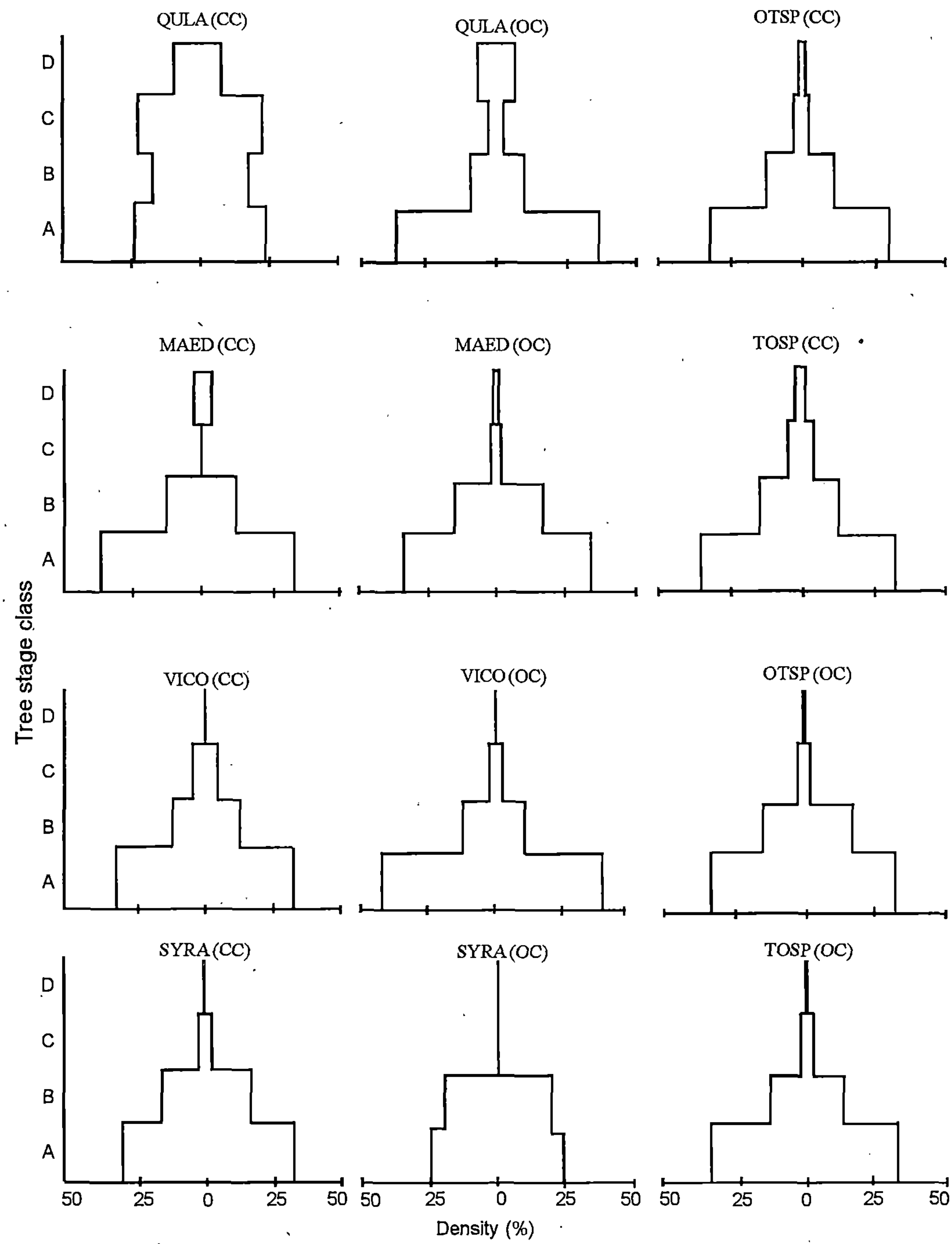

Fig. 5.2.1. Density of tree species, in different stage classes (A = seedling, height < 20 cm, B = sapling, height > 20 cm but diameter < 10 cm, C = small tree, diameter >10 cm but < 30 cm and D = large tree, diameter >30 cm) in lower forest. QULA = *Quercus lamellosa*, MAED = *Machilus edulis*, VICO = *Viburnum cordifolia*, SYRA = *Symplocos ramosissima*, OTSP = other species, TOSP = total species, CC = closed canopy and OC= open canopy.

