Analysis of structure, composition and single tree selection systems in broad leaved forests of West Central Bhutan

Purna B.Chhetri

Dissertation

University of Natural Resources and Life Sciences, Vienna
Department of Forests and Soil Sciences
Institute of Silviculture

Advisor: ao Univ.Prof. DI Dr.Manfred J.Lexer

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Abstract

In the current study broadleaved forests in west central Bhutan were analyzed with regard to structure and composition and the response of regeneration to light and lateral competition. Furthermore, equilibrium diameter distribution models as means to analyse the implications of single stem selection harvesting regimes were developed and two alternative harvesting scenarios were compared.

The database consisted of three one-ha exploratory plots where every standing tree above 5cm DBH had been measured. Stumps, snags and coarse woody debris (CWD) were also fully recorded. Regeneration status as well as microsite characteristics including light indices derived from HemiView photographs were recorded at sub-plots within the exploratory plots. Spread over the entire study area for four selected tree species (*Cinnamomum bejolghota (Cb)*, *Castanopsis tribuloides* (Ct), *Macaranga pustulata* (Mp) and *Symplocos ramosissima (Sr))* 20 saplings each were selected and measured including their immediate neighbourhood (up to 4m distance). The saplings were analyzed destructively for aboveground biomass compartments (stem, branches, leaves and total). For the large trees a total of 26 discs from harvested stumps were collected for tree ring analysis. The tree rings were analysed after sanding to a fine scale and radial increment was measured in two cross-sections. To explore the demands of local residents the household survey was conducted in 10 villages within the administrative region with a total of 39 households surveyed (9% sampling rate).

The result of the analysis showed that on all three exploratory plots together 52 tree species from 29 families were present in the tree layer. The most dominant species in the study region was *Castanopsis tribuloides* which constituted more than 50% of the relative frequency and relative basal area. The DBH distribution in all three large plots was of the inverse-J type mimicking uneven aged “plenter” forests. The regeneration inventory in the exploratory plots indicated a remarkable density in seedlings (<130cm height) and saplings (>130cm height, <5cm DBH) ranging from about 6020 (Plot B) to 17467 (Plot C) seedlings and 1000 (Plot B) to 3400 (Plot C) saplings including shrubs and bush species. The ratio of the regenerating tree species (<5cm DBH) and canopy species (>5 cm DBH) was 0.58 in Plot A, 0.46 Plot B and 0.60 in Plot C, showing on average more than 50% of the species present in the tree layer were also present in the regeneration layer. The differences observed between plots were mainly the number of saplings between 50-200cm heights and also the origin of saplings (sprouting versus seed origin). However, in species rich forests like Rimchu, the stock numbers of regeneration alone may be misleading. A closer look at the species level would be necessary, generally the most dominant species such as *Castanopsis tribuloides*, some intermediate shade tolerant species *Symplocos spp*, and pioneers species like *Macaranga spp* were abundant in number; however some key late successional species such as *Alcimandra catcarthii* were present in very low numbers or none at all in some plots. Many canopy species did not have regeneration at all. The ordination of the plant species (both trees and others) with multivariate redundancy analysis (RDA) techniques showed partitioning of species along the altitudinal and light gradients. According to the analysis other recorded microsite attributes were not decisive for the establishment of regeneration. The relative light levels in the regeneration layer as inferred from HemiView photographs were in general fairly low (90% below 0.1 relative light in Plot A, 70% and 75% in Plots B and C). In Plots B and C a few subplots showed relative light levels between 0.3 and 0.6.

Results of the biomass allocation study in saplings of four selected species showed partly strong contrasting partitioning of biomass compartments between these species. However, no clear results could be obtained from the analysis of relationships between morphological attributes and biomass allocation on one hand and indices of light environment and lateral competition on the other. However, Mp clearly showed a characteristic very specific response

to different light environments. The species seem to invest in height growth in shade while under higher light levels more biomass in invested in leaves. Lateral competition indices did not correlate well; sometimes the correlations were even counter-intuitive. Thus, no clear picture on the species-specific response could be established.

Summarizing the findings from the exploratory plots it seems that the prevailing disturbance regime comprising of individual tree fall gaps was the main driver of forest regeneration. Recently, these natural processes were re-inforced by human single stem selection harvesting activities. The harvests in these forests were concentrated on areas accessible by a recently constructed forest road. Stumps indicated that single stem selection harvesting was spread over a wide range of tree diameters and tree species. It appeared that plots above the forest road had been utilized more intensively compared to the plot below the road indicating the importance of technical transport boundaries.

The steady state diameter distribution models (EDDM) established for the Rimchu plots were the first attempt to utilize this technique for broadleaved forests in Bhutan. Analysis showed that continuing with current harvesting rates would result in an increase in basal area by about 10%. Whether this would substantially reduce the recruitment of new trees into the lowest diameter class remains open. To account for such a possible feedback in the analysis the assumed ingrowth rates in the lowest diameter class had been set to values of 8-10 trees per ha and year, which is substantially lower then what can be inferred from the regeneration inventory. Important feature in the analysis is that harvesting strategies can be due to shift the shares of species and species groups towards more stakeholder oriented targets. In scenario "alternative harvesting" increased emphasis was put on increasing the shares of species groups 1 and 2 providing the most preferred timber species.

Based on the findings of the exploratory plots as well as the analysis of alternative harvesting regimes with the EDDM it is concluded that a single tree selection regime may be an option to maintain the species pool as well as the timber harvest potential in the study area. However, due to the many species involved further research is required to shed light on the role of different species and their niche requirements.

Kurzfassung

In der vorliegenden Studie wurden Laubwälder in West-Central Bhutanim Hinblick auf Artenzusammensetzung, Struktur und Verjüngungszustand analysiert. Spezielles Augenmerk wurde auf den Zusammenhang von Verjüngung und Lichtverfügbarkeit bzw. Konkurrenz innerhalb der Verjüngungsschicht untersucht. Weiters wurden Gleichgewichtsmodelle entwickelt und zur Analyse von zwei Nutzungsszenarien verwendet.

Die Datenbasis bestand aus drei 1 ha grossen Beobachtungsflächen auf denen alle Bäume mit BHD >5cm, alle Stöcke, liegendes Totholz mit Durchmessern >20cm und stehendes Totholz gemessen wurden. Verjüngung und Mikrostandorte wurden in kleineren Plots auf einem Raster innerhalb der 1ha Flächen erhoben. Auf jedem dieser insgesamt 64 Subplots wurden Lichtindikatoren über Hemiview Auswertungen ermittelt. Zusätzlich wurden von vier ausgewählten Baumarten (*Cinnamomum bejolghota (Cb)* , *Castanopsis tribuloide* (Ct), *Macaranga pustulata* (Mp) und *Symplocos ramosissima (Sr))* je 20 Individuen in der Verjüngungsschichte (Baumhöhen zwischen 2 und 5 m) detailliert nach morphologischen Merkmalen erhoben sowie deren Biomassenkompartimente (Schaft, Äste, Blätter) ermittelt. Ebenfalls für alle diese Einzelbaumproben wurden Hemiview Photographien sowie die unmittelbare Konkurrenz bis zu 4m Distanz innerhalb der Verjüngungsschichte erhoben. Ausserdem wurden insgesamt 26 Stammscheiben von Stöcken geworben und Jahrringmessungen durchgeführt. Schliesslich wurde eine explorative Befragung in 10 lokalen Dörfern in insgesamt 39 Haushalten durchgeführt um den derzeitigen und zukünftigen Bedarf an Holz- und Nichtholzprodukten aus Laubwäldern abzuschätzen.

Auf allen drei 1ha Flächen wurden insgesamt 52 Baumarten aus 29 Familien gefunden. Auf allen drei Flächen wies die Stammzahlverteilung über dem Durchmesser eine inverse J Verteilung. Die Verjüngungsinventur ergab erstaunlich hohe Verjüngungszahlen zwischen 6020 und 17467 Individuen je Hektar (von 10cm Höhe bis 5cm BHD). Insgesamt waren über 50% der Arten im Hauptbestand auch in der Verjüngungsschichte vertreten. Einige wichtige spätsukzessionäre Arten wie etwa *Alcimandra catcarthii* waren nur mit sehr geringen Anteilen in der Verjüngung vertreten. Mittels multivariater Ordinierungsmethoden (RDA) konnten die Arten entlan eines Höhengradienten und auch entlang eines Lichtgenussgradienten geordnet werden. Andere Mikrostandortsattribute waren nicht signifikant mit dem Auftreten von Verjüngung korreliert. Insgesamt waren die relativen Lichtwerte in den Verjüngungsplots gering und (0.1 relatives Licht auf insgesamt 70-90% aller Subplots in den Probeflächen). Einige wenige Subplots wiesen relative Lichtwerte zwischen 0.3-0.6 auf. Die Biomassenstudie erbrachte starke Kontraste zwischen den vier analysierten Baumarten. Allerdings konnten kaum Abhängigkeiten zwischen individuellen Allokationsmustern und Licht- sowie lateralen Konkurrenzindikatoren gefunden werden.

Die erstellten Gleichgewichtsmodelle für die Laubwaldflächen in Rimchu waren der erstmalige Versuch, dieses Modellkonzept für die Analyse von Erntestrategien in Laubwäldern in Bhutan anzuwenden. Die Analysen ergaben, dass die Fortführung des derzeitigen Ernteschemas zu einer Erhöhung der Grundfläche um ca. 10% führen würde. Wie sich dies auf die Verjüngungsdynamik auswirken würde kann nicht sicher abgeschätzt werden. In einem alternativen Ernteszenario wurde vermehrt Augenmerk auf die Steuerung der Baumartenanteile von wertvollen Nutzholzarten gelegt. Aus diesen Analysen wird gefolgert, dass ein Einzelstammentnahmeschema geeignet erscheint, die Laubwälder in Rimchu nachhaltig zu nutzen. Allerdings sollten unbedingt zusätzliche Analysen durchgeführt werden, um vor allem die hohen Artenzahlen besser in ein Nutzungskonzept integrieren zu können.

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1 Introduction

1.1 General

According to the latest estimates by Forest Resource Development Division (FRDD) the broad-leaved forests represent about 34.5 % of the total area of the country and accounts for about 54% of forest cover in Bhutan (Table 1-1).
These forests serves multiple functions such as commercial as well as subsistence timber production, watershed protection, biodiversity, soil and water conservations, resource base for subsistence farming such as grazing in the country. The conservation and wise utilization of these forest resources is one of the biggest management challenges in Renewable Natural Resources sector, this is largely because the government has put strong efforts in environmental protection and conservation that resulted in the commitment to maintain a minimum of 60% of the country's area under forest cover for all times to come (RGoB 2002). In this respect 51% of the nation's land area is entrusted as under "strict protection" in the forms of National Parks, Wildlife Sanctuaries and Biological Corridors linking protected areas (MoAF 2009). Approximately 7-10% from the total forest is available as commercial forest with special emphasis on environmentally sound and economically viable production systems (Dhital, 2002), managed under Forest Management Units (FMUs). Remaianing forests are managed under territorial system. The accurate estimates of different forest types under specific land uses are unavailable for the country, the latest estimates of the broad forest types are provided in Table 1-1.

Table 1-1: Land uses and forests area of Bhutan. B&C = mixed broadleaved-conifer forests.

Land uses	Area (Square km)	Percetage of total land	Percentage of Forest cover
Broadleaved Forests	13357.00	34.50	53.57
B&C forests	1626.00	4.20	6.52
Bluepine forest	1200.00	3.10	4.81
Chirpine forest	1007.00	2.60	4.03
Mixed conifer forest	4569.00	11.80	18.32
Fir forest	3175.00	8.20	12.73
Total Forests	24933.00	64.4	100.00
Other landuses	13783.00	35.60	
Grand total	38716.00	100.00	

(Source: working paper Ministry of Agriculture: Review of the land cover exercises from 1976 to 2007, Namgyel, P., 2010 based on TERI estimates 2007).

1.2 Brief history of forests administration in Bhutan

As far as modernization of Bhutan is concern, the department of forests is one of the oldest institutionalised bodies. It was created in 1952 (Norbu, 2000), after 18 to 19 years of its creation a legally binding document popularly know as Bhutan forest Act 1969 was enacted, which brought all the forests resources under state control. Meanwhile Bhutan started its modernization in 1960s with launching of first five-year plan in 1961 and forests was seen as vital resources to generate revenue for modernizing the country. The first management plan was drawn for forests of present Sarpang Dzong in the southern Bhutan with the help of Indian foresters. The first ever management planning was done on broad-leaved forests of Sarpang district in 1964. The plan was fairly simple in fact; it was clear felling of sub-tropical forests and planted with few species such as teak such operations of broad leaved forests continued till late 1970s in the southern belt of the country. And the harvested timbers were sold in log forms mostly to India. In 1970s, department of forests carried out pre-investment survey of forests resources with the help of the Government of India, that was the introduction of modern planning process in the country. In 1974, the Department of forestry promulgated the national forest policy and the preparation of scientific management plans begun for various forest areas in the country. The most important objectives of the policy have been preserving and promoting the forest sector to obtain maximum revenue for the national economy. In 1977, a management division responsible for preparing the management plan was created under the department of forests. The large scale logging of broad-leaved forests occurred with creation of forest utilization division in 1978. In early 1980s a plywood factory with the assistant of FAO was also established in Gedu. Since then forest management planning took the central stage and by 1992, the department was in a position to prepare at least three management plans per year. Although the national forest policy of 1974 covered most essentials part of the forest management and administrations; with passage of time there were inadequacies and was revised in 1991 (Dhital, 2002) In 1995, the forest act 1969 was replaced by forest and nature conservation act, which specifically required the sound management plans, based on sustainable management of forests resources, meanwhile the plans that we have mentioned prior to 1991 were mostly tree centric the plan did not consider any other social and environmental obligations. Following the guidelines provided by the forest policy 1991 and Forest and nature conservation Act 1995, many FMUs were created in broad-leaved forests in 1990s with financial support from Western donor countries and World Bank. These forest managements units are operational till date. The main focus of the government shifted from timber productions from forests to hydropower productions and the conservations forests became pivotal. In 1999, the government has banned the exporting of logs in round form to other countries, many areas of forests was brought under protected areas system. There was drastic changed in the management planning by 1990s and many social, environmental and economic considerations were incorporated in various stages of planning process.

In the 9th Five Year Plan (2002-2007) the government has identified four general goals for the renewable natural resources (RNR) sector. (1) Enhancing household and national food security, (2) Conservation and management of natural resources, (3) Enhancement of rural income and (4) Generation of employment opportunities.

Since, the forest is the largest sector within RNR system and it is also expected a significant contribution to all four goals. The Forest Policy (1991) clarifies the role of the forestry sector in this regard and lay down four primary goals for the sector as follows (FAO, 2000).

(a) The protection and conservation of the land, forests, soil, water resources and overall biodiversity against degradation, such as loss of soil fertility, soil erosion, landslides, floods and other ecological devastation and to improve degraded forest through management systems and practice.

(b) Contributes to the production of food, water, energy and commodities by effectively co-ordinating the interaction between forestry and farming systems.

(c) Meeting the long term needs of the people for wood and other forest products through sustained production system.

(d) Contribute to the growth of national and local economies, including exploitation of export opportunities through fully developed forest-based industries, and to contribute to balanced human resources development through training and creation of employment opportunities.

These policy directives require that forest conservation and resources use remain compatible which entails that the sustainability of resource uses to be a main guiding principle.

1.3 Forests resource management and constraints

The forestry sector is still centrally controlled by the state under Ministry of Agriculture and Forests. The forests sector had its directorate under the heading Department of Forests and Park Services and to ease the management and administration of the forestry sector, the department is further sub-divided into five functional divisions. These divisions are (i) Nature conservation divison, (ii) forest resources development division (iii) social forestry division, (iv) forest protection and utilization divisions and watershed division.
The Nature conservation division that manages about 51 % of the total forestland of the country administers and manages forestry resources through network of national park, wildlife sanctuary and other field offices spread across the country. The collective term for the national parks, wildlife sanctuary, nature reserves, and biological corridors is called protected Area System (PAS). Within PAS harvesting or logging of trees is limited to single tree harvesting and was granted only for the residents within the PAS. For the non wood forests component (if the NWFPs are abundant within the PAS) the residents of the park are allowed to collect and sale such nwfps with an approved sustainable management plans endorsed by the authorities example of such approved management plans are collection and sale of Cordyceps chinensis in Jigme Dorji Wangchuck National Park and Daphne spp collection for handmade paper industry in Bumdeling Wildlife Sanctuary.

Generally the forest resources regulation and management falls into four types (1) commercial harvesting with approved forest management units (FMUs) (2) rural subsidised use of forests resources out side PAS and FMUs without appropriate management plans and (3) community and private forests and (iv) single tree harvesting and sustainable uses of nwfps with approved management plan within PAS (as mentioned earlier).

The broadleaved forests generally occur on steep and rugged terrain and very small fraction of the total forest area can be effectively harvestable and that too depending on degree of slope and the extent to which accessibility through road construction can be attained. The effectively operable areas are estimated at the beginning of the planning process and considered the most important yield regulation parameter (Seydack, 2001).

Putting aside the nature conservation reserves forests under PAS and inaccessible areas due to steep and rugged terrains the commercial harvesting with approved FMUs constituted about 7 to 10 percent of the forestland in the country.

The FMUs are usually connected with forest roads which more or less bisect the whole area of the FMU, the cable crane is used to harvest the trees and the silviculture system employed in broad leaved forests are clear cuts, extending upto 1000 meter uphill or down hill. The current practice of harvesting in broad leaved forests is clear-felling of alternate strips followed by planting of seedlings of species of commercial importance that were present before logging (Samal, 1996) and with expected rotation period of 80-90 years. In such system the timber harvesting is done with skyline cable yarding system from a felled coupe of about 6 ha in size, running in a narrow strip about 60 meter wide for an average distance of about 1000 meters (Davidson, 1999). The successive cable lines are placed parallel to each other leaving some 100-120 meters of unlogged forests (interlines) left between for return logging in 30 or 60 years time, however because of the terrainous mountains and also environmental requirement to leave buffer along the water streams, the lines are never parallel nor spaced equidistant. The FMUs have fixed annual allowable cut (AAC) calculated based on the total area of the FMUs, rotation period and available volume or basal area. The harvesting is regulated based on AAC.

The FMU plans are prepared by Forest Resources Development Division (FRDD) and leased out to Natural Resources Development Corporation Limited (NRDCL) (the only corporation responsible for timber logging in the country). The logged timber is sold in open auctioning system and is limited to Bhutanese bidders only. The export of timber to other countries in round form (raw form) had been banned since 1999. The FMUs are prepared in such way that they fulfilled the domestic commercial demand of the timbers for Bhutanese construction industries. As part of the social obligation the plans should also cater to provide subsidised timber to the rural communities residing close by the FMUs.

However, very often these management units are controversial especially in broad-leaved forests. There are often debates over failure of natural regeneration on logged over areas (LOA), over grazing on LOA and excessive use by local people and in many cases the local people are excluded from decision making and their views, perceptions, knowledge and their interests are not fully appreciated in operational management of forest resources in the FMUs although at the strategic planning their views are included.

In the rural subsidised use (RSU) type there are no written management plans to managed the forest resources, the rural people or even institutions like religious monasteries, rural schools etc placed their demands to local administrator called Gup (local elected official at the block), the gup sends the compilations of such demands to beat offices then it follows ascending order of hierarchy to range and then to CFOs. The final evaluation and approval is done by the CFOs, in case of large-scale requirements of timbers, the CFOs consult the Department of forests and Park Services for its final approval. It is to be mentioned that in this system the beat officers or forest guards on the basis of single tree selection finally do the marking of the trees. Usually the farmers select the trees and forest guards give a legal marked on the tree to be felled. The systems has merits as well as demerits; one of the demerits of the system is that in absence of written management plan for such forests, and repeated harvesting of trees for timber from more or less the same area may led to structural and compositional changes. Moreover these areas are most of the time not connected with motorable roads, so still very primitive types of timber transportations are used such as dragging along slope. Such practices in the long run deteriorate the forest conditions and promote active soil erosions from the forests. On the other hand, a single tree selection still maintains continuous forest cover compared with clear felling of strips in FMUs. Likewise the non wood forests products are also collected by the villagers on adhoc basis from such forests without knowing the extend of the resources. There are no clear guidelines on marking of the trees in this system.

The third type of management that is getting popular in the recent times is the community and private forestry. The community forestry is basically a mixture of FMUs and rural use forestry. It is still centrally controlled; the timber harvesting is limited to fulfilling the demand of the community members. It has a specific areas and clear guidelines on management, harvesting etc. The timber harvesting is regulated with AAC (Buffum, 2008). The silvicultural system so far followed in broad-leaved region is single tree selection. The forests roads are absent in community forestry.

1.4 Synopsis of research in broadleaved forests

So far very few studies had been under taken to understand ecology of broadleaved forest and the impact of different management systems. In the following a brief synopsis of major studies in broadleaved forests is provided.

(a) Norbu (2002) emphasized that grazing is integral part of broadl leaved forest management. One major finding of this study was that unregulated and uncontrolled grazing and its related activities (lopping, clearing of under brushes) has led to undesirable consequences such as elimination of some tree species, change in tree species composition and overall reduction in tree density. Such uncontrolled cattle grazing practices in broadleaved forests would be detrimental both ecologically and economically. Therefore a systematic planning and integration of grazing in forest management planning was considered compulsory.

(b) Structure and regeneration of species along an altitudinal gradient in dry valleys of Central Bhutan were studied by Wangda and Oshawa (2005, 2006). They found sporadic regeneratiopn related to individual tree gaps. The authors found soil moisture responsible for the non-expansion of broadleaved forests towards the lower part of the dry valley (below 1650m asl). The mean monthly temperature of the coldest month of -1°C was mentioned as threshold for the possible upward expansion of broadleaved forests. This threshold coincided with an altitude of 3000m asl. The study basically captures species partitioning along the moisture and temperature regimes.

(c) Davidson (1999) reported on silvicultural management of broadleaved forests in Eastern Bhutan, Korila Forest management unit. The study had reported that two families, Lauranceae of the genera Litsea, Beilschmedia and Persea and Fagaceace of the genera Quercus and Castanopsis were dominant in the upper canopy and comprised of few large trees only. The seedlings and saplings were reported relatively low in numbers (70-80/ha) and alarmingly insufficient seedlings to replenish the mature tree classes by recruitments as forest grows and senile trees are lost from the upper canopy. Reasons for such low density of seedlings and saplings was speculated being due to grazing as indicated by the low density of palatable species compared with non palatable tree species. The study suggested a comprehensive analysis of grazing with controlled experiments.

(d) Sustainability of broad leaved forests managed as community forestry was assessed by Buffum et al. (2008, 2009). They have shown that moderate grazing of broadleaved forests and timer production was possible (0.4 cattle/ha, and timber of 4.64 m^3/ha/year) in late successional broadleaved forests of Eastern Bhutan.

1.5 Research needs in broad-leaved forests

For decades all forestry research meetings concluded that knowledge on broad leaved forests (BLF) is still limited in terms of understanding of its ecology, forest dynamics, impact of harvestings, impact of grazing, regeneration in logged over areas etc in the country. The studies as described in the preceding section showed mosaic of knowledge pieces about BLF in the country. Therefore there are many areas where researches in BLF is required, most importantly, the knowledge on the following natural and social processes deem urgent.

(i) Deeper understanding of natural processes
(ii) Deeper understanding of societal needs for natural resources and
(iii) Consistent management planning, implementation and monitoring

The sustainability is only achievable with an adequate understanding of forest dynamics and the associated constraints that pertain to the functioning of the forest system. In Bhutanese context the sustainability of the natural resource depends on how constraining factors such as steep terrain, accessibility and ecological (inadequacy of understanding of broadleaved forest ecology) be matched.

Thus an adequate understanding of broad leaved forest dynamics and vis a viz the introduction of regulation systems to ensure sustainability of resource is overriding; especially an understanding of regeneration dynamics is necessary for timber yield regulation as well as the regulation of other forest uses such as grazing, soil water conservations, non wood forest productions etc. The knowledge on growth and age patterns of forest trees is required for the selection and development of yield regulation options. Obviously, the role of research specifically addressing these requirements of information and understanding for the broadleaved forests is vital.

Moreover, despite having logging operations for decades on broad-leaved forests, there is no single recommended standard silvicultural system for sustainable resource utilization. A brief history of forest management in Bhutan is provided to get the clear picture of the broad-leaved forest management.

Many changes at the policy levels and various stages of forest management planning have taken place since the creation of department of forests in 1952, one thing was always lacking in the broad –leaved forests. It was the silvicultural system; it was and has been topic for discussion in all forestry workshops and seminars, as lately as 2008, the Director of Forest and Park Service noted.

*“… **Broad-leaved forests** encompass the largest forest resource of the country in terms of area and diversity. **Economic utilization** of these forests started later than that of conifer forests, due to their extreme complexity and thus resulting difficulty in terms of their management. At present, harvesting operations in most broadleaved areas lead **to failure of regeneration due to lack of knowledge on the ecological and silvicultue aspects of these forests**...”*

It implies that there are knowledge gaps in managing the broad-leaved forests especially its silviculture. Although there are some reasonable bases of managerial skills and growth data based on operational inventories to make some management decision, but substantial information is lacking on various aspects. Clearly, there is an urgent need for research relevant to these forest´s management, as pressure from local and commercial viewpoint increases day by day. The knowledge on the effect of disturbances both natural and anthropogenic on the structure and composition of broadleaved forests is still lacking, which may be very crucial for making management decision.