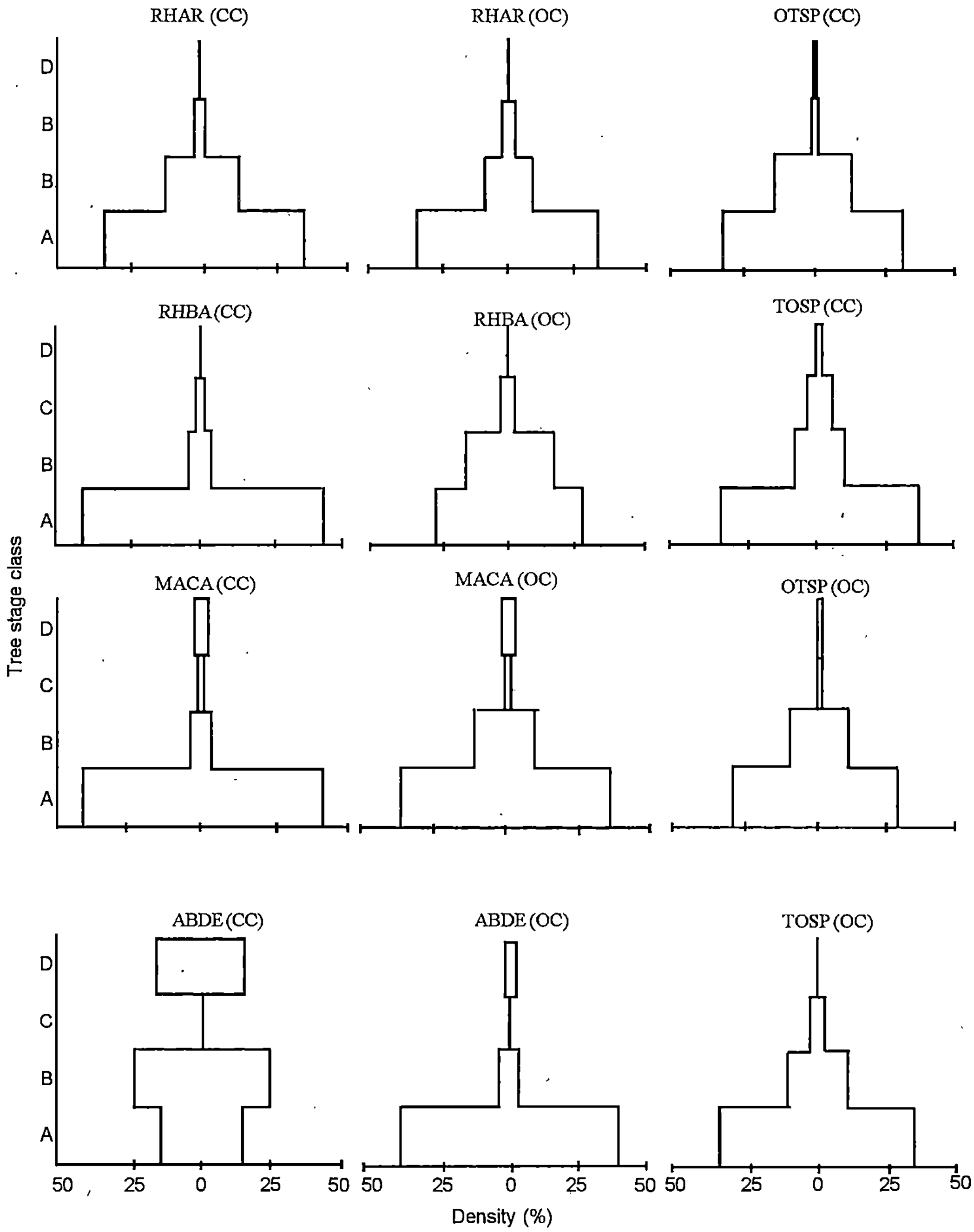

Fig 5.2.2. Density of tree species in different stage classes (A = seedling, height < 20 cm, B = sapling, height > 20 cm but diameter < 10 cm, C = small tree, diameter >10 cm but < 30 cm and D = large tree, diameter >30 cm) in sub-alpine forest. RHAR = *Rhododendron arboreum*, RHBA = *R. barbatum*, MACA = *Magnolia campbellii*, ABDE = *Abies densa*, OTSP = other species, TOSP = total species, CC = closed canopy and OC= opened canopy.

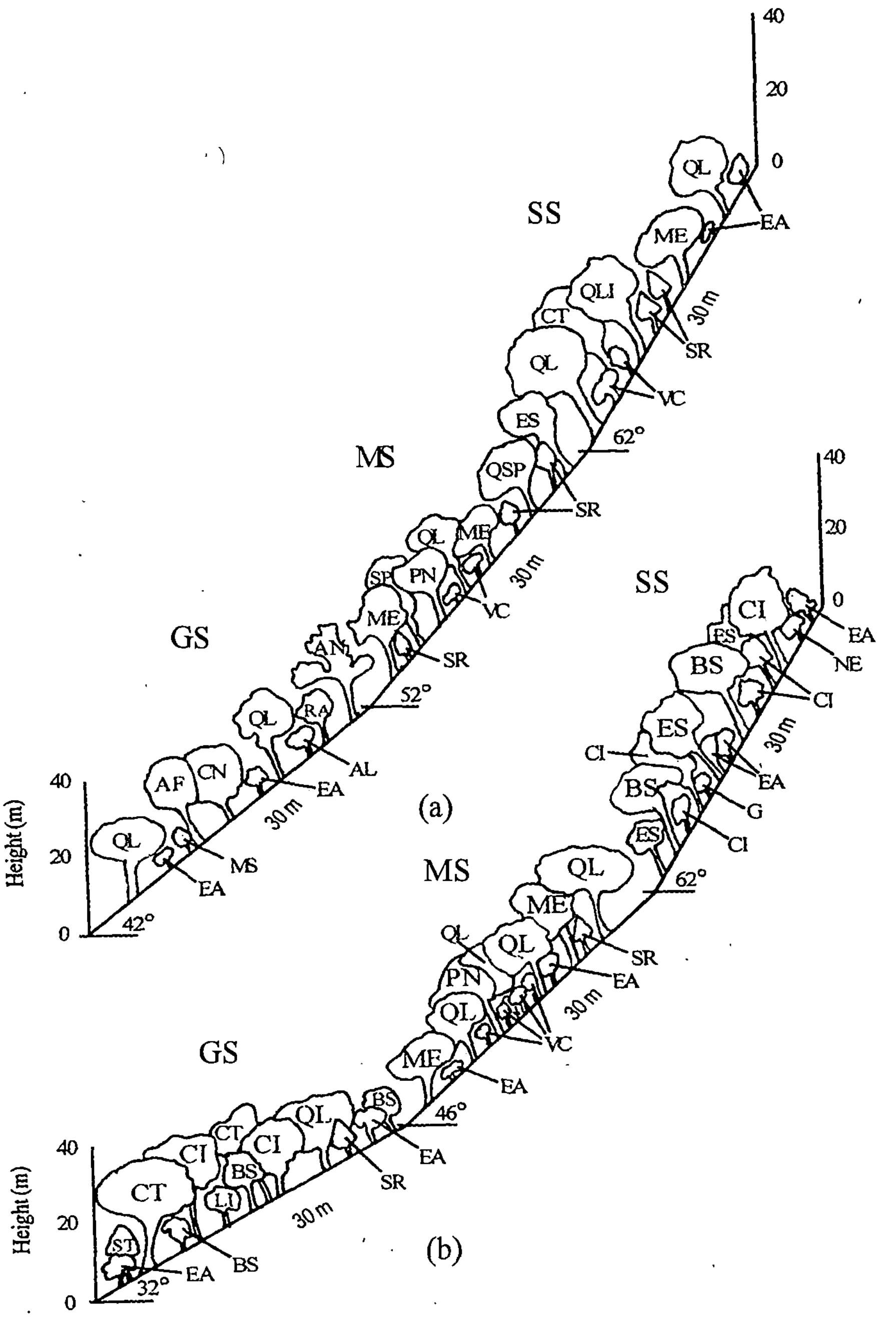

Fig. 5.3. Profile diagram for open canopy forest (a) and closed canopy forest (b) from the lower forest along the Yuksam-Dzongri trekking trail. Each profile diagram is made up of three sections as follows: GS = gentle slope, MS = medium slope and SS = steep slope. AF = *Acrocarpus fraxinifolius*, AN = *Alnus nepalensis*, BS = *Belschmiedia sikkimensis*, CT = *Castanopsis tribuloides*, CI = *Cinnamomun impressinervium*, CN = *Castanopsis* sp., EA = *Eurya acuminata*, ES = *Engelhardtia spicata*, ME = *Machilus edulis*, PN = *Prunus nepaulensis*, QL = *Quercus lamllosa*, QLI = *Quercus lineata*, QSP = *Quercus* sp., SP = *Symingtonia populnea*, ST = *Symplocos theifolia*, RA = *Rhododendron arboreum*, SR = *Symplocos ramosissima*, VC = *Viburnum cordifolia*.