2 Objectives of the study

The overall objective of the current study is to analyse stand structure and composition in broadleaved forests (BLF) in Rimchu, West Central Bhutan and to shed light on impacts of single tree selection on BLF dynamics. The study can be structured into several components.

(1) characterizing the structure and composition of BLF under low intensity single stem selection use

(2) ecological characterisation of regeneration establishment and early growth via biomass allocation study of four co-occurring tree species

(3) to develop equilibrium diameter distribution models as a means for forest management planning and to project consequences of single stem selection silviculture on structure and composition of BLF.

The specific objectives of part (1) are:

(a) to quantify and describe the species composition in BLF in Rimchu
(b) to quantify and describe the stand structure in BLF in Rimchu
(c) to quantify and describe the deadwood pools (stumps, snags, coarse woody debris) in BLF in Rimchu
(d) to quantify and describe tree quality
(e) to quantify and describe the regeneration pattern as correlated to light and other site conditions.

The specific objectives of part (2) are:

(a) to analyse interspecific differences in aboveground biomass partitioning and plant architecture in saplings of four co-occurring tree species
(b) to analyse whether architectural variation within species is related to the light regime and lateral competition (i.e. the plasticity of plant morphology)
(c) to characterize the behaviour of tree species in the regeneration phase based on architectural traits, and
(d) to conclude on the applicability of the findings in practical silviculture.

The specific objectives of part (3) are:

(a) to provide the data required to calibrate an equilibrium diameter distribution model (EDDM) for BLF in Rimchu
(b) to analyse the likely implications of different single tree selection harvesting regimes on forest structure and composition.

3 Study sites

3.1. Location

A significant proportion of the forests in Bhutan are classified as warm to cool broad-leaved. These forests occupy a very unique position in vertical stratification of the forests types. According to a classification by Grierson and Long (1983) their range starts from loosely 1000m asl and extend up to 2300m asl. The present study was conducted in West Central Bhutan in Rimchu which is situated North of Punakha Dzong at 27°45´07´´North and 89°45´21´´East at altitudes between 1610m asl to 2070m asl (Figure 3-1).

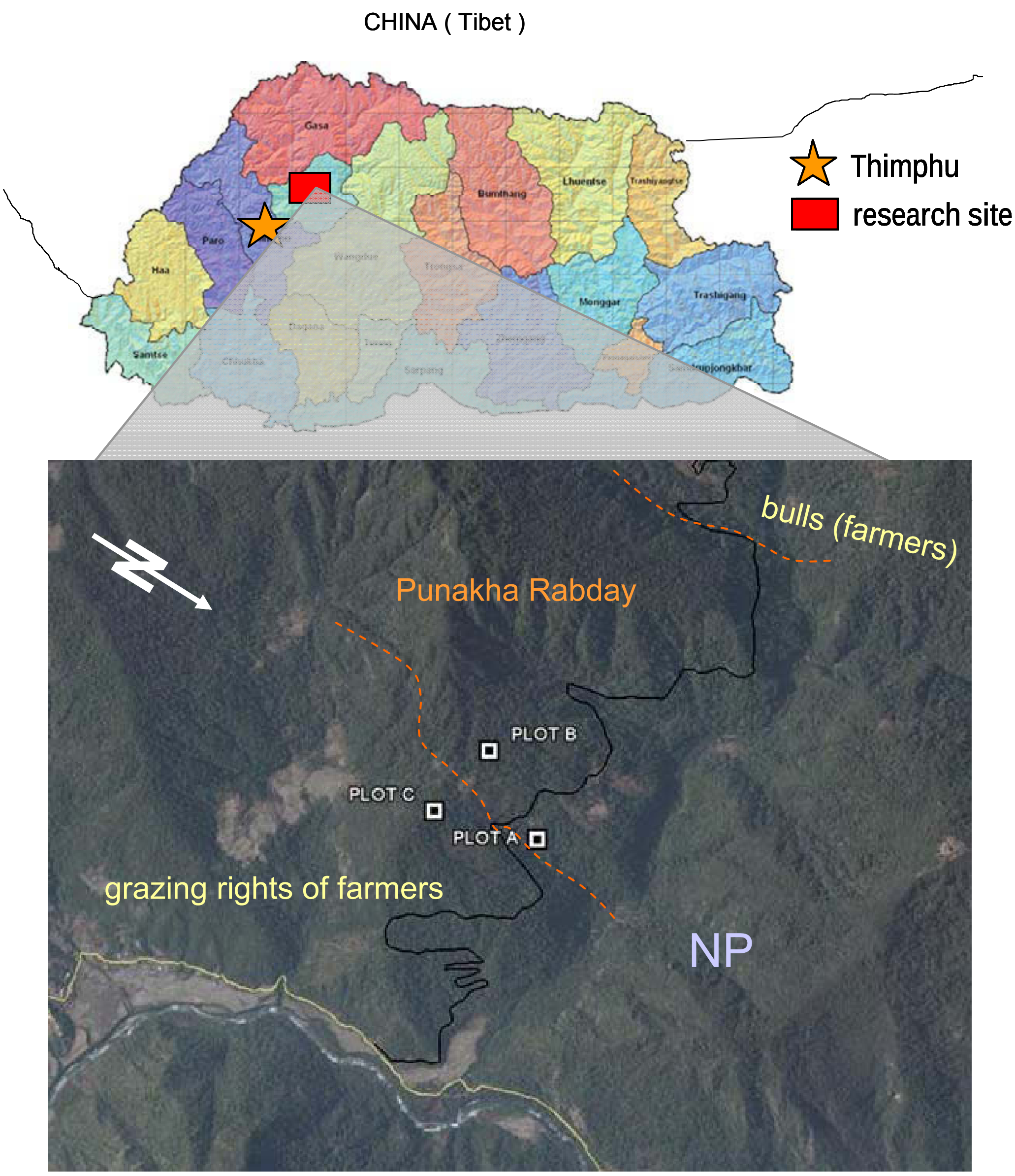


Figure 3-1: Location of the study site and the exploratory plots in Bhutan. Punakha Rabday is designated as grazing ground for cattle of Punakha monastic body, to its left is the area designated for grazing of cattle from farmers of Kabji geog and to its right is the area for grazing the bulls of Kabji geog farmers after rice plantation. The black line is a forest road. Sources of maps: Population and housing census 2005 of Bhutan and Google Earth.

3.2 Ecological conditions and forest types

The geology of the study area is calc-silicate, a metamorphic rock consisting mainly of calcium-bearing silicates such as diopside and wollastonite, and formed by metamorphism of impure limestone or dolomite) and high grade gneiss (metamorphic rock consisting mostly of quartz and feldspar) and schist belonging to the Thimphu Formation (personnel communication by geologist Mr. Indra Kumar Chhetri, 2010).

The soil texture is predominantly silty loam with low coarse fraction (i.e. particles larger 2mm diameter) and with 6-7 cm of humus layer. No details on the soils of Rimchu are available otherwise. All the study plots are generally located on North to Northeast facing slopes. The topography of the study area ranges from relatively flat (10%) to moderately step slope up to 40% in some parts of the study plots.

A generalised rainfall pattern for warm and cool broad leaved forests in relation to an altitudinal gradient is shown in Figure 3-2. Generally, Bhutan falls under monsoon type of climate with rainy seasons starting in June and ending in September. The temperature and precipitation peaks in the months of July and August. The study sites fall under warm to cool broad leaved forests according to the classification by Grierson and Long (1983) which is based on altitude and precipitation and locates warm broadleaved forests between 1000 - 2300m asl) and 2500-5000 mm precipitation per year.

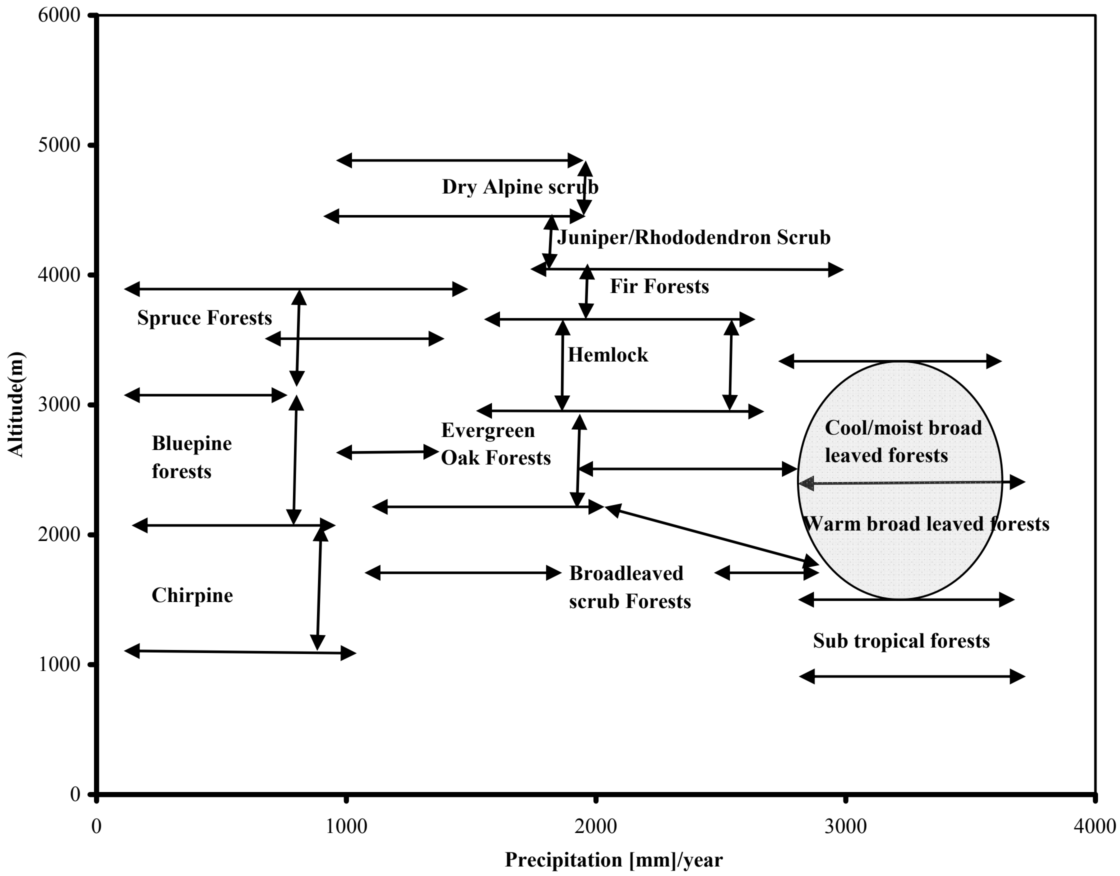


Figure 3-2. Vegetation zones of Bhutan based on the vegetation classification of Grierson and Long (1983), in relation to altitude and precipitation. The shaded ellipse shows the generalised vegetation types of the study area.

Forests are of the evergreen broad leaf forest type with trees species from sub-tropical, warm broadleaved to cool broad-leaved vegetation types based on the classification system by Grierson and Long (1983) . The common genera are *Castanopsis, Alcimandra, Quercus, Elaeocarpus, Michelia, Beilschmiedia, Cinnamomum, Schima, Engelhardtia, Albizia, Carpinus* and others in the canopy layer. The sub-canopy layers are usually also represented by the canopy species and just few tree species are consistently present in the sub-canopy layers. These species are Daphniphyllum *sp*, *Turpinia nepalensis, Macaranga pustulata, Symplocos lucida and Styrax grandiflorus* and the under storey species *Symplocos ramosissima, Maytenus kurzii, Eurya acuminate, all* were consistently present in all study plots. In all the plots the most dominant canopy species is *Castanopsis tribuloides*. Generally, on the wet sites, the area is covered with wild bananas (*Musa sikkemensis).* In the present study sites with bamboo and bananas have been avoided due to the very special site conditions and related forest structure.

3.3 Forest use history of study area

Political administration of Rimchu falls under the Kabjisa geog of Punakha district, however the forest resources are under the administration of Wangdue Territorial Forests Division, where the general administration is done by former and forestry related activities are controlled by the later with its local beat office in combination with a local forestry extension office attached with Kabji geog. The geog office is the local government office that usually has forestry extension staff, agricultural extension and livestock extension offices.

The site was partially logged as a special working circle (small forest management unit especially approved to meet the timber demands of local population for a short time period of maximum 10 years) in some part of the forest area largely around roads which cross through the Rimchu forests (see Figure 3-1) since the late 1980s to meet the timber demands of local population and saw mills (MoA, 1995). The study plots have been chosen in areas not affected by any of these commercial harvesting activities. The commercial harvesting was done by clear felling. The size of the clear felled blocks ranged from 4 ha to 8 ha. In between the felled blocks a chunk of continuous forest approximately at an interval of 100-150 meters was left as cushion against degradation (MoA, 1995). The harvested blocks were planted with five to six species endemic to the Rimchu area. Currently the timber harvesting is done in single tree selection approaches and mostly to fulfill the timber and non timber demands of the local population in the Punakha district. The forest is still accessible by one forest road that provides access to about one-fourth of the total forests area of about 6,800 ha. In the present study the focus was on those parts of the forests where single tree selection by the local people has been the prevalent harvesting system. The detailed criterion for selection of sample plots will be elaborated in the field methods section 4.1.

A socio-economic study in 2001 reported six out of eleven villages under Kabji Geog with approximately 271 households were partly dependent on Rimchu FMU for various needs including grazing, timber, non-timber, and other ecosystem services (Pradhan, 2001). The average family size was 5.8 persons per household (PHC, 2005). The total population estimated in these six villages in 2002 was more than 1500 people. About 14% of the income of the farming communities was reported to origin from forest products (Pradhan, 2001). The same author estimated the cattle population at more than 1400 animals in these six villages. During the field camp in 2008, many fauna species were observed in the forests. These were Himalayan black bear (*Selenarctos thibetanus*), Sambar deer (Cervus *unicolor*) barking deer (*Muntiacus muntjak)*, *Rhesus macaque* and many species birds.

The area has also been used by local farmers of Kabji geog and the monastic body of Punakha Rabney (monastery) for grazing in different seasons for centuries. According to the local people the whole forest area was traditionally divided into three parts regarding grazing rights with the forests close to the villages being allocated to the farmers. Part of the forest grazing area was given to the monastic body of Punakha Rabday and some portion were assigned to graze the village bulls after the time rice had been planted on the fields. The Rimchu study area falls under Rabday and farmers grazing rights areas respectively (Figure 3-1). However the grazing intensity in recent years in the study area was very low at about 1 cattle/ha for about two months per year (research team assessment during the field inventory in December 2008).

During the field data collection it has been observed that the local residents of the Kabji geog and other parts of the Punakha Dzongkhag collect mushrooms, bamboo and cane and other wild vegetables such as edible ferns from Rimchu forests. Furthermore, it has been observed that Rimchu forest is the only forest in Punakha Dzongkhag where access to timber resources is given not only to the local residents (around the periphery of the forests) but also to residents of other geogs and institutions. With the access to the forests by road and limited supply of the timber resources from other parts of the Punakha Dzongkhag there has been moderate pressure on the timber resources from Rimchu forests.

4 Data acquisition

4.1 Plot selection

The data for the entire study were collected from October 2008 to February 2009. Prior to the detailed data collection the site reconnaissance survey was carried out jointly with the local forest managers (territorial division forests office based in Lobesa which has a range office in Punakha and a beat office in Kabji and local people in September 2008. The selection of the study sites were based on more or less natural conditions with low human impacts having single occasional gaps in the canopy, but overall reduction in crown closure not exceeding 20-25%. Additionally, the stumps along a transect of 100 meter length and 20m width were counted. The area which had a minimum of 2 to maximum of 5-6 stumps in the transect of 100 meter was selected for the study.
The reason for selecting plots above and below the road was base on the fact that there were not much areas left which has similar trees species composition and which has more or less been impacted by single tree harvesting by local people. Hereafter the exploratory plots used in analysis are named as Plot A (located below the forest road), Plot B vertically above Plot A, and Plot C in the neighbourhood of Plot B (see Figure 3-2).
The sampling for the biomass allocation study on four important tree species in Rimchu forests was done within the altitudinal range of these exploratory plots. Details follow in data section 4.4.

4.2 Plot establishment

Once representative sites had been selected plots were laid out with minimum plot size of one hectare and approximate quadratic shape whenever possible. Depending upon the site the plot size was adjusted to represent the most homogeneous site conditions in terms of canopy openings, species composition, topography etc. Each plot was further divided into 20m x 20m square grids (see Figure 4-1) following the method described by Schöngart (2008).

The exploratory plots were established as permanent monitoring plots. They were marked at the four corners of the large plot using galvanised iron pipes. The centers of regeneration plots within the large plots were marked temporarily with wooden pegs (Figure 4-1) and Modi thread was used to make the grid as accurate as possible. At the intersection of each auxiliary plot (Figure 4-1, unfilled) small circular sample plots were established (see Figure 4-1) to record the regeneration <5cm DBH at two levels, four meter radius for pole size trees, two meter radius for saplings and seedlings. The same type of sampling was used to record the regeneration around the biomass tree samplings.

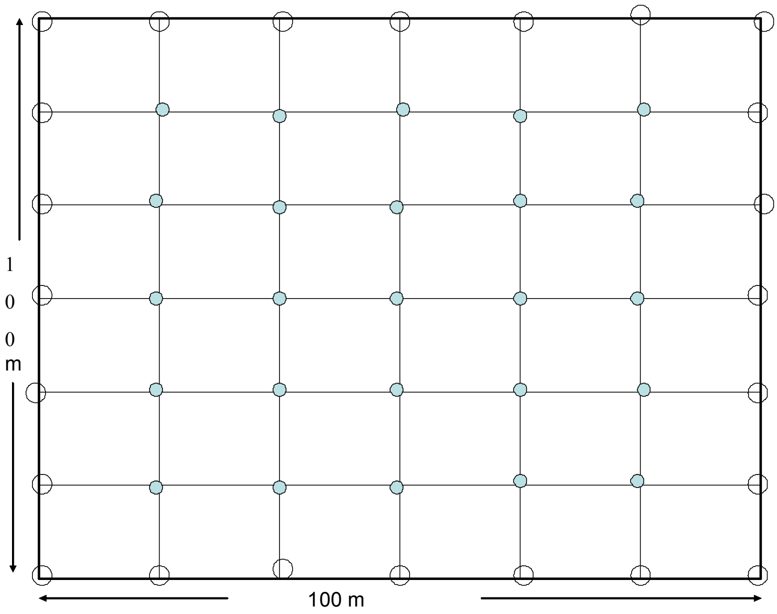


Figure 4-1: Study plot lay out for exploratory plots in Rimchu. The filled circles were regeneration sample plots of radius 4 meter for regeneration <5 cm DBH and >130cm tree height, and 2 meter radius for regeneration <1.3 meter height. Hemispherical photos were taken on both filled and unfilled circles.

4.3 Data collection

4.3.1 Measurements in the exploratory plots

The data collection in the exploratory plots was done through inventory of trees, stumps, snags, deadwood >5cm DBH on the whole plot and regeneration <5cm DBH through sub-sampling of the main plot (see Figure 4-1).

4.3.1.1 Trees, snags and stumps

In the exploratory plots trees >5cm DBH were identified at species level using the flora of Bhutan and a well known botanist, Ms. Rebecca Pradhan and Dr. D.B. Gurung (a lecturer in college of Natural Resources in Lobesa, Bhutan) were consulted for proper validation. A few individuals could not be classified in absence of floral parts and were presented as unknown. The identified trees were marked with aluminium tags with a unique identity number. The DBH was measured using a steel tape at 1.3 meter above the ground from up-slope and an iron pin was dowelled at the point of measurement. The height of the tree and the height to the live crown were measured with the Haglöf Vertex Hypsometer, two crown diameters were measured as well for most of the trees. The timber quality of each tree based on shape and damages was also assessed (Table 4-1). Furthermore, the presence and absence of tree associates such as lianas, orchids, tree ferns, mosses etc. have been recorded. Apart from live trees, all snags and harvested stumps had been recorded. For snags the DBH as well as height was measured, for stumps the height of the stump and diameter at stump height. For both snags and stumps the decay classes (see Table 4-1) were recorded. Trees, snags and stumps were basically segregated into two types according to their origin, that is sprouting and seed-origin. For each of the trees, snags and stumps the local co-ordinates were measured from local reference points.

4.3.1.2 Coarse woody debris

The coarse woody debris (CWD) >10 cm diameter was recorded throughout the exploratory plots following methods described by Manser (1979). The dead wood was classified using the Renvall classification system as cited by Sandström et al (2007) (see Table 4-1). The variables recorded for CWD were the diameter at the tip and the base of the CWD and the length of the CWD. For the completely decomposed CDWs, evidence of the source of CWD was identified (decomposition class 4, Table 4-1), and the diameters were estimated wherever possible, if the source was not evident then such CWD was only counted.

4.3.1.3 Regeneration

A four meter radius was used for recording saplings larger 130cm height and smaller than 5cm DBH, a two meter radius was used for recording seedlings of woody species <130cm height. As far as possible trees were identified up to the species level, those that could not be identified were presented as unknown species. For each species >10cm and <5cm in DBH, the DBH or collar diameter, height and lateral crown dimensions were recorded. The frequency per species was recorded for those seedlings below 10cm height. The vitality of seedlings was assessed using the slightly modified visual criteria by Carter and Klinka (1992). The classes were as shown in Table 4-1.

Table 4-1: Definition and classification of some variables recorded in the exploratory plots.

Variables	**Definition and characterization**
Tree quality (alive trees larger 5cm DBH)	• Good tree (GT): straight stem, healthy, without sign of damages, • Poor Trees (PT): forking, bending and signs of any damages
Diameter of stumps (from harvests)	Mean of maximum diameter and diameter perpendicular to it; at stump height and at height 30cm above the ground
DBH of snags (natural tree mortality)	DBH or diameter at snag height if below 130cm height
Decay classes of coarse woody debris (CWD) (>10cm diameter)	• Class 1: Solid dead wood. The volume of the stem consists 100% of solid wood and the stem has a hard exterior surface. The wood is not at all affected by wood decaying organisms. • Class 2: Solid dead wood. The volume of the stem consists more than 75- 90% of solid wood and the stem has a hard exterior surface. The wood is to a small extent affected by wood decaying organisms. • Class 3: Decayed dead wood. The volume of the stem consists to 26–75% of soft or very soft wood. • Class 4: >Decayed dead wood. The volume of the stem consists of >75% of soft or very soft wood.
Vitality of seedlings (10cm < height <130cm)	Vitality 1: dead individuals Vitality 2: seriously declining vitality, sapling not expected to survive more than two years and is of very poor vigour with typical symptoms including poor foliage retention, dieback of leading shoots, arrested growth or loss of apical tendency. Vitality 3: declining vitality, sapling is of poor vigour usually showing many of the symptoms described above but continues to produce new foliage and annual increment. Vitality 4: medium vigour, sapling is of medium vigour showing poor height and diameter growth but little or none of the symptoms as described above. Vitality 5: sapling is of good vigour showing adequate height and diameter growth and none of the symptoms described above. Vitality 6: sapling is of very good vigour showing height and diameter growth commensurate with site quality and none of the symptoms described above.

4.3.1.4 HemiView pictures

To quantify the light environment for the recorded regeneration a digital camera with fish-eye lens (Canon EOS 5D Digital, Canon Inc. Japan) was used to take hemispherical photographs of the canopy from the height of 1.3m above the ground from the center of the regeneration subplots

4.3.1.5 Other micro-site characteristics

The microsites were recorded for each of the regeneration plots by the presence and absence of ground vegetation (GV). Since it was not possible to identify all the GV species to species level in the short period of time available for the field data collection, the species were grouped into functional group as climbers, graminoids, ferns, forbs, mosses, shrubs and succulent. Two genera that were particularly prominent were retained as *Rhaphidophora spp* and *Pipers spp*. For each of the samples plots site attributes such as altitude [m], slope [%] slope position, fine woody debris , humus depth etc. were recorded. The inventory sheets are enclosed in the Annex 3.

4.4 Biomass of young trees

To study the allocation pattern of biomass four tree species were chosen that represent certain ecological characteristics with in broadleaved forests. The species were (1) *Castanopsis tribuloides* (Smith) A.DC. (Ct). This species was found to be very dominant all over the Rimchu study area, (2) *Cinnamomum bejolghota* (Hamilton) Sweet, (Cb). This species appeared to be mostly a co-dominant species; (3) *Macaranga pustulata* Hook.f. (Mp). This species was found to be a vital pioneer species in open areas, and (4) *Symplocos ramosissima* G.Don. (Sr). It grows from an altitude of 1600-2560m a.s.l. (Grierson and Long 1999) and occurs in cool broad leaved as well as in oak forests in Bhutan. This species was seen as a very prominent understorey species. It was found from very poor light to open canopy environments.