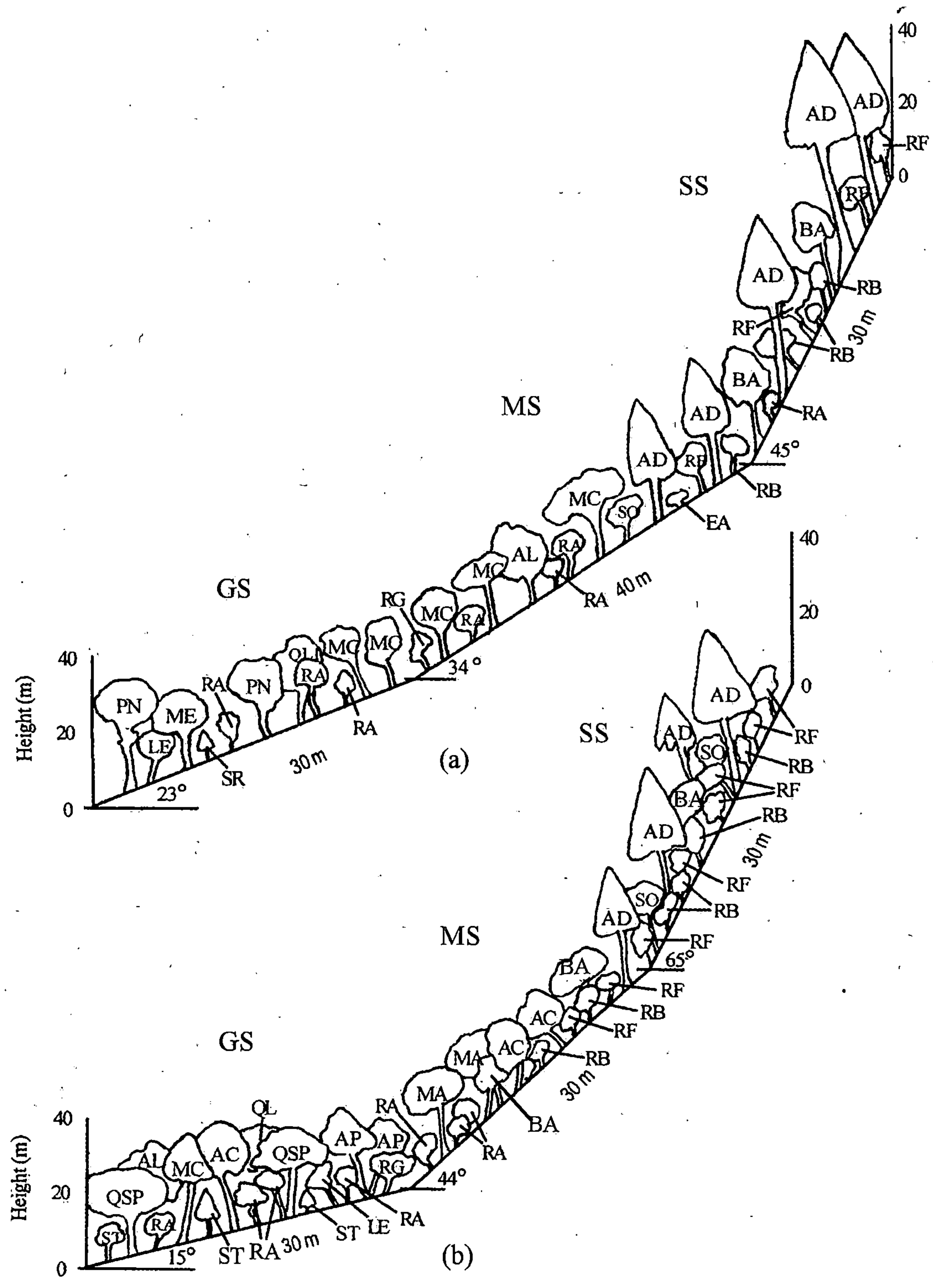

Fig. 5.4. Profile diagram for opened canopy forest (a) and closed canopy forest (b) from the upper forest along the Yuksam-Dzongri trekking trail. Each profile diagram is made up of three sections as follows: GS = gentle slope, MS = medium slope and SS = steep slope. AF = *Acrocarpus fraxinifolius*, AD = *Abies densa*, AL = *Acer laevigatum*, AP = *Acer papilio*, BA = *Betula alnoides*, EA = *Eurya acumunata*, LE = *Lisae elongata*, MA = *Magnolia* sp., MC = *Magnolia campbellii*, PN = *Prunus nepaulensis*, QL = *Quercus lamellosa*, RA = *Rhododendron arboreum*, RB = *R. barbatum*, RF = *R. falconeri*, RG = *R. grande*, SO = *Sorbus* sp, SR = *Symplocos ramosissima*, ST = *Symplocos theifolia*.

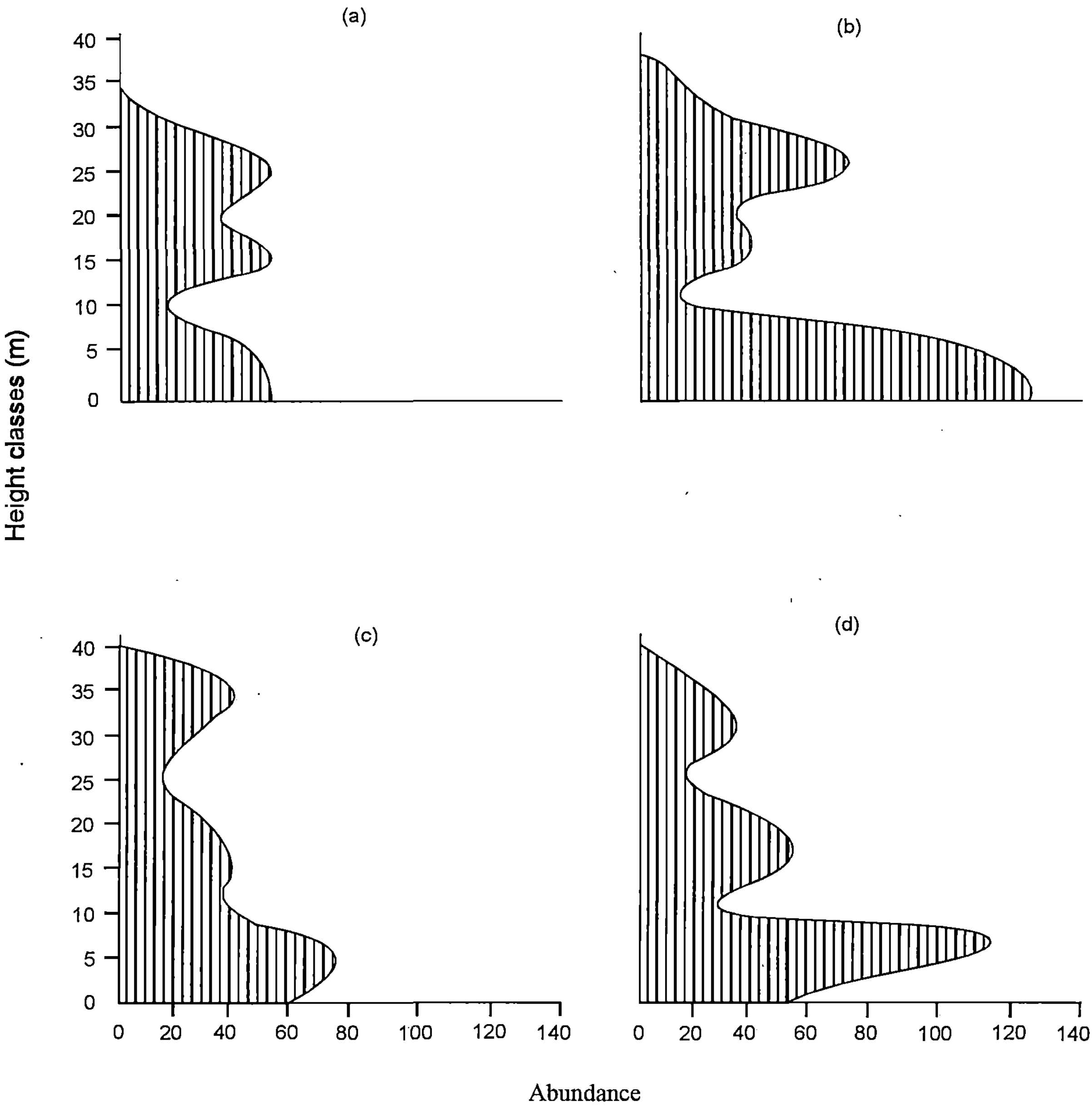

Fig. 5.5. Foliage height abundance in two forest types showing well stratified forest at closed canopy compared to open canopy at Yuksam-Dzongri trekking corridor. (a= lower open canopy, b = lower close canopy, c = upper open canopy and d = upper close canopy)