4.4.1 Selection of saplings

Young trees of these four species growing under the canopy were selected with DBH of selected trees ranging from 2-5cm and height from 2-7m. The samples were chosen randomly along transects in the area of the exploratory plots (but not from within the exploratories) as described earlier. A minimum of 15 meter distance between sampled saplings was maintained. Additionally, the sampling was restricted to areas with no signs of major disturbances for at least the past 8-10 years (no stumps, broken trees etc.) within 30 meters of the sample tree. Twenty (20) trees were selected from each species.

4.4.2 Biomass measurements

Henceforth the sampled trees are called biomass trees (BT). Once a BT was selected its total height (H), collar diameter (Dcoll), diameter at 10 cm above ground (D10), diameter at breast height (DBH) at 1.3 meter above the ground, crown length (CL) and crown width (CW) were recorded. After recording all vital parameters the BT was cut 10cm above the ground and carried to the camp site where the aboveground biomass was separated into stem, branch and leaf biomass and total fresh weight of the biomass compartments was taken with an electronic balance The electronic balance was stationed at the camp site and was powered with a small portable power generator. Once all fresh weights were taken for the three components, composite sub-samples were extracted for stem (SFWcs), branch (BFWcs) and leaves (LFWcs), respectively. A stem disc at D10 was taken for tree ring counts from each BT.

4.4.3 Characterisation of neighbourhood

All the competing trees surrounding the BTs along with their height, collar diameter, DBH (if applicable), crown length and width were recorded within two concentric plots. The trees those were taller than 130cm were recorded at four meter radius, trees below 130cm at two meter radius, respectively. The detailed characterization of neighbours of the BTs is presented in the data preparation section. Additionally, at the height of the upper third of the crown of each BT a hemispheric photo was taken.

4.4.4 Laboratory analysis

The biomass samples from the tree compartments were taken to the laboratory in order to determine the oven-dried weights for each component. The biomass samples were oven dried in the facilities of the Renewable Natural Resources Research Centre at Bajo at 62°C to constant weight. Accordingly, oven-dried weights for each component (stem oven dried weight (SODWcs), branch oven dried weight (BODWcs) and leaves oven dried weight (LODWcs) was obtained.

4.5 Tree ring samples

The coring of broad leaved trees posed great difficulties in getting the materials for tree ring counting and measurement. Discs from stumps and fallen trees from within the altitudinal range of our study site from 12 key tree species (representing different canopy layers) were taken for tree ring analysis. A total of 47 discs were collected from 12 species with varying sizes. The discs were marked and put into paper bags and taken to the laboratory. The details of the tree ring measurement and ring analysis are elaborated in data preparation section

4.6 Data preparation

4.6.1 Exploratory plots

The field measurement alone was not sufficient to acquire the complete set of data for further statistical analysis. The following sub-sections elaborate the workflow for the further preparation of the data set.

The coarse woody debris (CWD) was quantified as volume [m^3/ha] categorised by species, decay classes and causes of tree death. The volume of CWD was calculated using Smalian´s formula (Avery 1994) as shown in Eq. (1).

$$CWD = \frac{Db + Ds}{2} * L \qquad (1)$$

Where Db is the cross-sectional area at the strong end of CDW, Ds is the cross-sectional area at the smaller end of the CDW and L is length of the CDW.

The regenerations from samples plots of exploratory were classified by height classes in 10 layers in cm (<10cm, 10-30cm, 30-50cm, 50-80cm, 80-130cm, 130-200cm, 200-300cm, 300-400cm, 400-500cm and >500cm height and <5cm DBH).

4.6.2 Characterisation of neighbourhood of biomass trees

To characterize the lateral competition by neighbouring trees the crown projection area (CPA) of the seedlings and saplings surrounding the biomass tree (BT) was calculated using Eq. (2). Table 4-2 shows all variants of the CPA index used in the analysis.

$$CPA = \pi * (\frac{CD}{2})^2 \qquad (2)$$

CPA = crown projection area of an individual tree
CD = crown diameter

Table 4-2: Lateral competition indices based on ac cumulated crown projection area of neighbouring seedlings and saplings.

Index	**Characterization**
CPA1	Total Crown projection area of trees taller 130cm and smaller then (height of biomass tree + 15cm) per unit plot area (plot radius = 4m);
CPA2	Total Crown projection area per un it plot area of trees between 10cm and 130cm height (plot radius = 2.0m)
CPA3	CPA1 + CPA2
CPA4	Total crown projection area per unit plot area of all saplings >130cm height and < 5cm DBH within 4 meter radius including individuals taller than in CPA1.
CPA5	CPA4 + CPA2

4.6.3 Biomass compartments of young trees

The ratio of fresh weight to oven-dried weight for stems, branches and leaves were calculated from samples and app lied to es timate the total ov en-dried biomass for each biomass component according to Eqs. (3) to (5). The total oven-dried biomass (TDW) for a tree was calculated as sum up of all the three components (Eq. 6).

$$SDW = \frac{SDWs}{SFWs} * SFW \qquad (3)$$

SDW = total stem dry weight [grams]
SDW_s = stem dry weight of sample [grams]
SFW = total stem fresh weight [grams]
SFW_{cs} = stem fresh weight sample [grams]

$$BDW = \frac{BDWs}{BFWs} * BFW \qquad (4)$$

BDW = total branch dry weight [grams]
BDW_s = branch dry weight od sample [grams]
BFW = total fresh branch weight [grams]
BFW_s = branch fresh weight of sample [grams]

$$LDW = \frac{LDWcs}{LFWcs} * TLFW \qquad (5)$$

LDW = total leaf dry weight [grams]
LDW_s = leaf dry weight of sample [grams]
LFW = total leaf fresh weight [grams]
LFW_s = leaf fresh weight of sample [grams]

TDW= $TDW = SDW + BDW + LDW$ (6)

4.6.4 Tree morphological attributes

To characterize tree morphology a set of indicators was calculated (Table 4-3). Effective height is an expression of biomass allocation to the shoot; the relative crown length is a cumulative indicator of competition experienced in the past. The ratio of height and diameter also represents the effect of past cumulative competition.

Table 4-3. Tree morphological indicators.

indicator	formula	characterization
effective height	$H_{eff} = a_0 \cdot TBM^{a1}$	Height per unit biomass
relative crown length	$RCL = \frac{CL}{H} \cdot 100$	Relative length of live tree crown
h/d - ratio	$HDR = \frac{H}{DBH} \cdot 100$	Slenderness
Mean diameter growth rate	$\overline{DGR} = \frac{D}{age}$	D10 or DBH divided by tree age
Mean height growth rate	$\overline{HGR} = \frac{H}{age}$	Total height divided by tree age

4.6.5 Analysis of HemiView pictures

The HemiView pictures taken at each regeneration subplot within the exploratory plots as well as for each BT were analysed using Hemiview Canopy Analysis Software Version 2.1 (Delta-T Devices, 1999). The software allows to calculate the gap fraction (i.e. the proportion of visible sky within a given sky sector). A gap fraction of zero means that the sky was completely blocked and gap fraction of 1 means that the sky was completely visible (Rich et al, 1999). Furthermore, Global Site Factor (GSF) and Diffuse Site Factor (DSF) were calculated for each BT. The GSF is the proportion of global radiation under a plant canopy relative to that in the open. It is calculated as direct plus diffused radiation (weighted) with reflected radiation ignored. DSF (direct solar radiation) and ISF (diffuse solar radiation) are the proportion of direct solar radiation reaching a given location, relative to that in a location with no sky obstructions. For all indices, GSF, DSF and ISF the values range from 0 to 1.0 being completely dark with full sky obstruction and 1 completely no obstruction.

4.7 Tree ring analysis

The discs from BTs were sun-dried and sanded using sand papers of 80 and 120 grit sizes. The rings were counted in the tree ring laboratory in RNR RC Jakar. In case of doubtful rings samples were taken to BOKU and tree ring experts from the Institute of Botany were consulted to count the rings properly. Some rings that were problematic with lots of wedge and indistinct annual rings were dropped from the study. The same laboratory was used for measurement of radial increment from bigger tree sample discs. Forestry research staff of RNR RC Jakar did the entire tree ring preparations and measurement. The measured parameter was annual radial increment. The measurements were done on two cross section of the disc and average of the two cross section was taken as the final increment. The measurement was done from the outermost ring towards the pith. As far as possible discs were measured upto the pith from the outer most rings, where there were excessive wedge rings, the sample was dropped from measurement.

Figure 4-2: Tree ring measurement in Renewable Natural Resource Research Centre at Jakar, Bumthang. Mr.Tsewang Dorji, Research Assistant, in picture.

4.8 Household survey

Finally, a household survey was done to collect socio-economic data from villages around the study site. The household survey was conducted in 10 villages, representing more than 80 % of the villages under Kabji geog of Punakha district. In total 39 households were selected (ca.9 %) of the total household in the geog). The respondents of varying age groups ranging from 19 to 69 years old from selected households were interviewed using questionnaires provided in Annex 5. Prior to selection of interviewees the administrative head of each village was informed through Gup (head of the local government office) of Kabji geog regarding the interviews. The village head was consulted about the background of the interviewees and four to five households per villages were selected based on income (1) low income household, (2) medium income households, and (2) high income household, at the same time the name of the interviewee was identified and was informed of the date and time of the interviews. A team of seven people from local government office and territorial division were dispatch to conduct the interviews. The information collected during the interviews were general bio data, household information, household land uses, income/livelihood sources, forests products requirements (past five years and future five years) trees species preferences by sizes and general perceptions of people on the current forest management. The copy of the questionnaire of the household survey is provided in the Annex 5.

5 Data analysis

5.1 Exploratory plots

5.1.1 Structure and composition

In this study the species composition was quantified by several approaches: (a) counting the number of species per plot, (b) using stem density (stems/ha) and basal area (m^2/ha) by species, and (c) share in crown projection area by species group was also used as stand characteristic. To quantify species diversity the Shannon-Weaver index (Eq. 7) and the Evenness (Eq. 8) have been used, species similarity or differences by Jaccard (IS_j) and Sorensen (IS_s) similarity indices (Eq. 9-10) (Dombois and Ellenberg 1974).

$$H = -\sum_{i=1}^{n} \frac{n_i}{N} \cdot \ln \frac{n_i}{N} \tag{7}$$

Where n (i) are the individuals of a species in a sample and n(i) is the total number of all individuals of all species, ln is the natural logarithm and where S is the number of species in a sample.

$$E = H / \ln S \tag{8}$$

$$ISj = \frac{C}{A+B+C} x100 \tag{9}$$

Where C is the number of common species in two samples ISj is the Jaccard similarity coefficient; A is the number of species unique to a plot or site and B the number of species unique to second plot or site. ISj is based on the presence-absence relationship between the number of species common to two sample plots and the total number of species, ISj therefore is the ratio of the common species to all species in two samples plots.

$$ISs = \frac{2C}{A+B} x100 \tag{10}$$

Where C is the number of common species in two sample plots/sites; A is the total number of species in a plot or site and B is the total number of species in second plot or site. ISs is the Sorensen similarity coefficient which is the ratio of the common species to the average number of species in two sample plots.

Distribution of stem numbers and basal area over diameter classes was used to assess stand structure. The vertical stand structure was characterized by calculating species shares in three relative height classes (each 1/3 of stand top height) by stem numbers and basal area as well.

5.1.2 Relationships of regeneration and micro site characteristics

In order to analyse the relationships of regeneration and micro site characteristics multivariate gradient analysis methods were used (Leps and Smilauer 2003, TerBraak 1985, Legendre and Legendre 1998). Firstly, detrended correspondence analysis (DCA) was used as an indirect gradient analysis and then the contribution of site and environmental factors in explaining the ordination axes was assessed using the direct gradient technique redundancy analysis (RDA). Ordination diagrams were employed to support the interpretation of differences in behaviour between the species.

Details on the employed analysis methods can be found in section 5.3.

5.2 Biomass and dimensional analysis in saplings

5.2.1 Biomass functions

For the regression of biomass versus other attributes the data were checked for possible outliers and normality tests were performed for the data. The heteroscedasticity did occur in the data set; therefore the data were linearised by logarithmic transformation using natural logarithms (Ln), following the procedures (e.g. Brown et al. 1989, Zianis and Mencuccini 2004). Two types of equations for each tree component were developed. Firstly, biomass of each component was estimated as function of DBH as only predictor variable (Eqs. 11 and 12; Peichl and Arain 2007). Second, the biomass compartments were estimated from a combination of DBH and additional explanatory variables as shown in Eq. (13).

$$y = a_0 \cdot DBH^b \tag{11}$$

$$\ln(y) = a_0 + b_1 \cdot \ln(DBH) \tag{12}$$

$$\ln(y) = a_0 + b_i \cdot \ln(x_i) \tag{13}$$

Y is the total oven-dried biomass of total biomass (TBM), stem (STBM), branch (BBM) or leaf (LBM) compartment, a_0 is the constant and $b_{(i)}$ is model coefficients for the predictor variables. In the analysis tree diameter at breast height (DBH), diameter 10cm above the ground (D10), collar diameter (Dcoll), tree height, tree crown length (CL) or tree crown width (CW) were tested. Those models were selected which showed the best fit regarding the residual pattern and maximized the coefficient of determination (r^2). The residuals were analysed using graphical methods with standardised residual values as abscissa and standardised predicted values as ordinate, respectively. The reason for applying two equations was to see if the biomass components could be explained sufficiently with the standard variable DBH alone.

For Eq. (13) the biomass components were step wise regressed against height (H), collar diameter (Dcoll), Diameter 10 cm above ground (D10), crown length (CL) and crown width (CW). The collinearity between independent variables was checked using the variance inflation factor (VIF). When VIF > 5 there is considerable multicollinearity and the standard error of the regression coefficients will be inflated (SPSS 2009).

5.2.2 Dimensional analysis

For the analysed species further dimensional relationships were analysed. Height development in relation to diameter as well as crown width in relation to diameter are frequently used indicators of tree morphology. Furthermore, the development of DBH as well as height in dependence of age was analysed by means of regression models.

5.2.3 Relationships between tree morphology and light and lateral competition indices

Univariate correlation analysis was conducted to explore relationships between light indices as an indicator of overhead competition and with lateral competition indices integrating the effect of neighbouring seedlings and saplings and tree morphological variables (height of biomass saplings in 2008, the last year shoot increment, DBH, relative crown length, CW, branch and leave mass fractions, H/D – ratio, etc.).

In order to further analyse the relationships of sapling morphology and light and lateral competition indices multivariate gradient analysis methods were used (Leps and Smilauer 2003, TerBraak 1985, Legendre 1998). Firstly, detrended correspondence analysis (DCA) was used as an indirect gradient analysis and then the contribution of site and environmental factors in explaining the ordination axes was assessed using the direct gradient technique redundancy analysis (RDA). Ordination diagrams were employed to support the interpretation of differences in behaviour between the analysed species.

Details on the employed analysis methods can be found in section 5.3.

5.3 Multivariate ordination

Regression approaches (GLM, OLS regression models) relating a single response variable and one or more predictor variables had been tested , too. However, due to the complexity of the data sets and the inherent variability in the data these methods did not reveal relevant significant findings.

In trying to explain the pattern of regeneration within the exploratory plots in relation to microsite characteristics as well as to explore sapling morphology in relation to overhead and lateral competition multivariate ordination techniques have been employed. From the toolbox of available ordination analysis (e.g., TerBraak, 1985; Legendre and Legendre 1988, Leps and Smilauer 2003) indirect and direct gradient analysis techniques were employed in the analysis. The general goal of ordination is to find the axes of the greatest variability in the data set (i.e. the ordination axes) and to visualize the data structure (i.e. to reveal the similarity structure of the analysed variables). Indirect ordination techniques (e.g. PCA, DCA) are applied when no explanatory variables are available which may explain (i.e. correlate) the ordination axes. Direct (constrained) gradient analysis (e.g. RDA) is used when such explanatory variables have been measured and can be sued to find the variability in response variables which can be explained by the measured environmental variables.

In the current study detrended correspondence analysis (DCA) as indirect method and redundancy analysis (RDA) as direct constrained method were used.

The detrended correspondence analysis (DCA) (Hill and Gauch 1980) is an eigenvalue ordination technique based on reciprocal averaging (Hill 1973). DCA is used to analyse the species composition data sets based on species presence and absence. The DCA ordinates both species and sample scores simultaneously. The scores refer to beta diversity (i.e. the length of the gradient). It is a measure of how different samples are from each other, and how far apart they are on gradients of species composition (Økland et al, 1990). This is done by dividing the first axis into segments, then setting the average score on the second axis within each segment to zero (Leps and Smilauer 2003). The tendency to compress the axis′ ends relative to the center is also corrected with DCA and is done by rescaling the axis to equalize as much as possible the within-sample variance of species scores along the sample ordination axis. The DCA uses a chi-squared distance measure. The species abundance data was log transformed before running the ordination analysis so that an abundance y = 0 is transformed into y' = log (0 + 1) = 0 for any logarithmic base.

Redundancy analysis (RDA) was performed as a direct ordination, assuming linear relationships between species performance and explanatory variables (Leps and Smilauer, 2003). The explanatory variables were standardized before the analysis. In direct ordination the explanatory variables were selected by manual forward selection. The effect of explanatory variables was tested by F-statistics via Monte-Carlo simulation, the number of permutations was 999, the accepted significance level was 0.05 (ter Braak and Smilauer, 2003). The significance of the canonical axes was tested in a similar way.

The relationship between the response variables and explanatory variables were mainly inferred from their pattern in the response-sample (site) biplots (and tri-plots respectively) of the RDA. From the position of the variables on the ordination diagram the similarity between them can be inferred (i.e. proximity is similarity). The ordination arrows are another means of interpretation. If the arrow of explanatory variables points in similar directions to a response variable arrow, the values of that response variable are positively correlated with the values of the predictors whereas the response variables with a large negative correlation are predicted to have arrows pointing in opposite directions.

The approximation of correlation in the predictor variables can be judged using the angle between arrows of predictors. Small angles between variables showed high correlation and wide angle show poor correlation and perpendicular angle showed no correlations (Leps and Smilauer, 2003).

5.4 Local demand of forests products from household survey

The societal demand of forest products in the vicinity of the study area for last five years and projected demand for future five years were accessed and accordingly the per household per year and per person per year demands were calculated using equations 14 and 15. Further the demand for forests products were ranked according to people's preferences and finally the non –wood forest produces were ranked and assessed for their importance for household economy.

$$\overline{HH_{FPC}} = \frac{\frac{\sum n}{\sum hh}}{Time\left[years\right]}$$

Average household trees/wood consumption (14)
Where hh= number of sample households, n= number of trees of different sizes used by or will be using by the sample local people of Kabjisa geog under Punakha district, $\overline{HH_{FPC}}$ = forest products consumptions rate per household per year.

$$\overline{PC_{FPC}} = \frac{\frac{\sum n}{\sum hhm}}{Time\left[years\right]}$$

Per capita trees/wood consumption (15)
Where n= number of trees of different sizes used by or will be using in future by the sample population, hhm = number of members in the households from sample survey, $\overline{PC_{FPC}}$ = forest products consumption rate per person per year.

5.5 Equilibrium diameter distribution model

In uneven aged silviculture there exist several conceptual models which describe the steady state condition of a managed forest according to single tree selection methods. These models usually characterize the "equilibrium" state of a forest by means of the diameter distribution. All these models are essentially based on work by de Liocourt (1899), Meyer (1933) and Biolley (1901) in France, Switzerland, and Germany. In these studies, the diameter distribution of a unevenaged forest in a steady state was characterized by a power function with the coefficient between 1.3 and 1.5. In North-American literature the q-value approach is a direct descendent of this approach (Davis et al, 1987). The q value is the model coefficient which determines the decrease in stem numbers per hectare with increasing tree diameter.

In Central Europe Prodan (1949) and later Schütz (1989) developed that idea further. Both concluded that the model proposed by deLiocourt and Meyer was too simplistic. Both authors state that in addition site conditions, silvicultural treatment (i.e. the removals) and the management goals need to be considered as well.

Core element of the concept is the idea that the steady state is maintained as long as ingrowth and outgrowth plus removals and natural mortality in any given size class is balanced. This assumption results in a stable diameter distribution. According to Prodan (1949) this can be formulated with Eq. (16).

$$X_{i-1} = X_i \cdot \frac{z_i}{z_{i-1}} + \frac{m_i}{z_{i-1}} \cdot \frac{b}{T} \tag{16}$$

X_i = stem number in DBH class (i)
z_i = diameter increment in DBH class (i) in period (t)
m_i = removal and natural mortality in DBH class (i) in period (t)
b = width of DBH class
T = period (t)

The management goals are defined via the target diameter, the target growing stock as well as the distribution of removals over the size classes. Prodan (1949) clearly distinguished between the “optimal” target steady state and the provisional steady state. The optimal conditions allow to maintain the removals with respect to volume as well as with respect to size distribution. The cuts at the end of a period set the structure back to the initial structure at the beginning of the period. The current removals aim at the establishment of the “optimal” steady state condition. From this it follows that the provisional steady state is actually not a steady state in a strict sense, as the change in stand structure will affect the increment in the size classes and thus the resulting equilibrium diameter distribution. This basic concept was also supported by Mitscherlich (1952).

Schütz (1989) proposed a slightly different approach based on ingrowths and outgrowth rates. In addition he explicitly formulated three preconditions for the sustainable maintenance of the steady state.

(1) ingrowth = outgrowth plus removals (including natural mortality)

(2) to maintain the steady state structure a minimum ingrowth in the smallest size class is required. The ingrowths in the smallest size class (i.e. recruitment) depends strongly on the accumulated growing stock.

(3) Volume removal = volume increment

Precondition (3) differs from the concept by Prodan (1949) insofar that during the convergence phase towards the steady state according to Prodan removals can be higher or lower than the periodic increment. Schütz (1989) and Prodan (1949) agree that the steady state concept should be seen as a guideline not a strict operational management plan. Thus, the value of the equilibrium diameter distribution model lies in the analysis of possible steady state conditions and the resulting implications on service provision and ecological constraints.

Crucial point in the overall conceptual framework is that changing stand structure will affect the diameter increment (e.g. Yue et al. 1997, Spiecker 1991). Thus, the greater the distance of the initial stand structure from the steady state target structure the higher the uncertainty introduced by the diameter growth model. As long as no dynamic model approaches to update the diameter growth in dependence of varying stand structural attributes are available for a given forest type an iterative planning approach of monitoring and updating the equilibrium model is imperative.

5.5.1 Model set-up for broadleaved forests in Rimchu

In order to implement an equilibrium diameter distribution model sensu Prodan (1949) and Schütz (1989) for broadleaved forests in Rimchu the following elements will be combined:

(i) The initial forest state was derived from the three large exploratory plots in Rimchu.

(ii) Diameter growth in each DBH class was derived from tree ring analysis of 26 stem disc samples collected from the sampling area in Rimchu (see sections 4.5 and 4.7). Species were grouped based on ecological behaviour.

(iii) Removal rates were inferred from a stump inventory in the exploratory plots. Assuming that based on local experience a stump will decompose within 10-15 years a removal rate can be calculated.

(iv) Natural mortality was estimated from snags in the exploratory plots and the assumption that snags are downed and decomposed within 10-15 years after tree death.

(v) Additional information for the definition of possible removal rates was derived from the results of a household survey in the region (see section 4.8). Particularly the demand for different species and size classes can be better characterized from these data.

6 Results

6.1 The structure and composition of broadleaved forests in Rimchu

6.1.1 General characteristics of the exploratory plots

The general characteristics of the three exploratory plots are listed in Table 6.1-1. The study plots were located from 1610 masl up to 2060 m asl on North to Northeast facing slopes; the slope of the plots varies from 15-25 %. Depending upon the situation, the shape of the plots was adjusted: Plot A was L-Shaped in order to avoid the marshy area towards its south east side), Plot B was square shaped, and Plot C was of rectangular shape. Each of theses plots represents 1 ha forest area. The stem density of trees >5 cm DBH differed between plots, the maximum DBH of the biggest tree was >160 cm on all plots.

Table 6.1-1. General characteristics of the three exploratory plots in Rimchu. R-ratio = ratio of species number in the canopy and in the regeneration layer.

Attributes	Plot A	Plot B	Plot C
Altitude [m]	1610-1760	1980-2060	1970-2050
Aspect	North East	North East	North East
Slope [%]	20-25	15-20	20-25
Area [ha]	1 ha	1 ha	1 ha
Shape	L-shape	Square	rectangular
Stems/ha	461.0	398.0	536.0
Basal area [m^2/ha]	41.92	40.39	38.65
DBHmax [cm]	181.3	197.0	166.0
Height max [m]	49.0	49.0	46.0
Quadratic mean diameter [cm]	34.03	35.95	30.31
Mean height [m]	15.42	14.58	16.31
R-ratio	0.58	0.46	0.60

The trees larger 5cm in DBH in each plot were spatially mapped using local coordinates (Figures 6.1-1 to 6.1-3). Species were grouped with regard to regional timber value. The related information had been gathered during a household survey in the region and reflects the needs and habits within the region and not necessarily the national tree species-grading scheme. The plots indicate a vertically and horizontally heterogeneous and complex stand structure. For additional stand-level characteristics see Table 6.1-2.