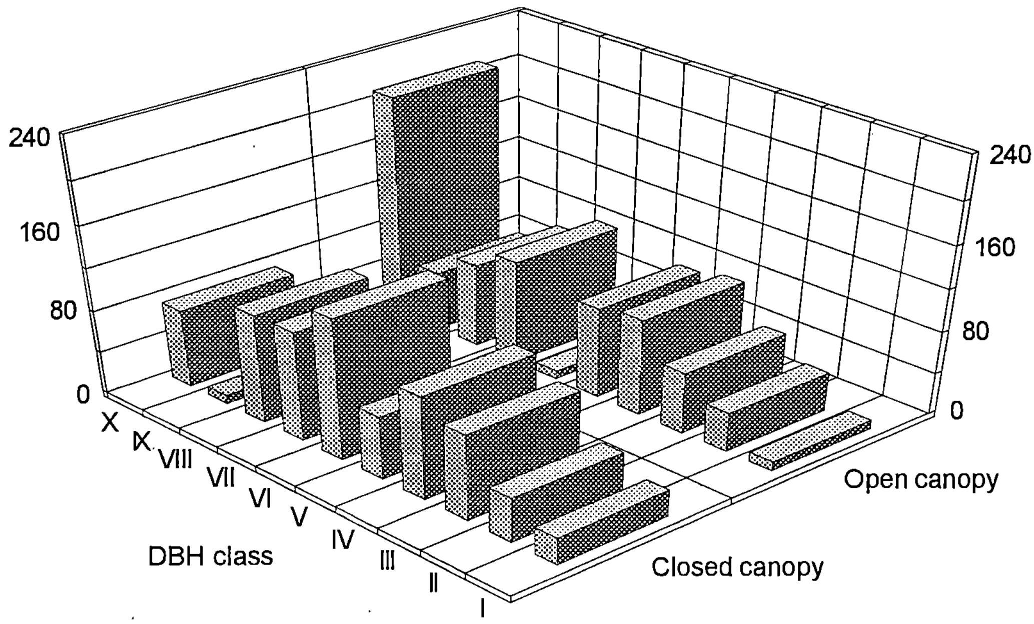

Fig 5.6.1. DBH class distribution of woody biomass (Mg ha^{-1}) in closed and open canopy forests at lower forest along Yuksam-Dzongri trail. DBH class (cm) I = 10-20, II = 20-30, III = 30-40, IV = 40-50, V = 50-60, VI = 60-70, VII = 70-80, VIII = 80-90, IX = 90-100 and X = > 100.