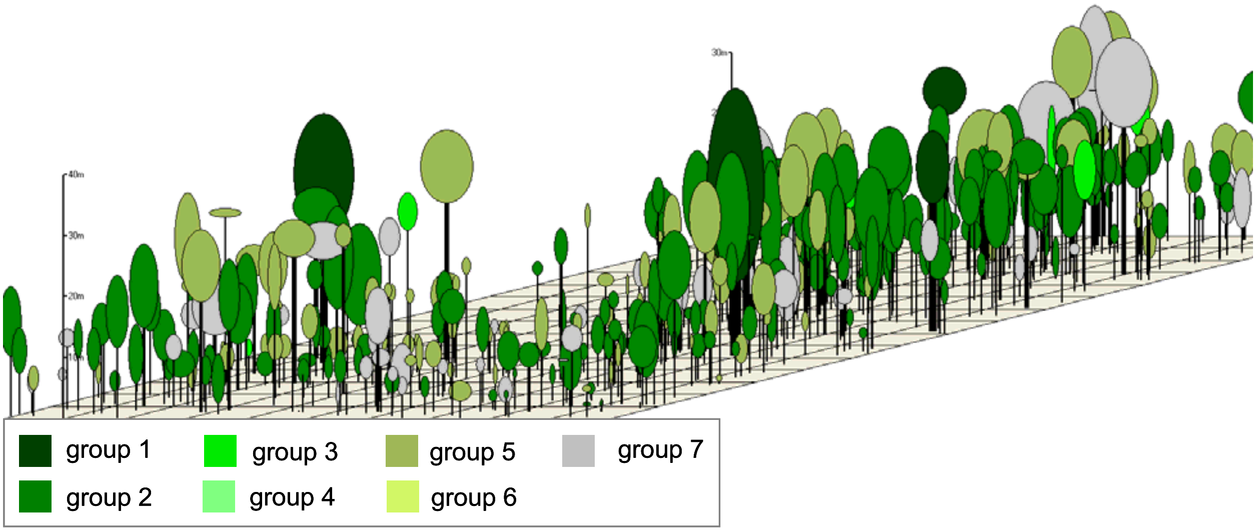


Figure 6.1-1: Spatial distribution of trees in Plot A. One gridcell in the plot represents a 10x10m patch. The different colors represent different timber value categories. Group 1 = most preferred timber species, group 6 = least preferred timber species, group 7 = not preferred as timber species. The complete list of tree species according to this ranking is provided in Table 6.1-3.

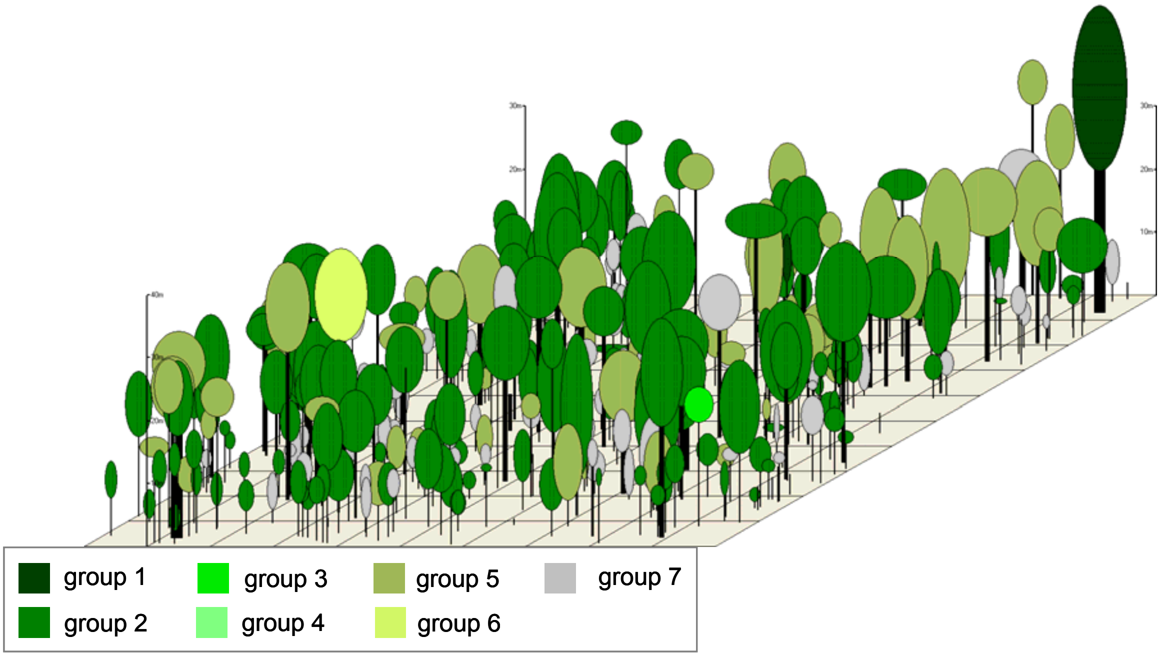


Figure 6.1-2: Spatial distribution of trees in Plot B. One gridcell in the plot represents a 10x10m patch. The different colors represent different timber value categories. Group 1 = most preferred timber species, group 6 = least preferred timber species, group 7 = not preferred as timber species. The complete list of tree species according to this ranking is provided in Table 6.1-3.

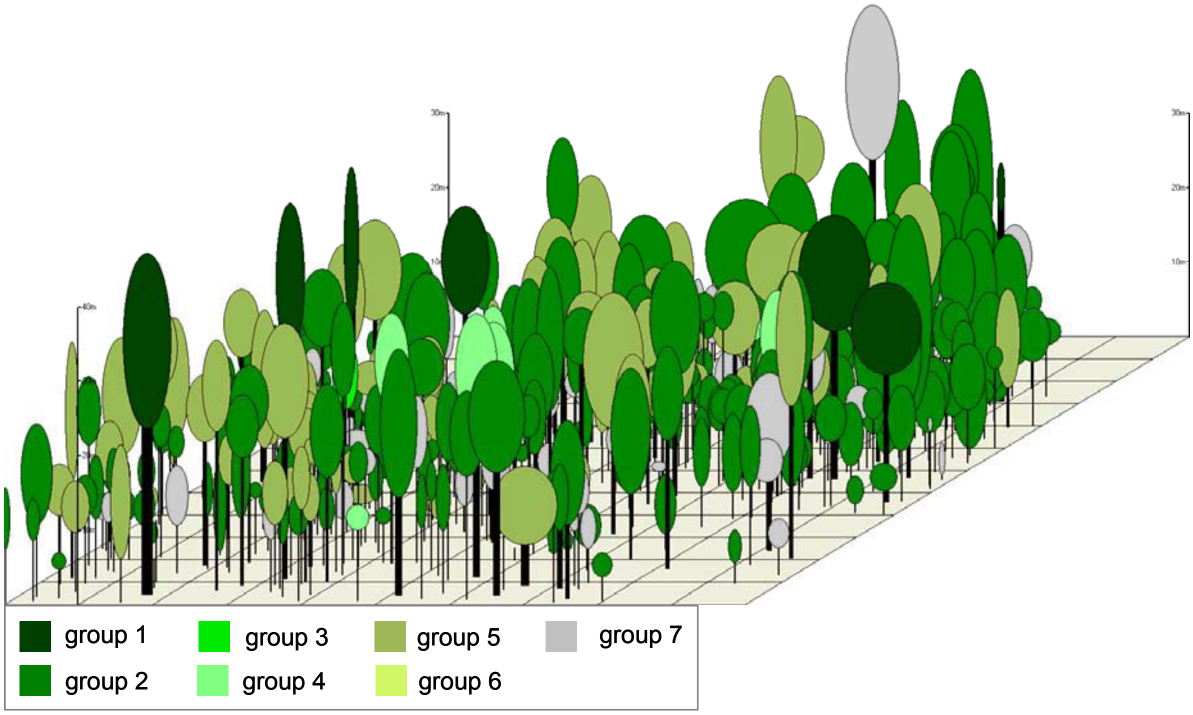


Figure 6.1-3: Spatial distribution of trees in Plot A. One gridcell in the plot represents a 10x10m patch. The different colors represent different timber value categories. Group 1 = most preferred timber species, group 6 = least preferred timber species, group 7 = not preferred as timber species. The complete list of tree species according to this ranking is provided in Table 6.1-3.

Table 6.1-2. General stand characteristics of exploratory plots in Rimchu. BA = basal area [m^2/ha], CPA = crown projection area [m^2/ha], Dg = quadratic mean diameter. Group 1 = most preferred timber species, group 6 = least preferred timber species, group 7 = not preferred as timber species. The complete list of tree species according to this ranking is provided in Table 6.1-3.

Group	Attributes	Plot A	Plot B	Plot C
1	N/ha	252.00	215.00	307.00
	BA	14.37	20.21	14.57
	CPA	11143.21	11645.00	17109.90
	Dg	26.95	34.60	24.59
2	n/ha	4.00	2.00	7.00
	BA	7.50	3.10	6.77
	CPA	1281.77	591.04	1628.07
	Dg	154.55	140.52	111.00
3	n/ha	9.00	1.00	1.00
	BA	0.44	0.08	0.14
	CPA	374.59	25.52	73.90
	Dg	24.96	31.92	42.23
4	n/ha	-	-	8.00
	BA	-	-	2.00
	CPA	-	-	825.40
	Dg	-	-	56.43
5	n/ha	-	1.00	-
	BA	-	2.04	-
	CPA	-	176.71	-
	Dg	-	161.21	-
6	n/ha	135.00	72.00	114.00
	BA	12.57	12.86	12.20
	CPA	4497.35	4431.11	7919.54
	Dg	34.44	47.70	36.92
7	n/ha	60	107	100
	BA	7.10	2.09	2.95
	CPA	2560.85	2573.23	3209.38
	dg	38.83	15.77	19.39
Total	n/ha	460.00	398.00	537.00
	BA	41.98	40.38	38.65
	CPA	19857.76	19442.61	30766.18
	Dg	34.03	35.95	30.31

6.1.2 Species composition

A total of 52 species (trees >5 cm DBH) that belong to 43 genera and 29 families was enumerated in the three one-hectare exploratory plots in Rimchu. *Castanopsis tribuloides* accounted for more than 50% of the relative density (RD) (Nebel et al. 2001) in all three plots in Rimchu. Eight to nine tree species accounted for more than 90% of cumulative relative density (CRD) (Figure 6.1-4, upper panel). The details are included in Annex 1.

In Plot A, *Castanopsis tribuloides*, *Cinnamomum bejolghota, Macaranga pustutlata, Quercus glauca, Turpinia nepalensis, Symplocos lucida, Sloanea tomentosa, Carpinus viminea*, *Elaeocarpus lanceifolius*, *Eurya accuminata, Cryptocarya bhutanica, Engelhardtia spicata* are the most dominant species with regard to number of individuals and accounted for 90% of the species composition of the stands.

While in Plot B Castanopsis alone accounted for 54% of the species CRD, other species such as *Symplocos ramosissima, S. lucida, Cinnamomum impressinervium, Cordia obliqua, Hovenia acerba, Daphniphyllum chartaceum* and *Elaeocarpus lanceifolius* added up to more than 90% of the CRD.

In Plot C *Castanopsis tribuloides* accounted for 56% of the CRD and other species such as *Symplocos ramosissima, Turpinia nepalensis, Quercus glauca, Elaecocarpus lanceifolius, Styrax gradiflorus, Cinnamomum bejolghota, Cinnamomum impressinervium, Alcimandra catcarthii* accounted for more than 80% of the CRD (Figure 6.1-4, upper panel).

The relative dominance (Nebel et al. 2001) of the tree species is shown in terms of relative basal area (RBA) in Figure 6.1-4 (lower panel). *Castanopsis tribuloides* remained dominant species in all the plots, it accounts for 34% in Plot A, 50% in Plot B and 37 % in Plot C respectively. However, the species that were frequent in terms of relative stem density were not dominant in terms of relative basal area. *Alcimandra catcarthii*, *Engelhardia spicata*, *Sloanea tomentosa, Elaeocarpus lanceifolius, Schima wallichi, Cryptocarya bhutanica, Turpenia nepalensis and Quercus glauca* formed the most dominant group in Plot A and these species along with *Castanopsis tribuloides* accounted for 90% of the basal area in Plot A. In Plot B, *Cordia obliqua, Alcimandra catcarthii, Michaleia valutina, Beilshmiedia gammieana, Hovenia acerba, Elaeocarpus lanceifolius, Cinnamomum impressinervium* accounted for 90% of the basal area. In Plot C, *Alcimandra catcarthii, Elaeocarpus lanceifolius, Quercus glauca, Q.glaucescens, Albilizia sherriffii, schima wallichi, Cinnamomum bejolghota* formed the dominant species.

The species presence in all plots is given in Table 6.1-2. *Castanopsis tribuloides* was present in all the plots and was the most dominant both in CRD and CRBA; other species were not equally common to all the stands. *Cryptocarya bhutanica, Sloanea tomentosa, Taulama hodgsonii, Cinnamomum glanduliferum* were some examples of species which were found in lower frequency in Plot A but were absent in Plot B and Plot C. Likewise, some species which occurred in Plot B and Plot C did not occur in Plot A.

Table 6.1-3: Distribution of trees species (trees > 5cm DBH) in three 1-ha plots in Rimchu. The letter indicates species categories in vertical strata; C=canopy species, SC= sub-canopy species and US = under-storey species, the number in () 1 to 7 indicates the timber ranking as shown in Figures 6-1 to 6-3, Group 1= first preferred timber species, Group 6= least preferred timber species, group 7 = not preferred as timber species; x indicates the presence of a species and 0 indicates absence of species in a particular plot. The species are sequenced alphabetically.

Species	Plot A	Plot B	Plot C	Species	Plot A	Plot B	Plot C
Acer laevigatum(C)(6)	*x*	0	*x*	*Ilex kingiana (US)(7)*	0	0	*x*
Albizia sherriffii(C)(6)	*x*	*x x*		*Juglan regia(C)(6)*	0	*x*	0
Alcimandra cathcartii(C)(2)	*x*	*x x*		*Lindera pulcherrima(SC)(6)*	0	0 0	
Brassaiopsis hispita(SC)(7)	*x*	0	0	*Lithocarpus pachyphyllus(C)(6)*	*x*	0	*x*
Beilschmiedia gammieana(C)(6)	*x*	*x*	*x*	*Lyonia ovalifolia (US)(7)*	0	0	*x*
Cryptocarya bhutanica (C)(6)	*x*	0	0	*Michaleia valutina (C)(5)*	0	0	*x*
Carpinus viminea (SC) (3)	*x*	0	*x*	*Myrica esculenta(SC)(6)*	*x*	*x x*	
Castanopsis tribuloides(C)(1)	*x*	*x x*		*Macropanax undulatus(SC)(7)*	*x*	*x*	*x*
Casearia glomerata(SC)(7)	*x*	0	0	*Macaranga pustulata (SC)(6)*	*x*	*x*	*x*
Celtis tetrandra(C)(6)	0	0	*x*	*Macropanax dispermus(SC)(7)*	*x*	*0*	*0*
Cinnamomum bejolghota(SC)(6)	*x*	0	*x*	*Myrsine semiserrata(US)(7)*	*x*	0	*x*
C. glanduliferum(C)(6)	*x*	0	0	*Maytenus kurzii (US)(7)*	*x*	0	*x*
C. glaucescens (C)(4)	0	0 x		*Prunus undulata(SC)(7)*	*x*	*0*	*x*
C. impressinervium(SC)(6)	0	x x		*Quercus glauca (C)(6)*	*x*	x	*x*
Choerospondias axillaris(SC)(7)	*x*	0	0	*Quercus lanata (C)(6)*	0	0	*x*
Cordia obliqua(C)(6)	0	x 0		*Quercus griffithii (C)(6)*	0	0	*x*
Daphniphyllum chartaceum(SC)(6)	*x*	*x x*		*Rhus succedanea(SC)(7)*	0	x 0	
Elaeocarpus lanceifolius(C)(6)	*x*	*x*	*x*	*Schima wallichii (C)(6)*	x	0	*x*
Ehretia wallichiana (C)(6)	0	0	*x*	*Sloanea tomentosa(C)(6)*	x	0	*0*
Engelhardia spicata(C)(7)	*x*	0	*x*	*Styrax grandiflorus(US)(7)*	x	x	*x*
Eurya acuminata(US) (7)	*x*	x	*x*	*Symplocos lucida(SC)(7)*	x	x	*x*
Eriobotrya dubia(SC)(6)	*0*	*x*	*0*	*Symplocos ramosissima(US)(7)*	x	x	*x*
Exbucklandia populnea(C)(6)	0	0	*x*	*Syzygium kurzii(SC)(6)*	x	0 0	
Ficus sp(US)(7)	*x*	0	0	*Talauma hodgsonii(SC)(7)*	x	0 0	
Glochidion acuminatum (US)(7)	0	0	*x*	*Turpinia nepalensis(SC)(7)*	x	0	*x*
Hovenia acerba(C)(6)	*x*	*x*	*x*	*Unknown sp (US)(7)*	0	0	*x*

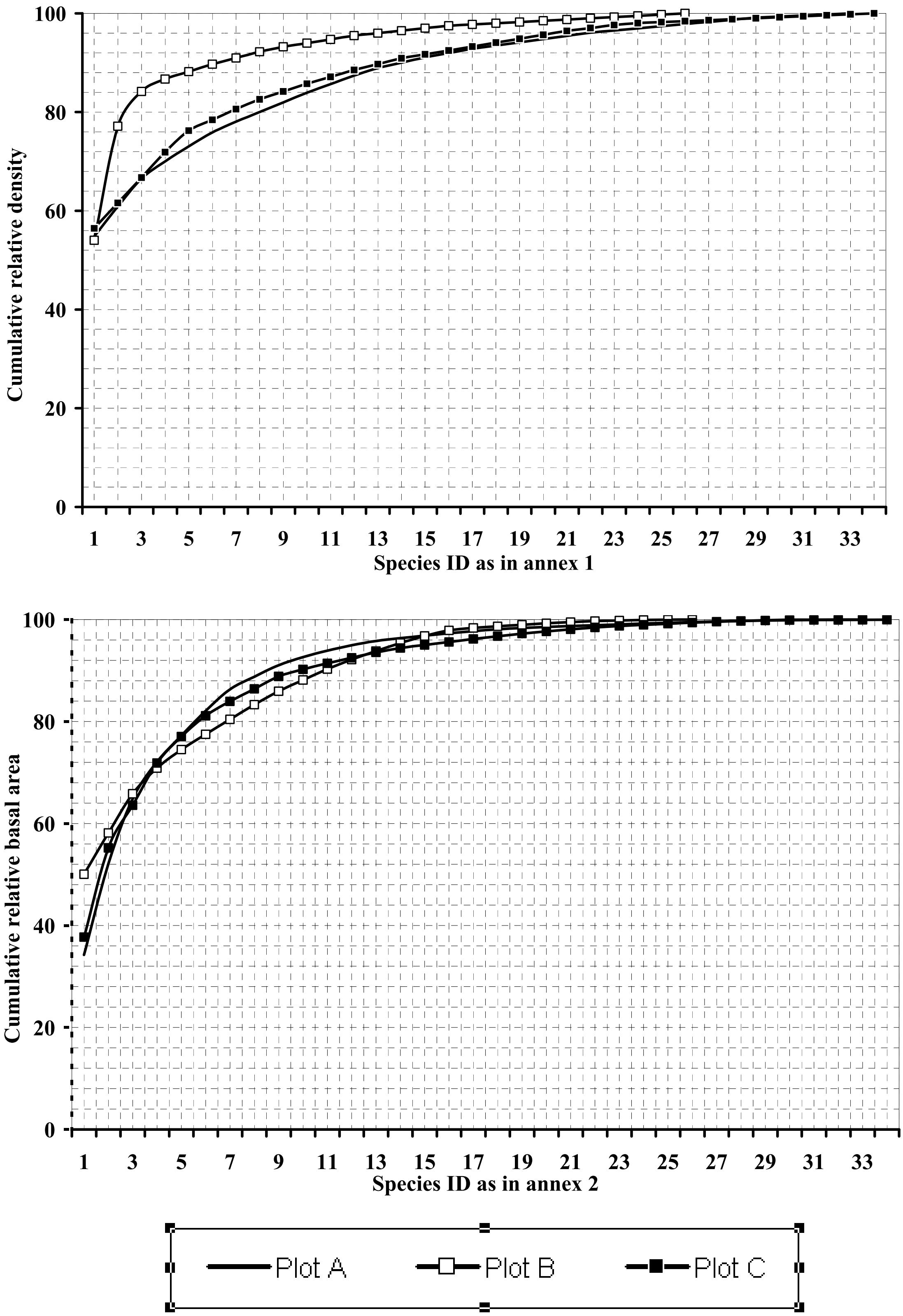


Figure 6.1-4: Cumulative Relative Density (upper) and Cumulative Relative Basal Area (lower) of all tree species (>5 cm DBH) in Rimchu. The species were numbered from the most frequent to the least frequent per plot. Details are shown in Annex 1.

6.1.3 Species richness and diversity

The species richness as well as the Shannon index differed among the three plots. The species richness was lowest in PLOT B (26) compared with PLOT A (33) and PLOT C (34). These differences were also observed both with regard to the Shannon index and the Evenness (Table 6.1-4). Both indices were low in PLOT B compared to PLOT A and PLOT C.

Table 6.1-4: The trees species diversity and Evenness calculated from trees >5cm DBH in three 1 ha plots named as PLOT A, PLOT B and PLOT C. R-ratio = Number of regenerating trees species <5cm DBH / adult species >5cm DBH.

Parameters	PLOT A	PLOT B	PLOT C
S (No. of species)	33	27	35
Number of genera	31	24	31
Number of families	22	20	24
Species occurring just once	4	9	8
H (Shannon index)	2.05	1.59	2.08
Evenness	0.587	0.47	0.57

Table 6.1-5: Jaccard (ISj) and Sørensen (ISs) similarities indices between and within plots of trees >5 cm DBH. S and F stand for species and family approach to calculate the indices.

Similarity indices	PLOT A & PLOT B	PLOT A & PLOT C	PLOT B and PLOT C
S Jaccard (ISj)	37.21	45.65	46.34
F Jaccard (ISj)	70.83	65.51	62.96
S Sørensen (ISs)	54.24	62.69	63.33
F Sørensen (ISs)	80.95	82.61	77.27

The similarity in indices between plots were quite obvious. The differences were largely due to species which occurred just once. In PLOT A there were four species with just one single species up to family level, similarly in PLOT B: nine species occurred just once, in PLOT C there were seven such species. At the family level the similarity index of Sørensen increased up to 83% between PLOT A and PLOT C, 81% between PLOT A and Plot B and 77% between PLOT B and PLOT C. Overall all, there were 52 species of which 22 were common to all plots. These 22 species constitute more than 90% of the stem densities in the investigated plots.

The trees and shrubs were not the only sources of diversity in the study area. Large numbers of plant species in the herb layer and lianas and epiphytes were also observed in the plots. No explicit attempts were made to enumerate them individually. However, presence and absence of lianas, epiphytes and other associated plant species (here called associates) on each individual tree >5cm DBH are presented in Figure 6.1-5. About 58% in Plot A, 55% in Plot B and 32% in Plot C of the recorded trees had associates. Some of these species are important resources as non-wood forests products for farmers.

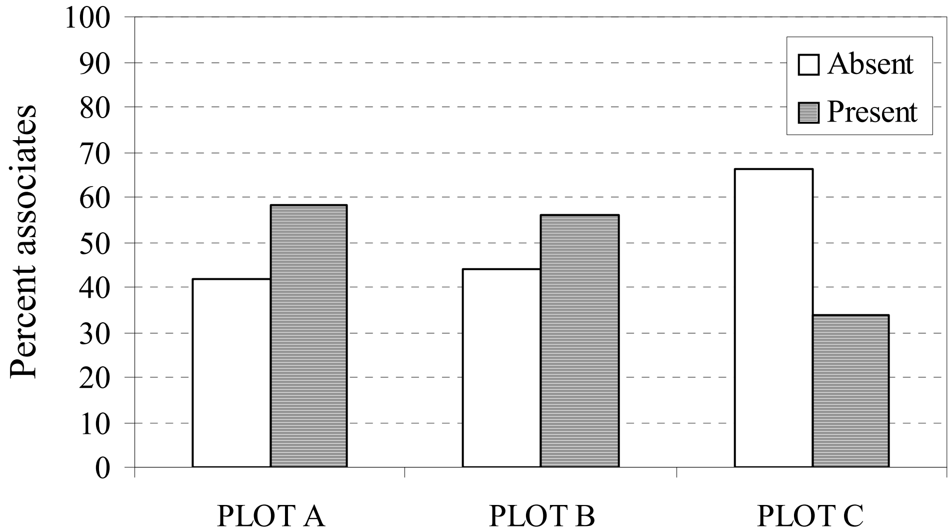


Figure 6.1-5. Presence and absence of lianas, epiphytes and other associated plant species expressed as percentage of recorded trees >5cm DBH on each plot.

6.1.4 The stand structure

The stand level attributes showed that there were differences in number of stems per hectare as well as in basal area. The observed quadratic mean diameter (Dq) of all trees >5cm DBH was lowest in PLOT C and highest in PLOT B (Table 6.1-2) and intermediate in PLOT A. The differences in stem number per hectare were observed between PLOT A (461 /ha) and (398 to 536 /ha) in Plot B and Plot C respectively. The stand-wise distribution of trees (stem number per hectare) >5cm DBH over the diameter range is presented in (Figure 6.1-6). All the plots depict an inverse J-shaped distribution of stems with diameter class. However there were differences between PLOT A and the other two plots (Figure 6.1-6) where in the former there was continuous recruitment up to the biggest diameter class while in the other two plots discontinuity of recruits in bigger diameter classes was observed indicating different disturbances between the stands.

Kruskal-Walis test showed a significant difference in mean ranks of trees basal area between the plots, the pairwise comparison yielded a significant difference between Plot A and Plot C and between Plot B and Plot C (Table 6.1-6).

Table 6.1-6: Non parametric K independent sample test of Kruskal-Wallis and pairwise comparisons by Mann-Whitney tests. Same letters indicate no significant difference at alpha = 0.05.

Test Variables	Group variables	Kruskal-Wallis test			Mann-Whitney test		
		n	χ^2	P-value	Plot A	Plot B	Plot C
Basal Area of trees	Plot	1395	7.51	0.02	a	ab	c
Height of trees	Plot	1395	18.42	0.000	a	ab	c

Generally, the basal area (m^2/ha) was bi-modal in all plots (Figure 6.1-6, lower panel). There was no distinct peak of basal area in PLOT A and PLOT B In PLOT C basal area peaked in the 60-69c DBH class. There was discontinuity of individuals in 110-140 cm DBH classes in PLOT C and in the 110-119cm class in PLOT B respectively, whereas in PLOT A there was continuous representation of trees from 5 cm up to 160cm DBH or greater. The basal area distribution by DBH classes according to functional canopy groups is shown in Figure 6.1-7, in relative height classes in Figure 6.1-8. The basal area based on functional groups was subjected to non-parametric tests within the plots. Significant differences in mean tree basal area were observed between US, SC and C layers respectively in all plots.

Kruskal-Wallis tests were conducted to see if discrepancies exist in mean ranking of basal area of individual trees between the plots, and the results showed, there was no significant differences in basal area of under-storey tree species between plots (Table 6.1-8). However there were significant differences in basal area of trees in sub-canopy and canopy groups (p-value <0.05, Table 6.1-8). The significant difference in mean ranking of tree basal area was observed between Plot C and PLOT B, PLOT A and PLOT B while there was no significant difference between PLOT A and PLOT C in sub-canopy trees. There was significant difference in mean ranking of trees basal area between plots in canopy trees (Table 6.1-8).

Table 6.1-7 : Kruskal-Wallis non-parametric tests and Mann-Whitney pairwise non-parameters tests of basal area of trees .Different letters indicate significant differences at alpha = 0.95. Here functional groups (US = under-storey species, SC = sub-canopy species and C = canopy species) were used as grouping variable to see the differences within plots in mean tree basal area (BA).

Plots	Test Variables	Grouping variables	n	Kruskal-Wallis test (k-intendment)		Mann-Whitney test
				χ^2	p-value	
PLOT A	BA	US	20	17.08	0.000	a
		SC	83			b
		C	105			c
PLOT B	BA	US	96	99.42	0.000	a
		SC	55			b
		C	32			bc
PLOT C	BA	US	51	25.57	0.000	a
		SC	74			b
		C	105			bc

Table 6.1-8: Kruskal-Wallis and Mann-Whitney tests on tree basal area (BA) between plots in canopy functional groups. Different letters indicate significant differences at alpha = 0.95. Here trees are grouped by functional groups (US = under-storey species, SC = sub-canopy species and C = canopy species).

Grouping variables	Test Variables	Plots	n	Kruskal-Wallis test χ^2	p-value	Mann-Whitney test
US	BA	Plot A	23	1.42	0.49	a
		Plot B	95			a
		Plot C	50			a
SC	BA	Plot A	119	13.75	0.001	a
		Plot B	60			b
		Plot C	81			ac
C	BA	Plot A	318	18.09	0.000	a
		Plot B	243			b
		Plot C	406			c

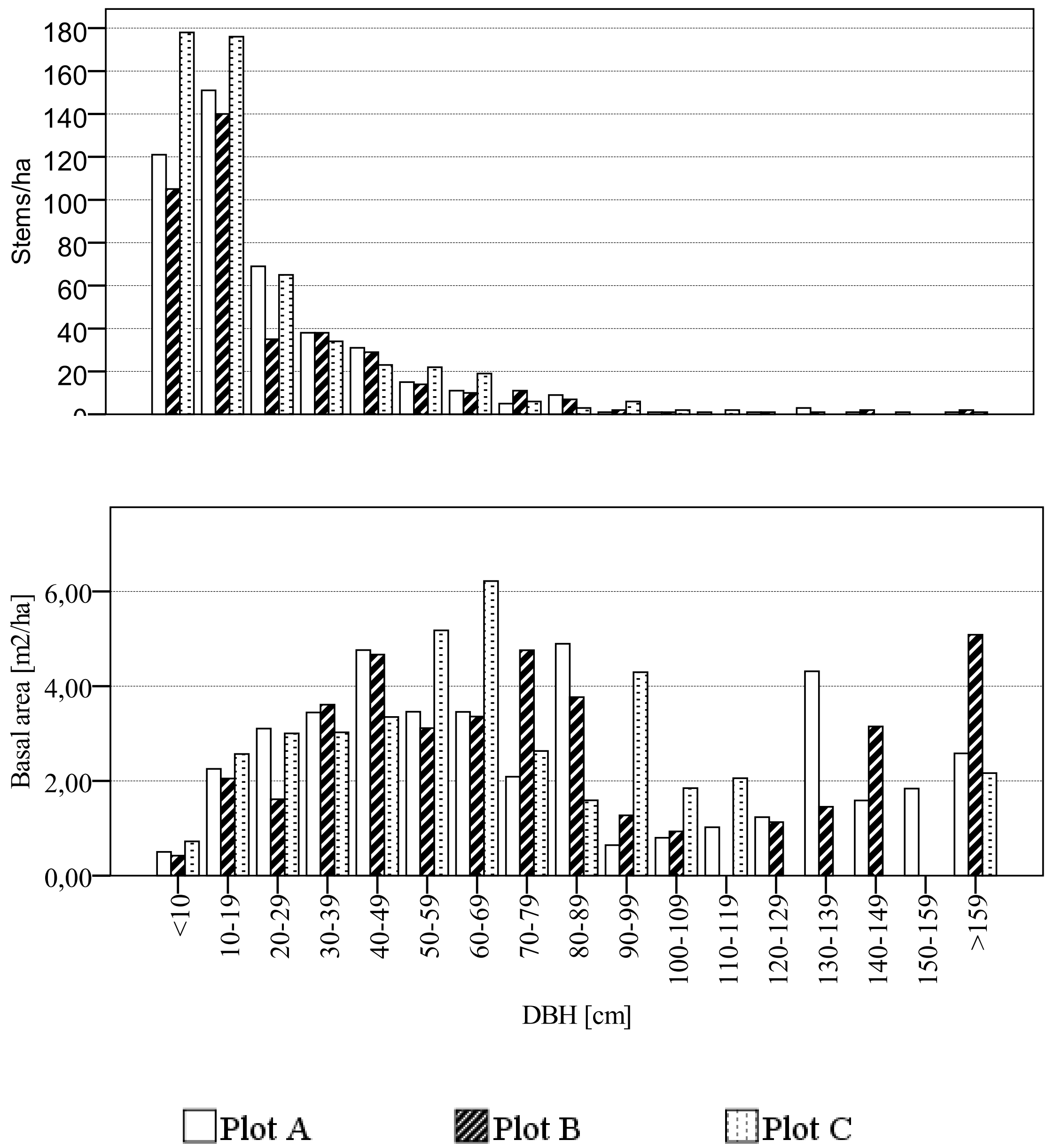


Figure 6.1-6: The distribution of stem number [n/ha] (upper panel) and basal area [m^2/ha] (lower panel) over DBH classes in three exploratory 1ha plots in Rim chu. Calculated for trees >5cm DBH.

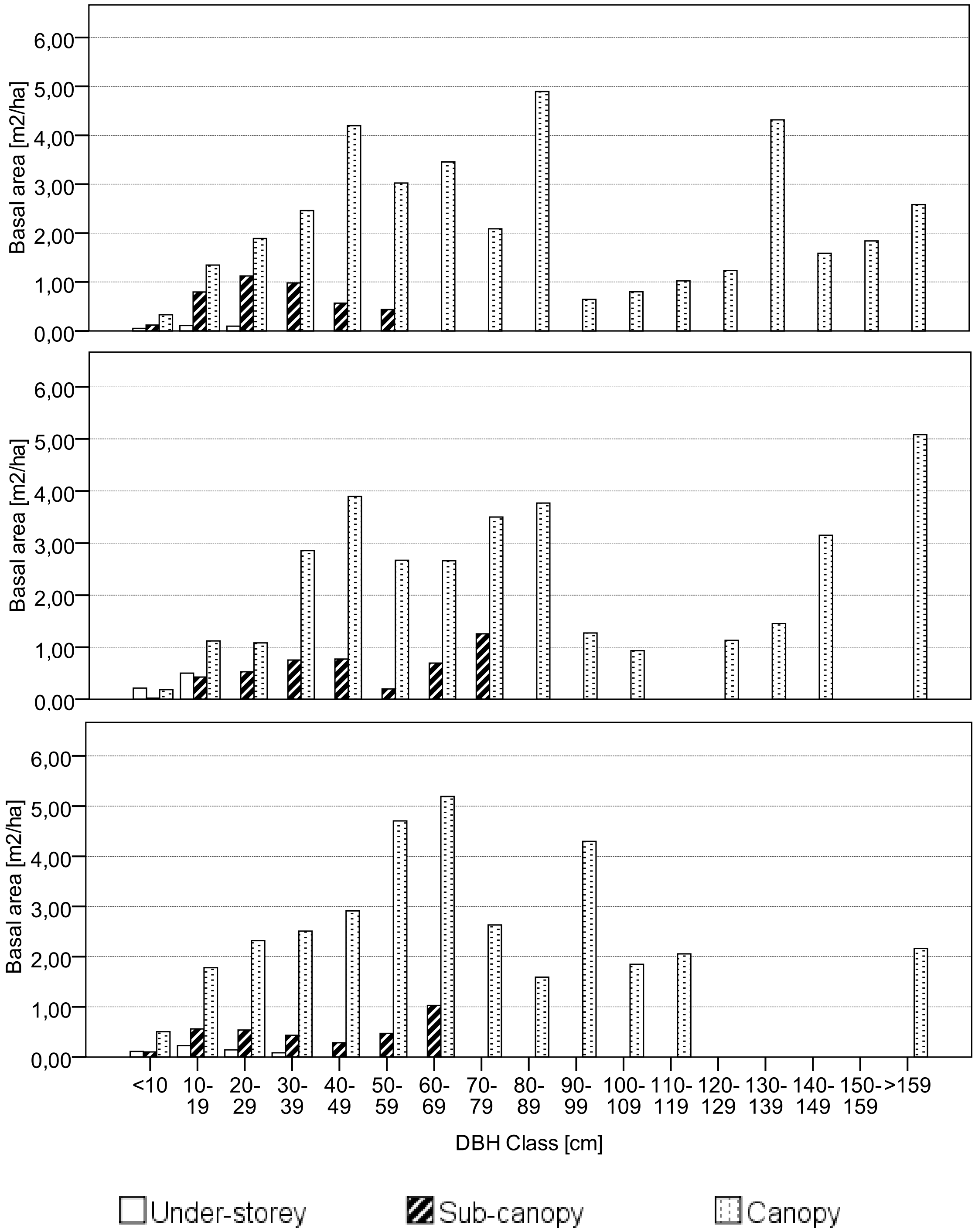


Figure 6.1-7: Distribution of basal area (trees >5cm DBH) by functional groups. The groups were formed considering the functional role in the canopy strata. The classification was based on general ecological knowledge of the trees species and observed height (those that are persistently present in lower canopy layers (<15 meters in height but never occurred above 20m or more height) are considered under-storey species, those species which did not occur above 35m height were considered sub-canopy and those able to attain heights taller than >35 meters were considered canopy species). Upper panel: PLOT A, center: PLOT B, lower panel: PLOT C.

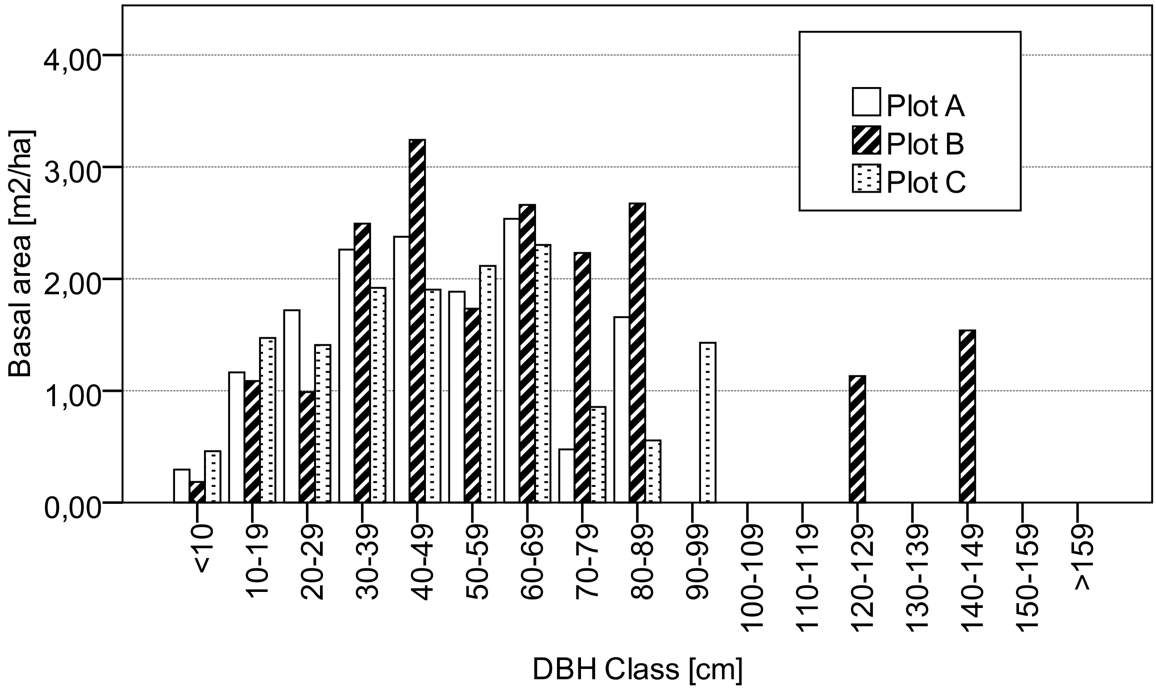


Figure 6.1-8: Basal area distribution over DBH classes of *Castanopsis tribuloides* trees >5cm DBH.

The further decomposition of stem density at the species level by DBH classes showed that the basal area distribution of *Castanopsis tribuloides (Ct)* showed a continuous distribution pattern (Figure 6.1-8). Another species that was common in all the stands was *Alcimandra catcarthii* (see Table 6.1-3). It constituted most of the basal area on bigger diameter classes especially in PLOT A and PLOT C (Figure 6.1-9, top and bottom panels) indicating it as a climax species. *Elaeocarpus lanceifolius* was another species common in all stands (Table 6.1-3) but its share in basal area was higher in PLOT A and PLOT C compared with PLOT B, its distribution along the DBH classes was rather sporadic. Other dominant species on the plots were *Sloanea tomentosa, Engelhardtia spicata, Cryptocarya bhutanica and Schima wallichii* in PLOT A. They also showed sporadic pattern of distribution. *Michaleia valutina* constituted a considerable amount of basal area in PLOT B (Figure 6.1-9, mid panel) likewise *Cordia obliqua* and *Juglan regia* were found only in PLOT B. In PLOT C, apart from those species common to all plots, *Albizia sherrriffii, Cinnamomum glaucecens, Quercus glauca* were some of the dominant species.

The species-specific distribution of the basal area based on functional canopy groups and on relative height categories are shown in Figures 6.1-10 and 6.1-11. It was observed that under-storey and sub-canopy trees accounted for a very low share of basal area. The major share of basal area came from the canopy species. The shares of other species were as described earlier. However, when all species were used under three height class categories *Castanopsis tribuloides* accounted for the major share of basal area in the tallest height class. Its share differs between plots in all height classes (Figure 6.1-11).

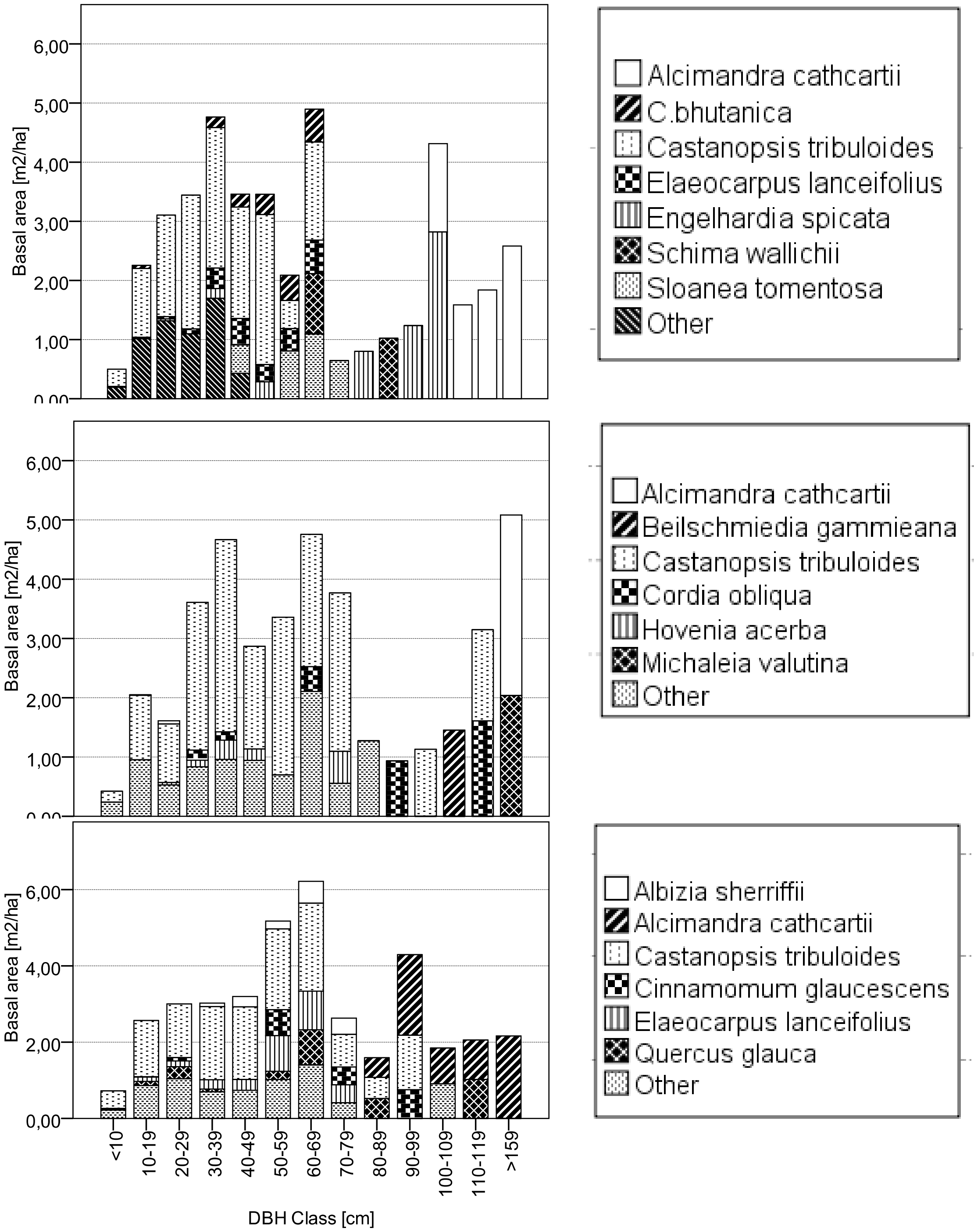


Figure 6.1-9: Basal area distribution of trees >5 cm DBH by species in the study plots. Upper panel is Plot A, middle panel is Plot B and lowest panel is Plot C.

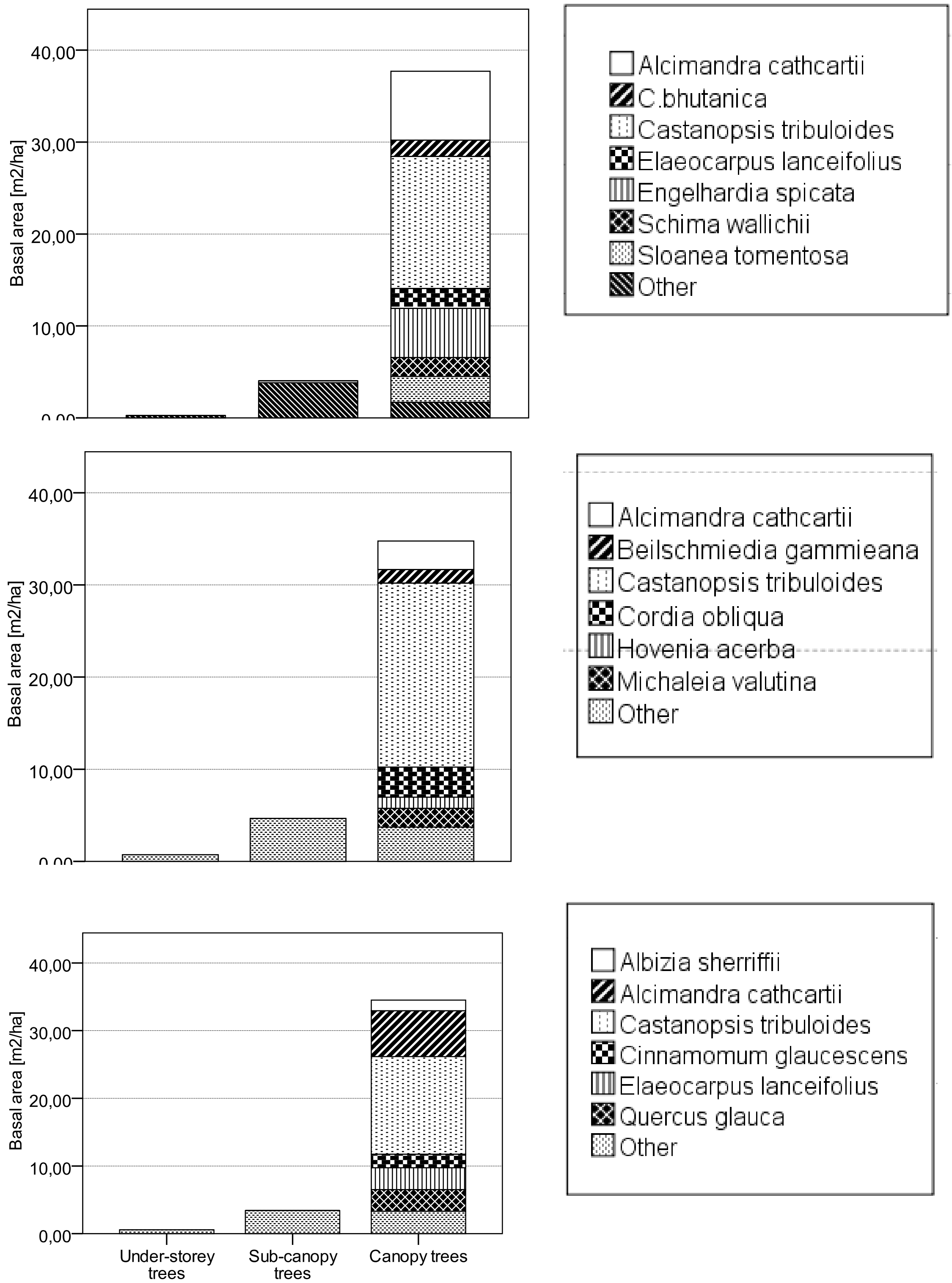


Figure 6.1-10: Basal area distribution of trees >5cm DBH by species categories based on the functional canopy groups which represent more than 90% of the total basal area. Upper panel is PLOT A, mid panel is PLOT B, and the bottom panel is PLOT C.