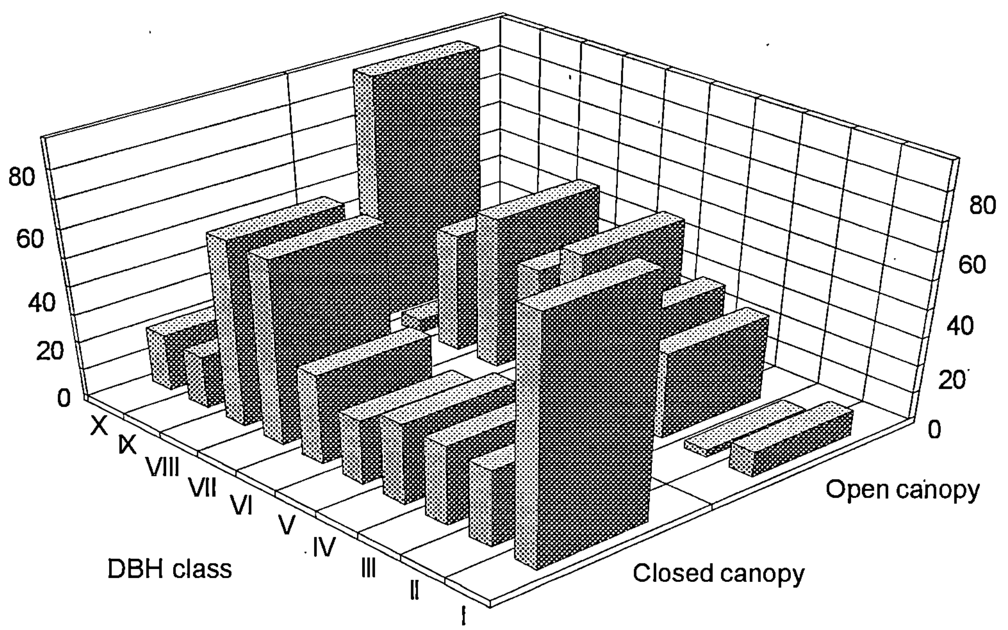

Fig 5.6.2. DBH class distribution of woody biomass (Mg ha^{-1}) in closed and open canopy forest at upper elevation forest along Yuksam-Dzongri trail. DBH class (cm) I = 10-20, II = 20-30, III = 30-40, IV = 40-50, V = 50-60, VI = 60-70, VII = 70-80, VIII = 80-90, IX = 90-100 and X = > 100.