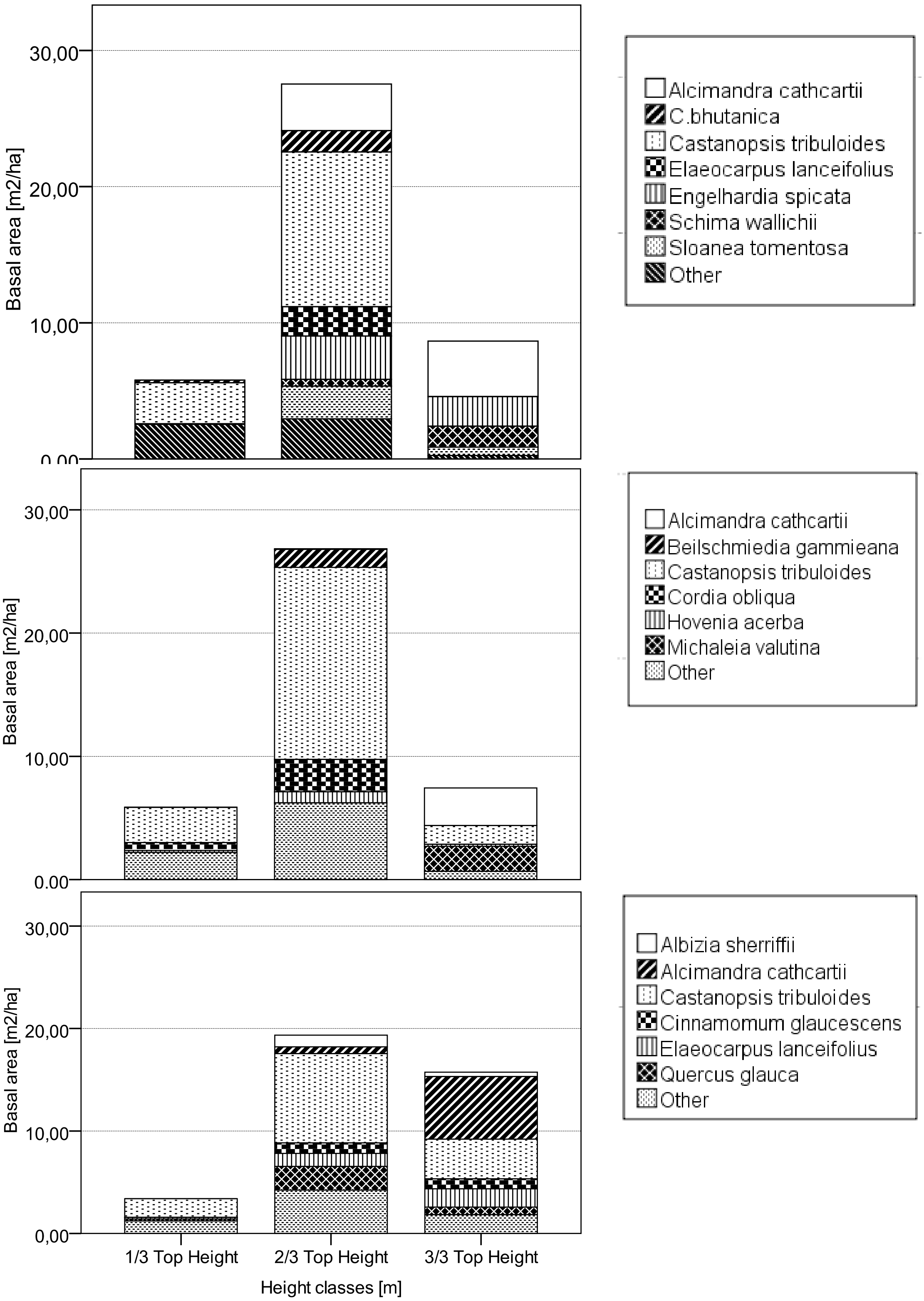


Figure 6.1-11: Basal area distribution of trees >5cm DBH by relative height classes. Top panel is PLOT A, mid panel is PLOT B, and the bottom panel is PLOT C.

6.4.2 Height structure

The scatter plots of tree height versus DBH are shown for the functional groups in Figure 6.1-12.

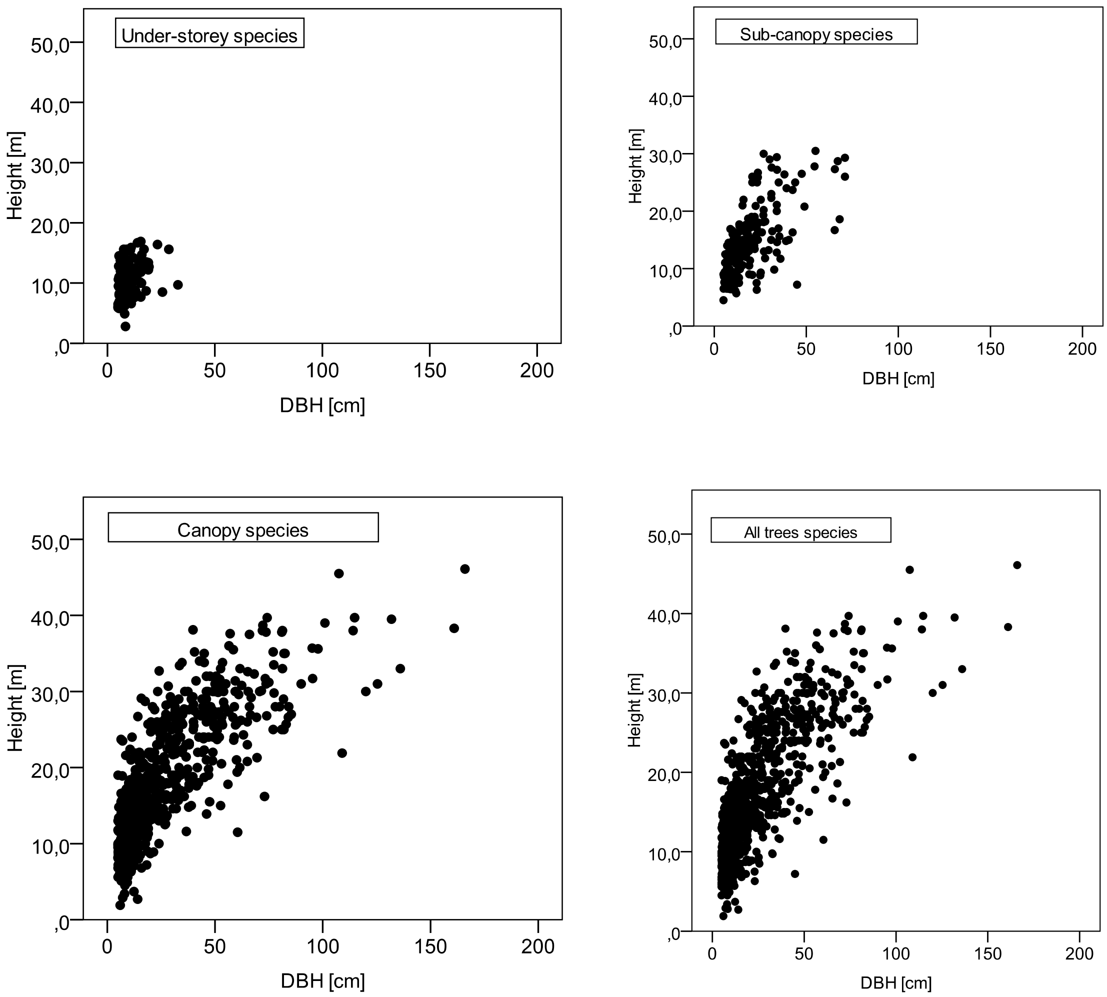


Figure 6.1-12: Scatter plots of height and DBH (>5cm) of trees by functional groups and for all species (lower right panel) over all three exploratory plots.

The DBH-height through Figure 6.1-12 showed asymptotic growth, generally trees reached asymptotic growth at about DBH of 80-100 cm in canopy species.

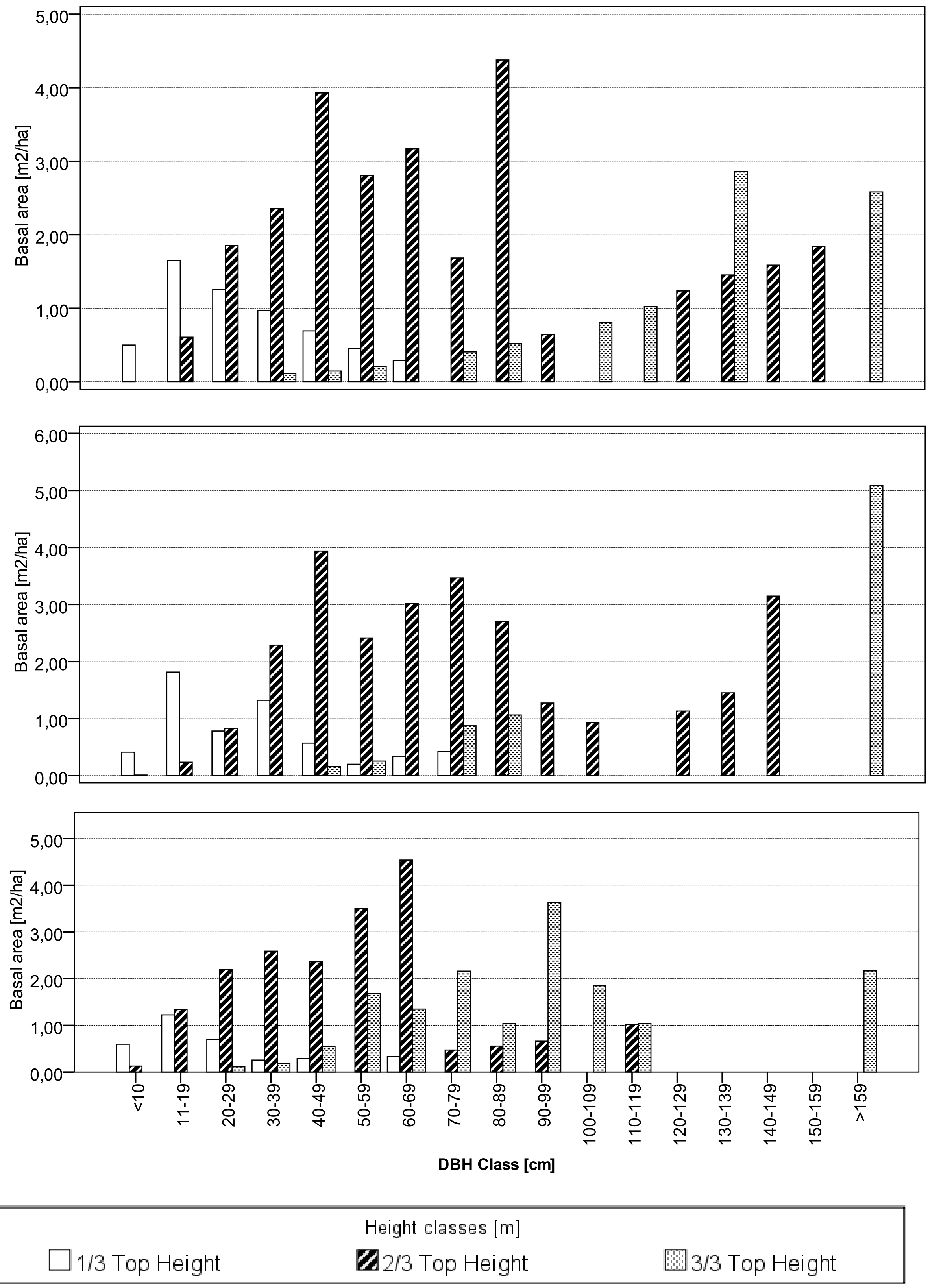


Figure 6.1-13: Distribution of basal area of trees >5cm DBH by three relative height classes. 1/3 Top Height = all trees smaller 1/3 top height at a plot; 2/3 Top Height = all trees larger 1/3 and smaller 2/3 of plot top height; 3/3 Top Height = all trees larger 2/3 plot top height. Upper panel: PLOT A, center: PLOT B, lower panel: PLOT C.

The mean height of all trees larger than 5cm DBH at PLOT A was estimated as 15.42 m, 14.58 m in PLOT B and 16.31 m in PLOT C, respectively. The basal area distribution over DBH structured into the three height classes shows that trees of the lower two height classes are also present in strong diameter classes (Figure 6.1-13). It is interesting to compare the basal area distribution pattern over DBH classes between the functional height class grouping and the actual height classes. The basal area distribution of all 1/3-height class trees accounted for much larger shares compared to the basal area contribution of under-storey species when the functional classification was used (Figures 6.1-14 and 6.1-15). The trees in the 2/3-height class constituted most of the basal area. Their distribution along the DBH classes differed between plots (Figure 6-13). There were clearly gaps with missing individuals of any species grouping in PLOT C and PLOT B in higher DBH classes (Figure 6.1-13, center and bottom panels).

The stem distribution using functional groups showed differences in number of trees of under-storey, sub-canopy and canopy trees between plots (Figure 6.1-14, left). When height classes based on plot top height was used (Figure 6.1-14, right), the highest number of individuals/ha was observed in the lowest height class. The intermediate height class (2/3 Top Height) had lower tree numbers compared with the lowest 1/3 Top Height class, however more individuals were observed in PLOT C compared with other plots. The smalles numbers of individuals/ha were observed in the tallest height class (Figure 6.1-14 right).

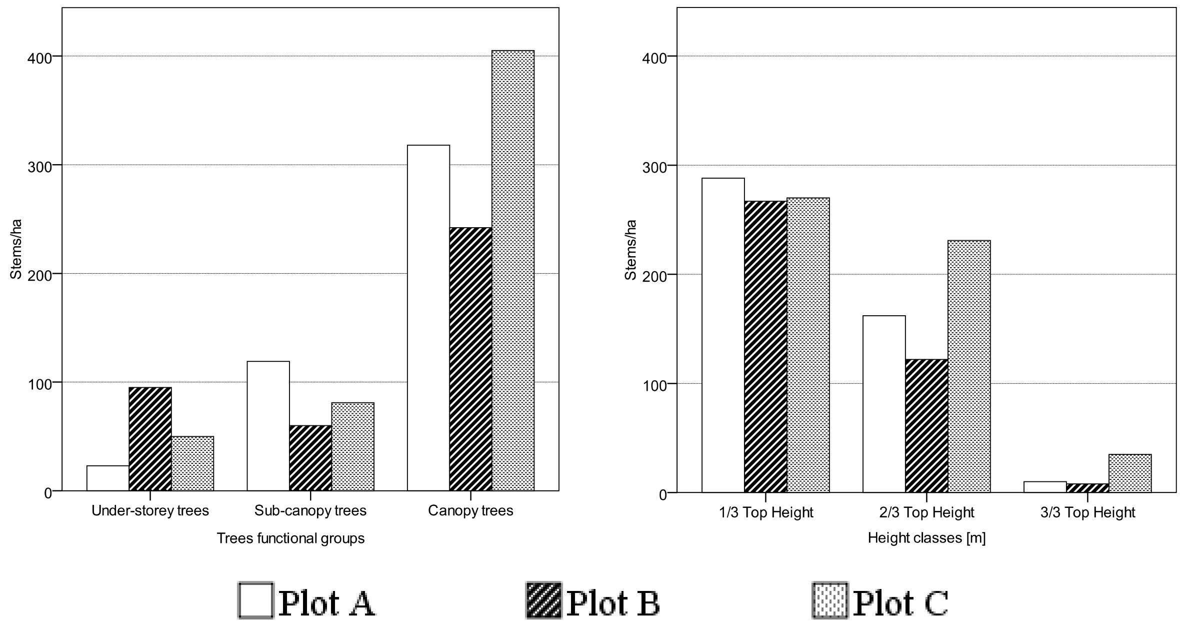


Figure 6.1-14: Distribution of trees >5 cm DBH by height categories. Left diagram : functional groups based on species occurrence on the different layers of the canopy. Right diagram: relative height classes based on plot top height. 1/3 Top Height = all trees smaller 1/3 top height at a plot; 2/3 Top Height = all trees larger 1/3 and smaller 2/3 of plot top height; 3/3 Top Height = all trees larger 2/3 plot top height.

The basal area distribution using functional groups of trees showed lowest basal area in under-storey species, highest in canopy species (Figure 6.1-15, left). The basal area distribution using relative height classes showed much higher shares in basal area in the intermediate height class

(2/3 Top Height), and lower shares in the tallest height class (3/3 Top Height) (Figure 6.1-15, right).

These differences indicate that a functional grouping of trees may not be useful to describe the actual stand structure. However, both approaches together can yield valuable insights on the current situation in a stand as well as ongoing stand dynamics. A high share of canopy species in the lower height classes may indicate ongoing recruitment processes of canopy species after a pulse of regeneration.

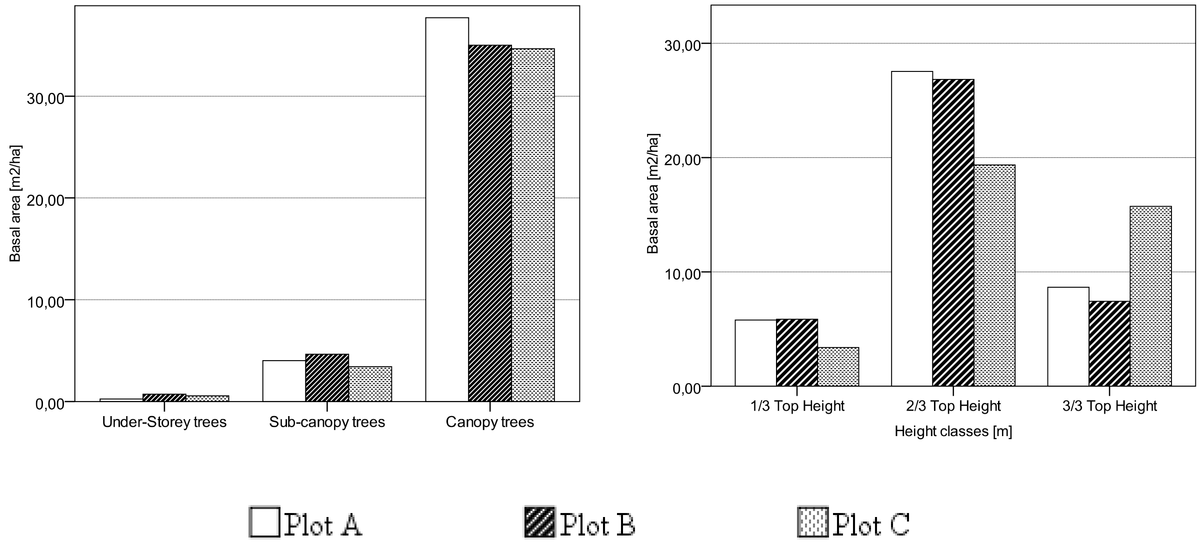


Figure 6.1-15: Tree basal area by height classes for trees >5 cm DBH. Left diagram: functional groups based on species occurrence on the different layers of the canopy. Right diagram: relative height classes based on plot top height. 1/3 Top Height = all trees smaller 1/3 top height at a plot; 2/3 Top Height = all trees larger 1/3 and smaller 2/3 of plot top height; 3/3 Top Height = all trees larger 2/3 plot top height.

6.1.5 Tree quality

The individual trees were visually assessed and classified into two categories as good trees and poor trees based on their stem shape and eventual damages (see Table 4-1 for quality definitions). From the three exploratory plots, overall about 68% of the standing trees were in the good category. There was more basal area in poor trees in PLOT A compared with PLOT B and PLOT C (Figure 6.1-16).

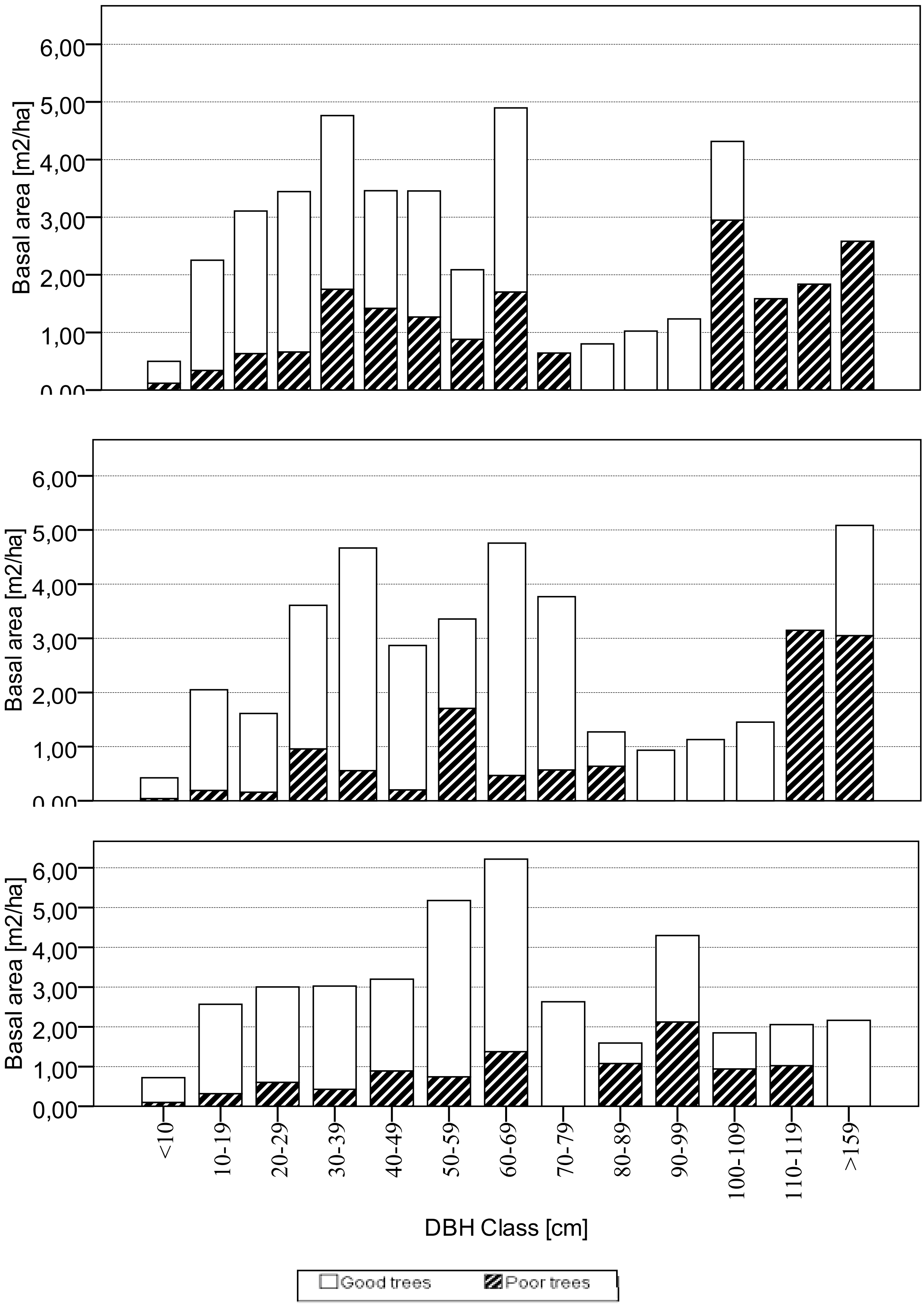


Figure 6.1-16: The distribution of good and bad shap ed trees over the DBH range. See Table 4-1 for definition of quality classes. Top pane l is PLOT A, cente r panel is PLO T B and bottom panel is PLOT C.

Table 6.1-9: Distribution of the most abundant tree species in terms of basal area [m^2/ha] and the corresponding percentages () of quality classes (see Table 4-1 for definitions). Species marked with * are used for construction purposes. *Ct = Castanopsis tribuloides, Ac = Alcimandra catcarthii, El=Elaeocarpus lanceifolius, Es = Engelhardia spicata, St = Sloanea tomentosa, Sw = schima wallichi, Co= Cordia obliqua, Ha= Hovenia acerba, Mv= Michaelia valutina, Qg = Quercus glauca, As= Albizia sherriffii, Cq = Cinnamomum glaucescen.*

PLOT A	Ct*	Ac*	El*	St*	Sw*	Es	Others	Total
	10.2	0	0.7	1.8	2.0	3.7	5.2	23.6
Good	(71)	(0)	(33)	(59)	(100)	(70)	(69)	(56)
	4.19	7.5	1.45	1.25	0	1.62	2.35	18.36
Poor	(29)	(100)	(67)	(41)	(0)	(30)	(31)	(44)
Subtotal	14.37	7.5	2.15	2.05	3.03	2.04	7.53	41.98
PLOT B	Ct*	Ac*	El*	Co*	Ha*	Mv*	Others	Total
	15.81	0.05	0.55	1.44	1.1	2.04	7.82	28.81
Good	(78)	(2)	(46)	(44)	(89)	(100)	(84)	(71)
	4.4	3.04	0.64	1.83	0.14	0	1.53	11.58
Poor	(22)	(98)	(54)	(56)	(11)	(0)	(16)	(29)
Subtotal	20.22	3.09	1.19	3.27	1.27	2.04	9.35	40.39
PLOT C	Ct*	Ac*	El*	Qg*	As*	Cq*	Others	Total
	9.93	4.7	3.1	1.57	1.00	1.96	5.99	28.25
Good	(71)	(67)	(97)	(49)	(87)	(100)	(88)	(76)
	4.04	2.34	0.11	1.63	0.15	0.00	0.81	9.08
Poor	(29)	(33)	(3)	(51)	(13)	(0)	(12)	(24)
Subtotal	13.97	7.04	3.21	3.2	1.15	1.96	6.8	37.31

The highest percentage of basal area of good trees was observed in ***Castanopsis tribuloides*** (Ct) in all plots.

Table 6.1-10: Kruskal-Wallis and Mann-Whitney tests on DBH and crown projection area (CPA) between plots. Alpha = 0.95. Same letter indicate no significant difference between groups.

Grouping variables	Plots	Test variables	Kruskal-Wallis test			Mann-Whitney Test
			n	χ^2	p-value	
Good trees	Plot A	DBH	351			a
	Plot B		347	6.78	0.034	a
	Plot C		456			c
	Plot A	CPA	115			a
	Plot B		351	15.42	0.001	b
	Plot C		347			bc
Poor trees	Plot A	DBH	109			a
	Plot B		51	2.59	0.27	a
	Plot C		81			a
	Plot A	CPA	109			a
	Plot B		51	13.87	0.001	b
	Plot C		81			ac

There were significant differences in mean rank of good quality trees in DBH between Plot C and the other two plots, the differences were also observed in CPA of good trees between plots (Table 6.1-10). There was also a significant difference in mean rank of CPA of good trees between PLOT A and two other plots. There were no significant differences in mean ranks of the DBH of poor trees between the plots, however differences were significant in CPA between PLOT B and the other two plots (Table6.1-10).

Based on the observation during the field inventory of stumps and interviews with local people about eleven species were used as timber species. The basal area of *Alcimandra catcarthii* (*Ac)* was mostly of poor quality (> 90% of basal area) in PLOT A and PLOT B and 67% of basal area was of good quality in PLOT C. Less than 50% of the observed basal area of *Elaeocarpus lanceifolius* (El) was in poor quality in PLOT A and PLOT B and >90% of the basal area was in good state in PLOT C (Table 6.1-9). The tree species which are not used as timber for construction purposes was below 20% of the total basal area (Table 6.1-9).

6.1.6 Stumps and dead wood including coarse woody debris

6.1.6.1 Stumps

All stumps which have been measured in the three exploratory plots originated from harvests. There were significant differences in mean ranks of basal area at 130 cm height from harvested trees (stumps) between the plots (Table 6.1-11) where the difference was significant between PLOT B and the other two plots. The highest amount of harvested basal area was observed in PLOT C, followed by PLOT B and PLOT A (Table 6.1-12, Figure 6.1-17). Interestingly a substantial share of the stumps occurred in relatively small diameter classes. The pattern of basal area of harvested trees is presented in Table 6.1-13. Amongst the individual species the basal area of *Alcimandra catcarthii* accounted for most harvested trees from PLOT C. The harvested basal area of *Castanopsis tribuloides* was highest in PLOT B. Other species that were harvested were *Juglan regia, Schima wallichi, Carpinus, Symplocos ramosissima* and *Eurya accuminata* (Table 6.1-11). The number of coppicing stumps was highest in PLOT C, followed by PLOT A and PLOT B (Table 6.1-13). In total over all plots 69% of the stumps were found with sprouts.

Table 6.1-11: Non-parametric tests (Kruskal-Wallis H test and Mann-Whitney U test for differences among plots. The test variables are stump basal area and volume of coarse woody debris (CWD). Same letters indicate no significant difference among plots. Alpha =0.95.

Test variables	Group variables	Kruskal-Wallis test			Mann-Whitney test		
	Plots	n	χ^2	P-value	Plot A	Plot B	Plot C
cross-sectional area [stumps]	Plot A, Plot B and Plot C	96	7.44	0.05	a	b	ac
Volume [CWD]	Plot A, Plot B and Plot C	327 (pieces)	22.99	0.000	a	b	c

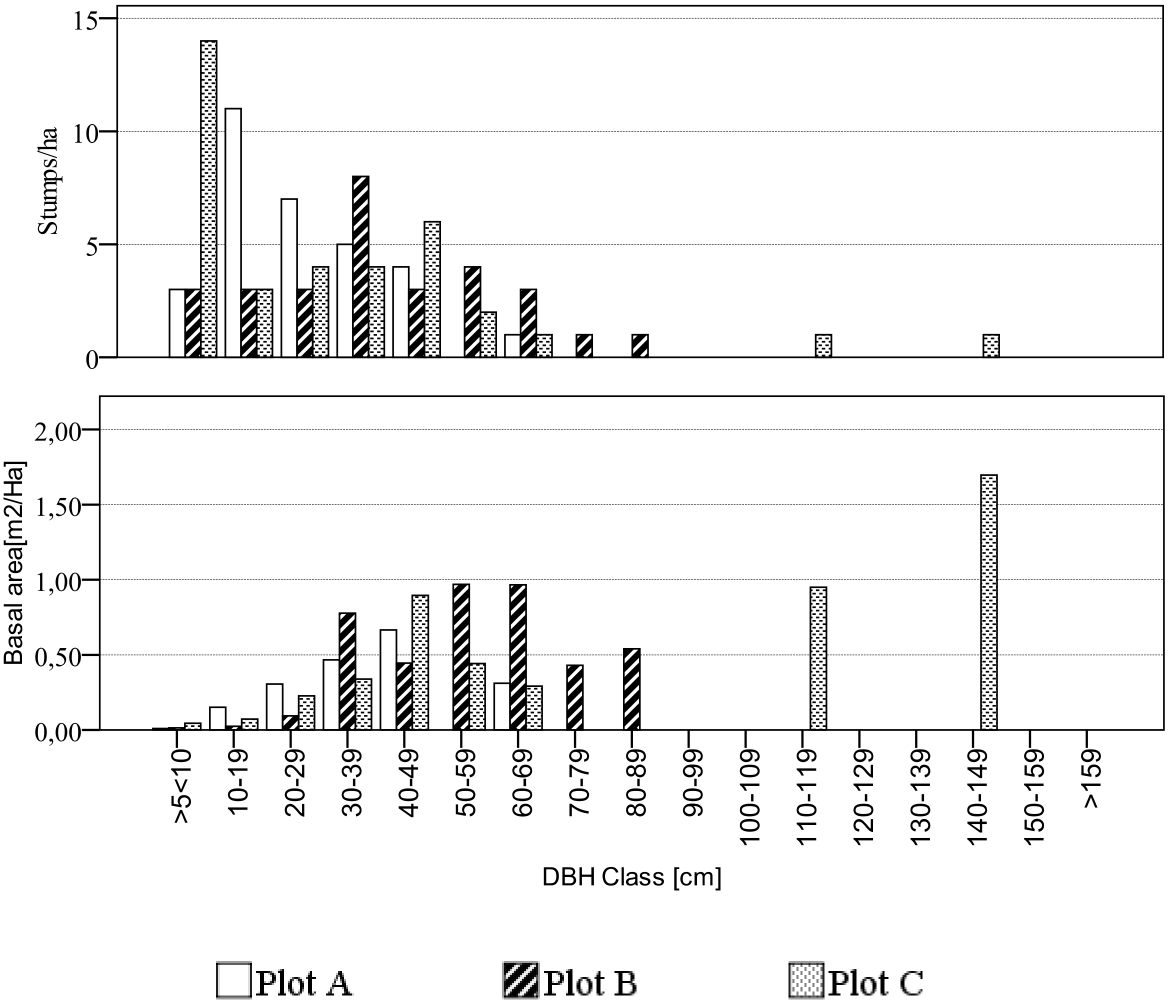


Figure 6.1-17: Distribution of stumps/ha (upper panel) and stump basal area/ha (lower panel) by DBH class in Rimchu exploratory plots. Here stumps means those harvested by humans.

Table 6.1-12: Distribution of basal area/ha and number of stumps/ha by tree species. Here stumps refer to harvesting activities.

PLOT A	n/ha	Basal area [m^2/ha]
Castanopsis tribuloides	24	1.29
Carpinus viminea	2	0.31
Symplocos ramosissima	2	0.04
Eurya acuminata	1	0.01
Hovenia acerba	1	0.17
Macaranga pustulata	1	0.1
Total	**31**	**1,92**
PLOT B	n/ha	Basal area [m^2/ha]
Castanopsis tribuloides	22	2.88
Symplocos ramosissima	3	0.02
Cinnamomum impressinervium	2	0.4
Juglans regia	2	0.97
Total	**29**	**4.27**
PLOT C	n/ha	Basal area [m^2/ha]
Castanopsis tribuloides	28	1.57
Alcimandra cathcartii	4	3.08
Schima wallichii	1	0.18
Daphniphyllum chartaceum	1	0.001
Lithocarpus pachyphyllus	1	0.03
Elaeocarpus lanceifolius	1	0.08
Total	**36**	**4.94**

Table 6.1-13: Distribution of stum ps and snags per hectare accord ing to their copp icing activities. Yes = sprouting; No = no sprouts.

Plot	Stump/ha		Snags/ha	
	Yes	No	Yes	No
Plot A	24	7	5	42
Plot B	11	18	4	46
Plot C	32	4	6	49
Total [n/ha]	67	29	15	137
Total [%]	69.79	30.21	9.87	90.13

6.1.6.2 Snags and coarse woody debris

No significant differences were observed in the number of snags between the plots. The same was true for coppicing activities on snags when subjected to Kruskal-Wallis tests. The majority of the snags did not show sprouting activities (Table 6.1-13). The basal area distribution of the snags did not show major differences among the plots (Figure 6-18, lower panel).
There were significant differences in volume (m^3/ha) of CWD between the plots when subjected to Kruskal-Wallis tests (Table 6.1-11). The differences between plots can be seen in Figure 6-19. In PLOT A the distribution of snags reached from the smallest to the biggest sizes continuously, however in PLOT B and PLOT C there were disruptions of CWD in low as well as in larger size classes.

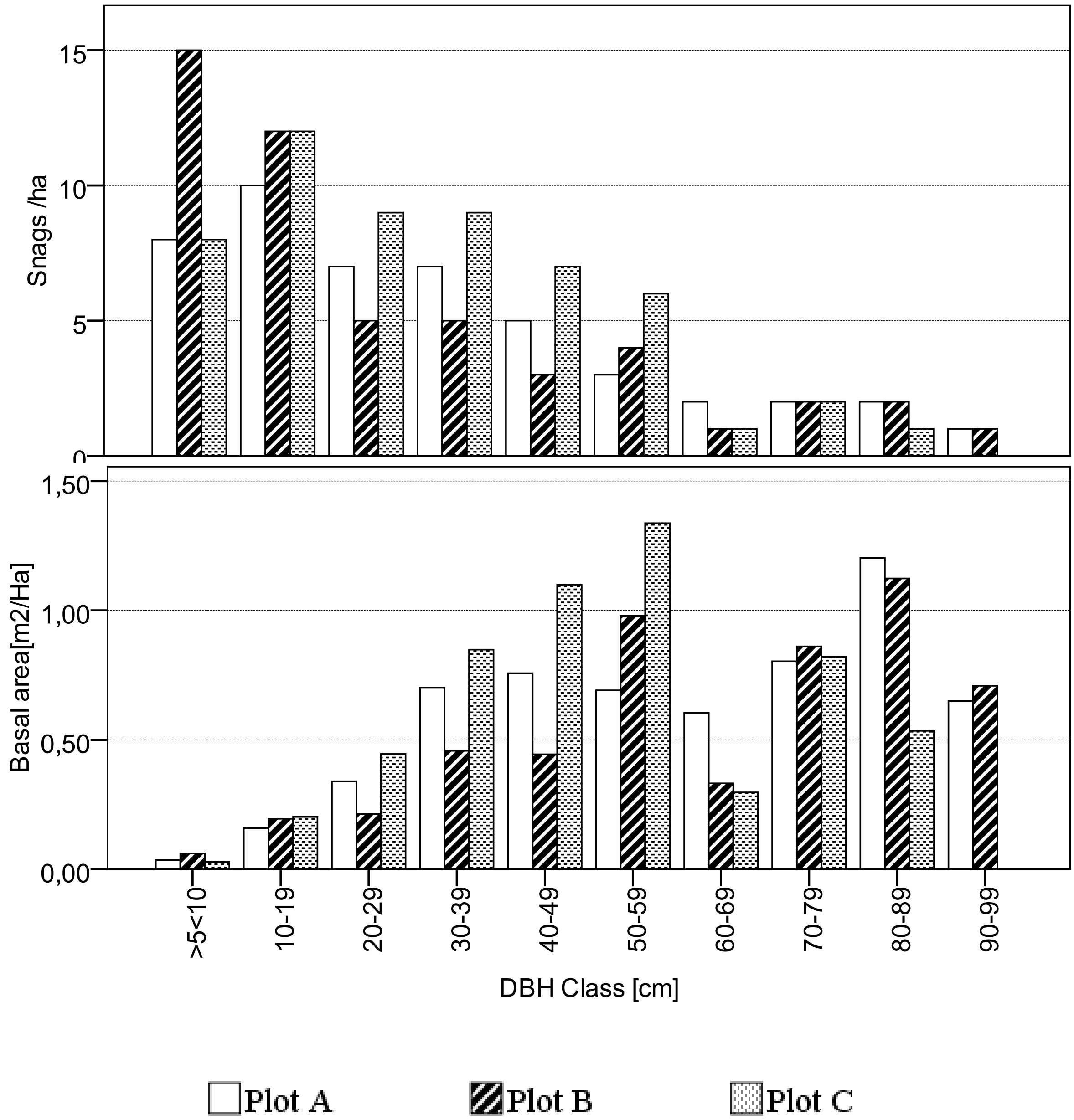


Figure 6.1-18: Distribution of snags/ha (upper panel) and snags basal area/ha (lower panel) in three exploratory plots in Rimchu. Snags mean trees, which died naturally.

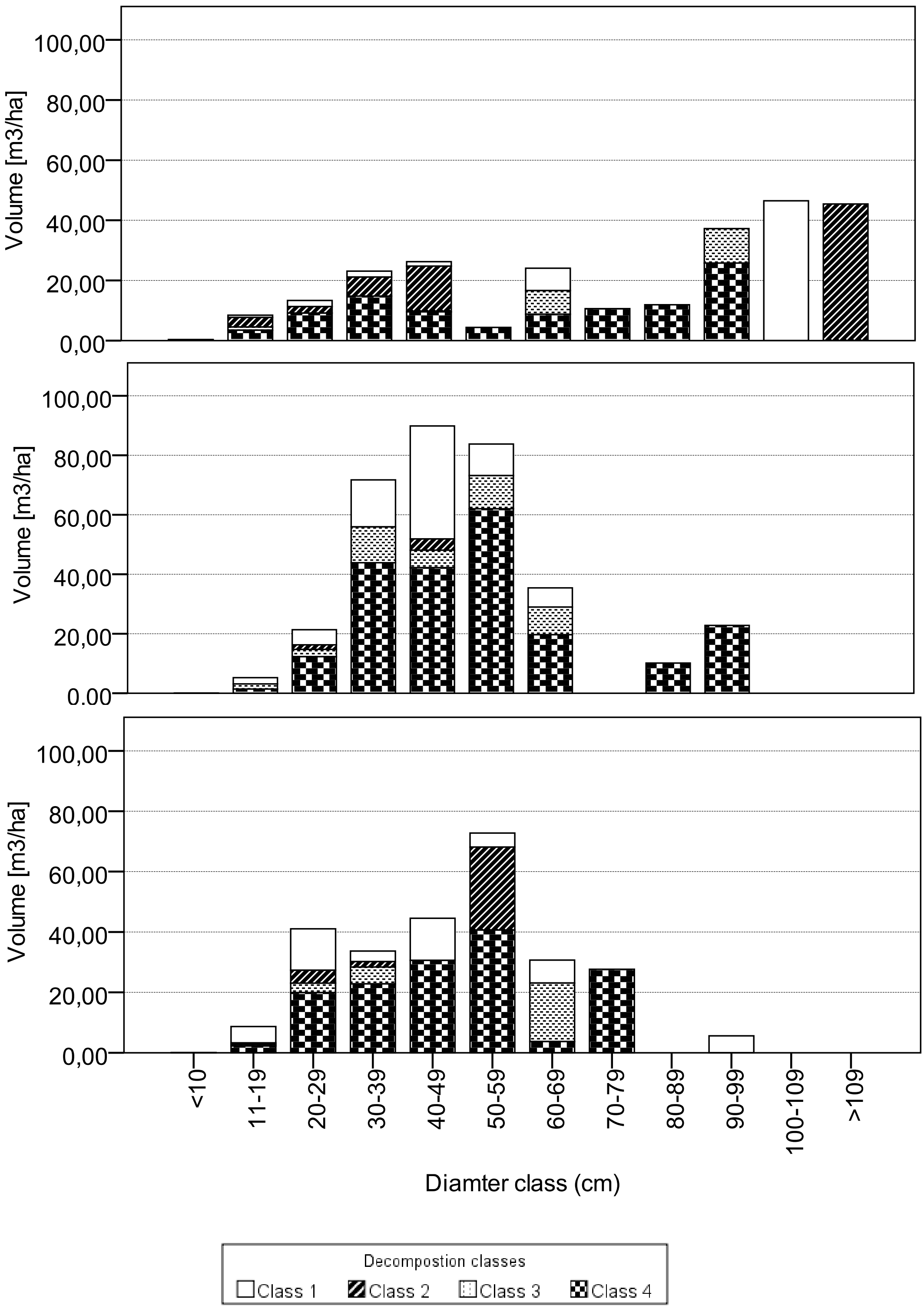


Figure 6.1-19: The volume distribution of CDW according to their stages of decompositions in Rimchu. Class1: Solid dead wood. The volume of the stem consist 100% solid wood and the stem has a hard exterior surface. The wood not at all affected by wood decaying organisms, Class 2: Solid dead wood. The volume of the stem consists more than 75- 90% of solid wood and the stem has a hard exterior surface. The wood is to small extent affected by wood decaying organisms, Class 3: Decayed dead wood. The volume of the stem consists to 26–75% of soft or very soft wood, Class 4: Completely decayed. The first row from top is PLOT A, second row is PLOT B and third row is PLOT C.

The plot wise distribution of CWD by origin is presented in Table 6.1-14. Most of the CWD may have its origins in wind damage and little may have resulted from human activities. Uprooted trees constituted major volume contribution in all stands, followed by broken stems, human fallings was the third important origin of CWD. There was a significant difference in volume of uprooted trees between plots (Table 6.1-14), the highest was observed in PLOT A, followed by PLOT B and least volume was observed in PLOT C. There were differences in the volume of CWD due to human harvesting, it was higher in PLOT A compared with PLOT B and PLOT C (Table 6.1-14).

The volume of the fresh CWD (class 1) was high in PLOT B and lowest in PLOT C, and medium in PLOT A. On the other end of the scale, too, the volume of class 4 CWD was still highest in PLOT C and lowest in PLOT A indicating different intensities of use/harvesting, and other natural disturbances (Figure 6.1-19).

Table 6.1-14: Distribution of volume (m^3/ha) of the coarse woody debris (CWD) of diameter > 10 cm according to their origin in Rimchu. SD = standard deviation.

Origin of CWD	PLOT A			PLOT B			PLOT C		
	Total vol/ha [m^3/ha]	Mean piece of CWD [m^3/ha]	SD	Total vol/ha [m^3/ha]	Mean piece of CWD [m^3/ha]	SD	Total vol/Ha [m^3/ha]	Mean piece of CWD [m^3/ha]	SD
Branch broken	2.41	0.30	0.14	16.47	2.06	2.20	15.79	1.05	1.48
Human felling	79.85	2.10	7.35	71.37	2.10	2.28	69.17	1.44	1.77
Stem broken	-		-	125.14	3.29	4.41	87.62	2.37	3.37
Uprooted	169.27	3.76	7.83	116.62	5.55	5.82	88.21	2.94	3.86
Others	-	-	-	10.76	3.59	3.54	3.97	1.99	2.32

6.1.8 Regeneration of broadleaved trees

The height class distribution of the regenerating plant species are presented in Tables 6.1-15 to 6.1-17 and in Figure 6.1-20. The estimated number/ha of individuals in the regeneration layer (<5 cm DBH) was highest in Plot C, followed by Plot A and lowest in Plot B. Apart from what has been enumerated in inventory of trees >5cm DBH additional woody species were encountered in regeneration phase and they were collectively termed as bush species.

Table 6.1-15: Regeneration of plant species/ha in PL OT A estimated from 16 samples by height classes [cm]. * Indicates tree species >5 cm dbh also present in regeneration layers and without any sign are bush species, 0 indicates absence in that height class. The species lists constituted more than 80% of the regeneration of the samples, the complete lists of species are provided in Annex 2.

Species	0-10	11-30	31-50	51-80	81-130	131-200	201-00	301-00	401-500	>500<5cm DBH	Total/ha	% Total
Castanopsis tribuloides*	99.52	547.36	547.36	1144.48	1990	485.16	547.36	248.8	223.92	162	5996.1	41.44
Sophora wightii	49.76	149.28	149.28	149.28	298.6	62.2	12.44	0	0	0	870.8	6.02
Sloanea tomentosa*	49.76	199.04	49.76	149.28	149.3	24.88	0	12.44	0	0	634.44	4.39
Symplocos ramosissima*	99.52	49.76	99.52	99.52	199	12.44	12.44	12.44	0	12.4	597.12	4.13
Mussaenda roxburghii	0	49.76	99.52	149.28	248.8	0	37.32	0	0	0	584.68	4.04
Albizia sherriffii*	0	199.04	49.76	99.52	99.52	0	12.44	24.88	0	0	485.16	3.35
Daphne bholua	0	49.76	149.28	99.52	49.76	12.44	0	0	0	0	360.76	2.49
Lindera pulcherrima*	49.76	149.28	0	0	99.52	49.76	0	0	12.44	0	360.76	2.49
Macropanax undulatus*	0	0	99.52	149.28	49.76	24.88	12.44	0	12.44	12.4	360.76	2.49
Styrax grandiflorus*	0	99.52	49.76	0	149.3	24.88	12.44	0	12.44	0	348.32	2.41
D. chartaceum*	0	99.52	0	99.52	49.76	12.44	0	49.76	0	12.4	323.44	2.24
Dichroa febrifuga	0	99.52	149.28	0	0	12.44	12.44	0	0	0	273.68	1.89
Engelhardtia spicata*	0	0	49.76	99.52	99.52	0	12.44	0	12.44	0	273.68	1.89
C. glaucescens*	0	99.52	0	99.52	49.76	12.44	0	0	0	0	261.24	1.81
Eurya accuminata*	0	49.76	0	49.76	99.52	37.32	24.88	0	0	0	261.24	1.81
Maytenus kurzii*	0	49.76	49.76	49.76	99.52	12.44	0	0	0	0	261.24	1.81
Cinnamomum bejolghota*	0	0	0	49.76	49.76	49.76	37.32	37.32	12.44	12.4	248.8	1.72
B. gammieana*	49.76	49.76	0	49.76	49.76	12.44	12.44	0	0	0	223.92	1.55
Cryptocarya bhutanica*	0	0	0	0	199	12.44	0	0	0	0	211.48	1.46
Alcimandra cathcartii*	0	49.76	49.76	0	49.76	0	0	0	0	12.4	161.72	1.12
Ficus sp*	0	99.52	0	0	49.76	12.44	0	0	0	0	161.72	1.12
Others	99.52	49.76	298.56	348.32	149.28	124.4	49.76	0	37.32	49.76	1206.68	8.3405
Total/ha	497.6	2139.7	1890.9	2886.08	4279.0	995.2	796.16	385.64	323.44	274.0	14468.00	100
% Total	3.44	14.79	13.07	19.95	29.58	6.88	5.50	2.67	2.24	1.89	100	

Table 6.1-16: Regeneration of plant species/ha in PLOT B estimated from 16 sample plots by height classes [cm]. * Indicates tree species >5 cm dbh also present in regeneration layers and without any sign are bush species, 0 indicates absence in that height class. The species lists constituted 100% of the regeneration of the samples.

Species	1-10	11-30	31-50	51-80	81-130	131-200	201-300	301-400	401-500	>500<5cm dbh	Total/ha	% Total
Macropanax undulatus*	149.28	995.2	248.8	99.52	0	24.88	0	0	0	0	1517.68	21.59
Castanopsis tribuloides*	248.8	298.56	49.76	99.52	248.8	161.7	136.8	37.3	49.76	87.08	1418.16	20.18
Symplocos ramosissima*	0	149.28	248.8	248.8	199.04	124.4	124.4	24.9	74.64	49.76	1244	17.70
Ardisia macrocarpa	49.76	497.6	497.6	99.52	49.76	12.44	0	0	0	0	1206.68	17.17
Macaranga pustulata*	49.76	199.04	348.32	49.76	0	0	0	0	0	0	646.88	9.20
Lindera pulcherrima*	49.76	149.28	0	0	0	0	0	0	0	0	199.04	2.83
Beilschmiedia gammieana*	0	99.52	0	0	0	0	12.44	0	0	12.44	124.4	1.77
Elaeocarpus lanceifolius*	0	99.52	0	0	0	0	0	0	0	0	99.52	1.42
Turpinia nepalensis*	0	49.76	0	0	0	24.88	0	0	0	0	74.64	1.06
Daphne bholua	0	0	0	49.76	0	12.44	0	0	0	0	62.2	0.88
Acer oblongum*	0	0	0	0	49.76	0	0	0	0	0	49.76	0.71
Cinnamomum bejolghota	0	0	49.76	0	0	0	0	0	0	0	49.76	0.71
C. impressinervium*	0	49.76	0	0	0	0	0	0	0	0	49.76	0.71
Eurya accuminata*	0	49.76	0	0	0	0	0	0	0	0	49.76	0.71
Hovenia acerba *	0	0	0	0	49.76	0	0	0	0	0	49.76	0.71
Juglans regia*	0	0	0	49.76	0	0	0	0	0	0	49.76	0.71
Maytenus kurzii*	0	49.76	0	0	0	0	0	0	0	0	49.76	0.71
Syzygium cumini	49.76	0	0	0	0	0	0	0	0	0	49.76	0.71
Quercus glauca*	0	0	0	0	0	0	0	0	0	24.88	24.88	0.35
Sophora wightii subsp.bhutanica	0	0	0	0	0	0	12.44	0	0	0	12.44	0.18
Total	597.12	2687.04	1443	696.6	597.12	360.8	286.1	62.2	124.4	174.16	7028.6	100.00
% Total	8.50	38.23	20.53	9.91	8.50	5.13	4.07	0.88	1.77	2.48	100	

Table 6.1-17: Regeneration of plant species/ha in PLOT C estimated from 16 sample plots by height classes [cm]. * indicates trees species >5 cm dbh also present in regeneration layers and without any sign are bush species, 0 indicates absence in that height class. The species lists constituted more than 80% of the regeneration of the samples, the complete lists of species are provided in annex 2.

Species	1-10	11-30	31-50	51-80	81-130	131-200	201-300	301-400	401-5009	>500<5 cm dbh	Total/ha	% total
Castanopsis tribuloides*	796.16	1293.76	1841.12	1492.8	1443	1007.64	435.4	136.84	111.96	447.84	9006.56	43.10
Symplocos ramosissima*	99.52	447.84	547.36	646.88	298.56	149.28	149.28	24.88	62.2	87.08	2512.88	12.02
Beilschmiedia gammieana*	199.04	696.64	49.76	99.52	49.76	49.76	0	0	0	12.44	1156.92	5.54
Macaranga pustulata*	0	199.04	248.8	149.28	447.84	99.52	0	0	0	0	1144.48	5.48
Daphne bholua	49.76	398.08	49.76	149.28	49.76	37.32	12.44	0	0	0	746.4	3.57
Quercus semiserrata*	49.76	298.56	149.28	49.76	99.52	24.88	0	0	0	0	671.76	3.21
Quercus glauca*	99.52	149.28	99.52	0	99.52	99.52	37.32	12.44	0	12.44	609.56	2.92
Cinnamomum glaucescens*	49.76	199.04	0	99.52	99.52	0	0	0	0	0	447.84	2.14
Engelhartia spicata*	49.76	149.28	99.52	149.28	0	0	0	0	0	0	447.84	2.14
Cinnamomum impressinerium*	0	99.52	99.52	49.76	0	49.76	24.88	0	0	74.64	398.08	1.90
Docynia indica*	248.8	149.28	0	0	0	0	0	0	0	0	398.08	1.90
Macropanax undulatus*	49.76	199.04	149.28	0	0	0	0	0	0	0	398.08	1.90
Ficus sp*	0	0	248.8	49.76	0	49.76	0	12.44	0	0	360.76	1.73
Ardisia macrocarpa	0	149.28	99.52	0	0	0	0	0	0	0	248.8	1.19
Alcimandra cathcartii*	49.76	149.28	49.76	0	0	0	0	0	0	0	248.8	1.19
Turpinia nepalensis*	0	49.76	149.28	0	0	24.88	0	0	0	12.44	236.36	1.13
Cinnamomum bejolghota*	49.76	149.28	0	0	0	0	0	0	0	0	199.04	0.95
Lithocarpus pachyphyllus*	49.76	99.52	0	0	49.76	0	0	0	0	0	199.04	0.95
Lindera pulcherrima*	0	49.76	49.76	49.76	0	12.44	12.44	0	0	12.44	186.6	0.89
Carpinus viminea*	49.76	99.52	0	0	0	0	0	0	0	0	149.28	0.71
Pongpoma (local name)	0	149.28	0	0	0	0	0	0	0	0	149.28	0.71
Eurya accuminata*	0	99.52	0	0	0	0	0	0	12.44	0	111.96	0.54
Schima wallichii*	0	0	49.76	49.76	0	0	0	0	0	12.44	111.96	0.54
Macaranga denticulata*	0	49.76	0	0	49.76	0	0	0	0	0	99.52	0.48
Quercus griffithii*	0	99.52	0	0	0	0	0	0	0	0	99.52	0.48
Others	49.76	99.52	149.28	49.76	99.52	62.2	37.32	0	12.44	0	559.8	2.68
Total/ha	1940.64	5523.36	4130.08	3085.12	2786.6	1666.96	709.08	186.6	199.04	671.76	20899.2	100.00
Total % share	9.28571	26.4286	19.7619	14.7619	13.333	7.97619	3.3929	0.8929	0.9524	3.21429	100.00	

There were 28 tree species in the regeneration layer that were represented in the adult tree population (>5cm DBH) and additional 5 bush species in PLOT A, 16 trees species and three bush species were observed in PLOT B and 28 trees and three bush species were observed in PLOT C. Overall more than 50% of the tree species occurring in the main canopy were represented in the regeneration phase. The regenerating tree species ratio (number of regenerating tree species/ total number of tree species present in the stand (Syndriyal and Sharma, 1996) was highest in PLOT C (r = 0.60), followed by PLOT B (r = 0.58) and PLOT C (r = 0.46) (compare Table 6.1-1). *Castanopsis tribuloides* accounted for 41% of all seedlings and saplings in PLOT a, 20% in Plot B and about 43% in PLOT C (Tables 6.1-15 to 6.1-17). However in PLOT B, *Castanopsis* tribuloides was not the most abundant species. *Macropanax undulatus* had most individuals, *Symplocos ramosissima* and *Ardisia macrocarpa* accounted for similarly high shares as *Castanopsis*.

When looking at the overall distribution of seedlings and saplings in the three exploratory plots it can be seen that there are distinct differences in the height classes up to about 200cm. beyond 200cm height the sapling density is comparably high among the plots. Overall, PLOT B had the lowest density in seedlings and saplings (Figure 6.1-20).

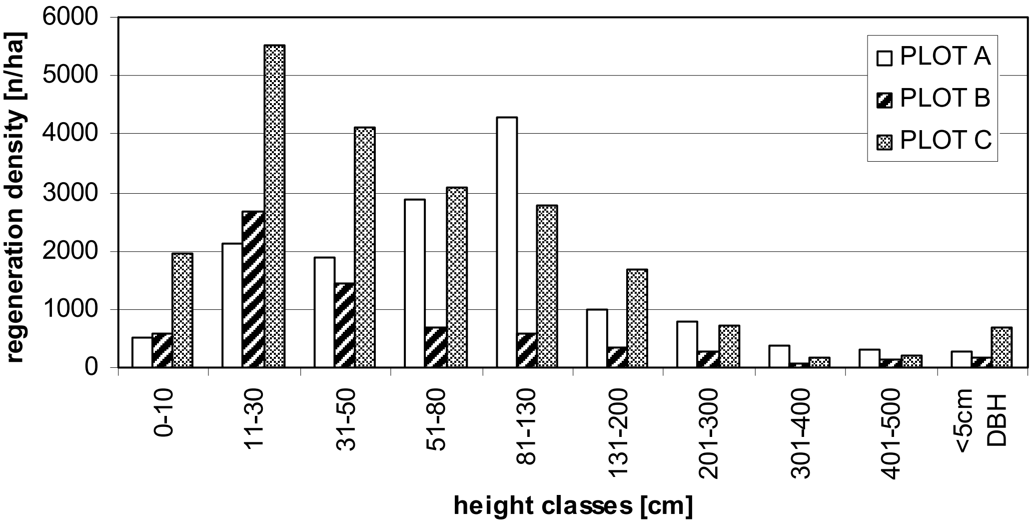


Figure 6.1-20. Distribution of seedlings and saplings over height classes in the exploratory plots.

Generally, the assessment of vitality of the saplings and seedlings based on shape, damages by biotic and abiotic agents, colour of the leaves etc showed that most of the seedlings and saplings had good vigour (90%), just negligible numbers assessed as having poor vigour (Table 6.1-18). However, there were differences between the plots, the highest number of regeneration of good vigour was observed in PLOT C, followed by PLOT A and PLOT B.

Nevertheless, it was observed that some species that were present in the main canopy were absent in regeneration phases. For instance, *Elaeocarpus lanceifolius* and *Schima wallichi* were prominent in terms of basal area distribution in PLOT A and PLOT C but were absent in regeneration phase indicating unfavourable germination and or growth conditions for such tree species.

Table 6.1-18: The frequency distribution of seedlings (>10 cm, < 130 cm) in stem density [n/ha] by vitality classes. The vitality was assessed only for these categories regeneration, refer Table 1 in methodology section for reference to vitality classes. (n=16 for each exploratory plot).

Vitality	PLOT A	PLOT B	PLOT C	total/ha	% Total
Freshly dead	99.52	49.76	895.68	1044.96	1.9
Very poor vigour	199.04	49.76	597.12	845.92	1.5
Poor vigour	0	0	0	0	0.0
Medium vigour	0	49.76	99.52	149.28	0.3
Good vigour	298.56	0	2985.6	3284.16	5.9
Very Good vigour	10598.88	5125.28	34234.88	49959.04	90.4
Total/ha	11196.00	5274.56	38812.8	55283.36	100.0

It was already presented in section 6.6 that a substantial number of the stum ps were found sprouting which contributed considerably to th e pool of regeneration. Mo re than 30% of the regeneration in PLOT A, 15% in PLOT B and 41% in PLOT C were sprouts from snags and stumps (see Table 6-19).

Table 6.1-19: Origin of regeneration (seed, sprout) on the exploratory plots.

	PLOT A		PLOT B		PLOT C	
Species	Coppice	Seed	Coppice	Seed	Coppice	Seed
Acer laevigatum	0	24.86	0	0	0	12.43
Acer oblongum	0	24.86	0	12.43	0	0
Albizia sherriffii	0	149.16	0	0	0 0	
Alcimandra cathcartii	0	49.72	0	0	12.43	49.72
Ardisia macrocarpa	0	0 0		310.75	0	62.15
Beilschmiedia assamica	0	49.72	0	0	0 0	
Beilschmiedia gammieana	0	74.58	0	49.72	12.43	323.18
Buddleja crispa	0	37.29	0	0	0 0	
Carpinus viminea	0	49.72	0	0	0	37.29
Castanopsis tribuloides	1441.88	1305.15	372.9	335.61	2821.61	1031.69
Cinnamomum bejolghota	12.43	161.59	0	12.43	0 49.7	2
Cinnamomum glaucescens	12.43	62.15	0	0	0	111.87
Cinnamomum impressinerium	0	37.29	0	12.43	0	211.31
Celtis tetrandra	0	0 0		0	0	12.43
Cryptocarya bhutanica	0	62.15	0	0	0 0	
Daphne bholua	12.43	87.01	0	24.86	0	223.74
Daphniphyllum chartaceum	0	136.73	0	0	0	12.43

Table 6.1-19. Continued

Desmodium renifolium	0	12.43	0	0	0 0	
Docynia indica	0	0 0		0	0	99.44
Dichroa febrifuga	12.43	74.58	0	0	0 0	
Ehretia wallichiana	0	0 0		0	0	24.86
Elaeocarpus lanceifolius	0	12.43	0	24.86	0	0
Elaeagnus conferta	0	0 0		0	0	24.86
Engelhardtia spicata	0	87.01	0	0	0	136.73
Eurya accuminata	24.86	87.01	0	12.43	0 37.29	
Ficus sp	0	49.72	0	0	0	136.73
Hovenia acerba	0	12.43	0	12.43	0	0
Juglans regia	0	0 0		12.43	0	0
Ilex kingiana	0	12.43	0	0	0 0	
Lindera pulcherrima	24.86	111.87	0	49.72	0 74.5	8
Lithocarpus pachyphyllus	0	0 0		0	0	49.72
Macaranga denticulata	0	0 0		0	0	24.86
Macaranga pustulata	0	24.86	0	161.59	0 360.47	
Macropanax undulatus	0	136.73	0	397.76	0	99.44
Maytenus kurzii	0	74.58	0	12.43	12.43	37.29
Mussaenda roxburghii	0	174.02	0	0	0 0	
Myrica esculenta	0	24.86	0	0	0	12.43
Myrsine semiserrata	0	0 0		0	0	12.43
Pongpoma (local name)	0	0 0		0	0	37.29
Quercus glauca	0	49.72	0	24.86	99.44	174.02
Quercus griffithii	0	0 0		0	0	24.86
Quercus semiserrata	0	0 0		0	186.45	0
Schima wallichii	0	24.86	0	0	0	37.29
Sloanea tomentosa	12.43	174.02	0	0	0 0	
Sophora wightii subsp.bhutanica	49.72	223.74	0	12.43	0	0
Styrax grandiflorus	37.29	87.01	0	0	0	24.86
Symplocos ramosissima	12.43	174.02	12.43	596.64	0	12.43
Toona ciliata	0	37.29	0	12.43	24.86	957.11
Turpinia nepalensis	0	62.15	0	37.29	0 87.0	1
Total	1653.19	4039.75	385.33	2125.53	3169.65	4623.96
% share /Plot	29.04	70.97	15.34	84.65	40.66	59.33

6.1.9 Responses of regeneration to light and site factors

The general light conditions of the regeneration sample plots are presented in Figure 6.1-21. In PLOT A more than 90% of the regeneration sample plots were below 10% relative light, in PLOT B about 70% and 75% in PLOT C.

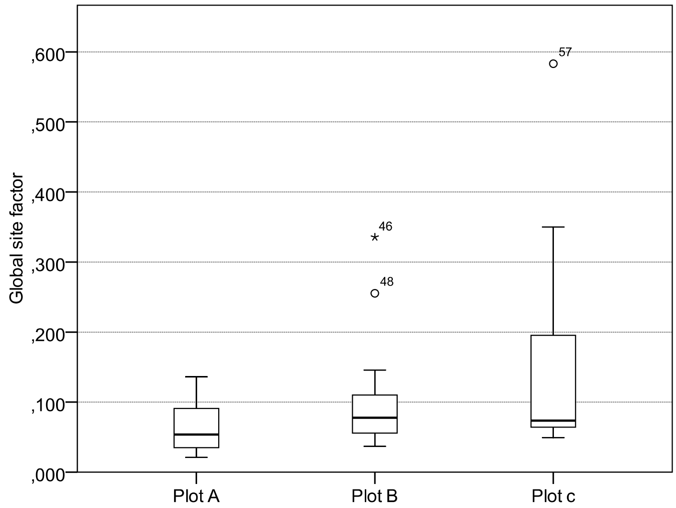


Figure 6.1-21: Box plots of global site factor (fraction of above canopy direct light) for the three exploratory plots in Rimchu. N per plot = 16.

The environmental variables such as light (GSF) and other specific microsite factors such as percent ground vegetation cover by herbaceous vegetations (CP), humus layer, area available for stocking, soil coarse fraction (SCF), maximum height of the ground vegetation (Hmax) at each plot level and additionally altitude and slope at the regional level (analysis covering all three exploratory plots) were used in ordination analysis using CANOCO 4.5 (Leps and Smilauer 2003). Firstly, detrended correspondence analysis (DCA) was used as an indirect gradient analysis and then the contribution of site and environmental factors in explaining the ordination axes was assessed using the direct gradient technique redundancy analysis (RDA).

For a first explorative ordination of the species detrended correspondence analysis (DCA) was used.

The result of the detrended correspondence analysis (DCA) is shown in Table 6.1-21 and in Figures 6.1-22 and 6.1-23 for the exploratory plots individually and for the pooled data across all three exploratory plots. The species beta diversity indicated by length of gradients and species variability as explained by each ordination axis is shown in Table 6.1-21. The length of the gradients is generally below 3 indicating that linear methods of explaining the underlying gradient with explanatory variables may be appropriate. The percentage variance explained in DCA is relatively high indicating that the species are spread over all samples.

Table 6.1-20: Cumulative percentage variance of species data explained by four ordination axes (1, 2, 3 and 4) in DCA. Length of gradient represents the species′ beta diversity.

All plots	**1**	**2**	**3**	**4**
All plots				
Eigen values	0.386	0.27	0.19	0.146
Length of gradient	3.024	2.48	2.176	1.922
Cumulative percentage variance of species data	9.4	16.0	20.7	24.4
PLOT A	**1**	**2**	**3**	**4**
Eigen values	0.402	0.219	0.146	0.095
Length of gradient	2.242	1.993	1.643	1.595
Cumulative percentage variance of species data	18.4	28.5	35.1	39.5
PLOT B				
Eigen values	0.403	0.198	0.061	0.029
Length of gradient	2.598	2.282	1.170	0.898
Cumulative percentage variance of species data	18.3	27.3	30.1	31.5
PLOT C				
Eigen values	0.401	0.226	0.122	0.064
Length of gradient	2.588	2.281	1.627	1.541
Cumulative percentage variance of species data	14.6	22.9	27.4	29.7

The species that are located close to each other in the ordination are likely to occur together in the stand, for example the four economically important species *Alcimandra catcarthii, Schima wallichi, Carpinus viminea, Elaeocarpus lanceifolius* formed a group in Figure 6.1-22 (upper panel) and a similar grouping of the same species can also be found in Figure 6.1-23 (upper panel). Species characteristic of gaps such as grasses, forbs, ferns formed another such group, in the respective figures. Two species, *Macaranga pustulata* and *Juglans regia,* which are typical for gaps occurred together on the right side of Figure 6.1-22 (PLOT B, bottom panel). The most dominant species *Castanopsis tribuloides* appears almost in the center in all the ordination plots indicating its presence in all the sample plots. All three individual plots show quite similar groupings. And also at the regional level (Rimchu level) the same general pattern can be found. Three major species groups can be identified. At the lower end of the regional diagram (Figure 6.1-23, bottom panel) *Alcimandra catcarthii, Carpinus viminea* and other major broadleaved species can be found; towards the right are the pioneer species such as *Macaranga pustulata* and *Juglans regia*. Another group represented by *Quercus semiserrata, Albizia sp*. and *Symplocos sp.* can be seen in the upper part of the diagram. However, what may have been the possible underlying reasons for species partitioning along these gradients was not clear from DCA ordination.

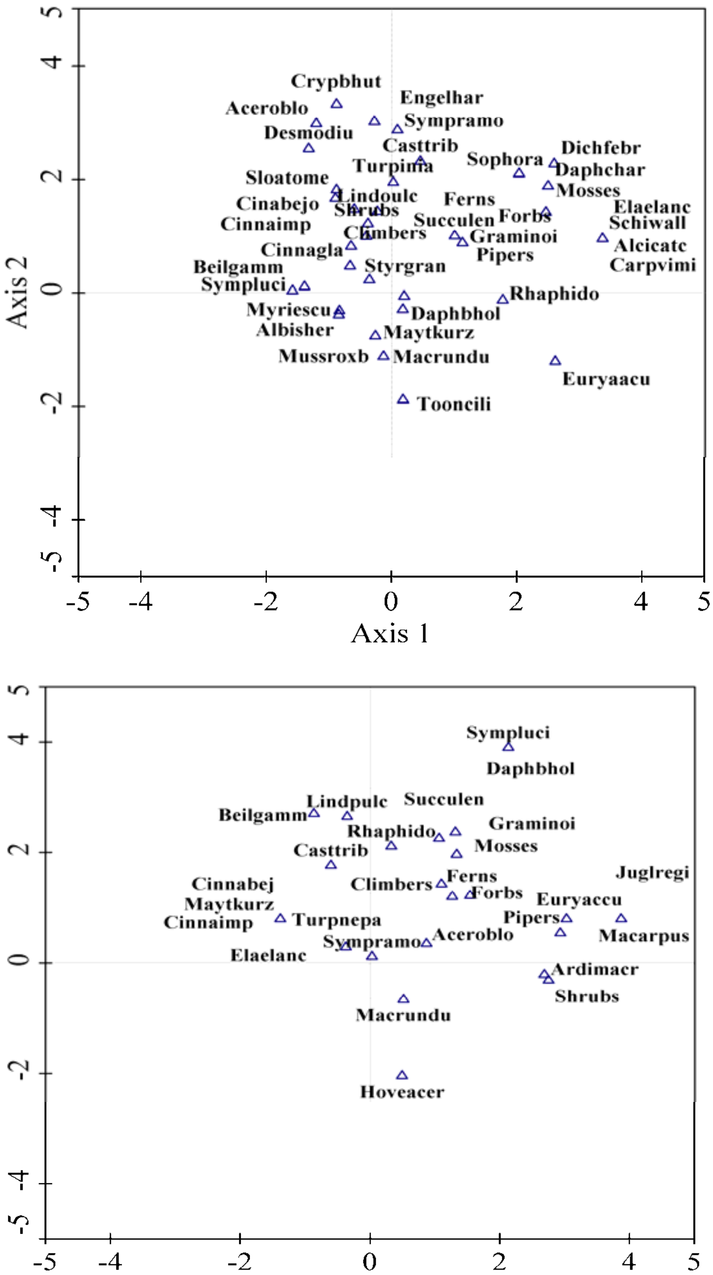
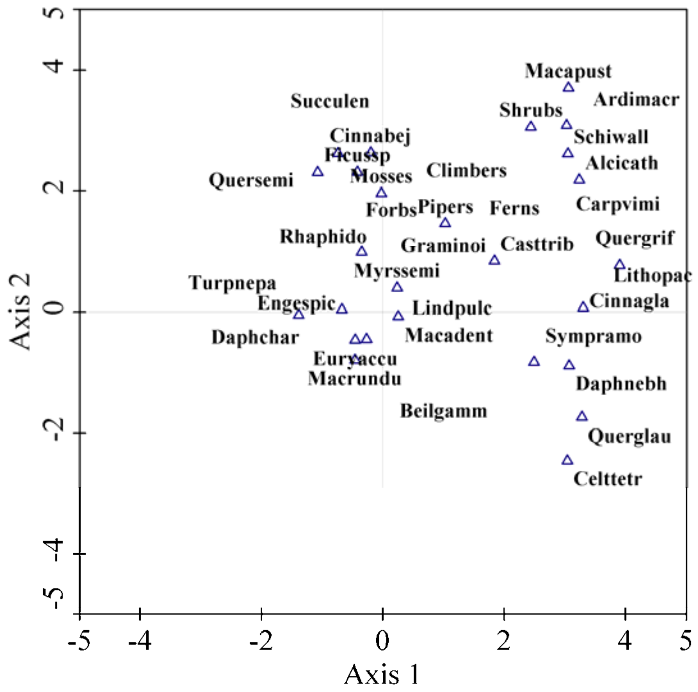


Figure 6.1-22: Biplots of species and samples produced using detrended correspondence analysis (DCA) based on presence and absence of regenerating species from 16 sub plots per exploratory plot. At the top is PLOT A, at the bottom PLOT B. The species list is provided in Table 6-21. The percentage variance explained by each axis in species data is shown in Table 6-20. The complete species list as used in this ordination diagram is presented in Table 6-21. Here regeneration <130 cm height was used. The axes represent beta diversity (length of gradients) as shown in Table 6-21. The first four letter of genus and first four letters of species were used as species name.



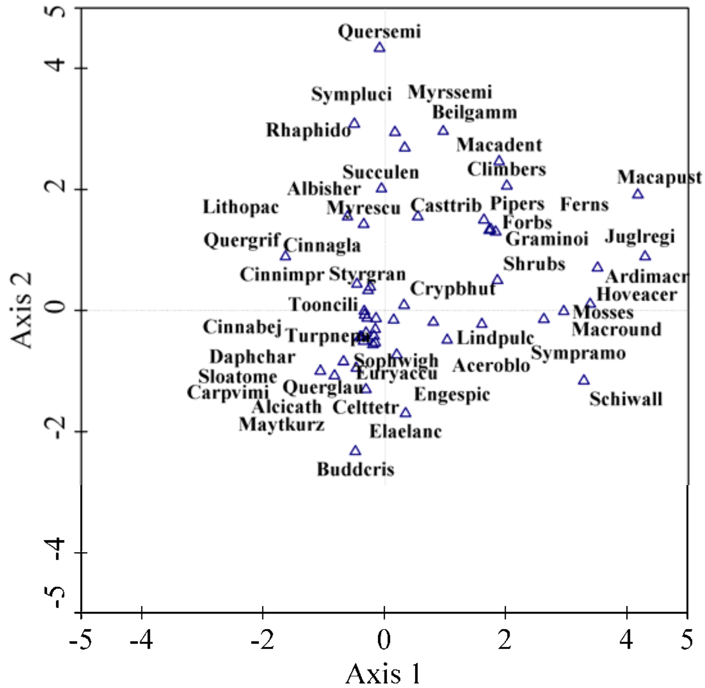


Figure 6.1-23: Biplots of species and samples produced using detrended correspondence analysis (DCA) based on presence and absence of regenerating species from 16 sub plots per exploratory plot. At the top is PLOT C, at the bottom aggregation of three plots. The species list is provided in Table 6.1-21. The percentage variance explained by each axis in species data is shown in Table 6.1-20. The complete species list as used in this ordination diagram is presented in Table 6.1-21. Here regeneration <130 cm height was used. The axes represent beta diversity (length of gradients) as shown in Table 6.1-21. The first four letter of genus and first four letters of species were used as species name.

Since the length of gradients of the data set was generally below 3 a linear method is recommended for further analysis of such gradients (Leps and Šmilauer, 2003). In order to find out the possible reasons of species occurrences in Figures 6.1-22 and 6.1-23, the further investigation was conducted with RDA (a constrained multivariate method) with light and other site factors as potential explanatory variables. Results are presented in Figure 6.1-24. At plot level none of the explanatory variables was significantly correlated with species data (tested by automatic forward selection procedures using Monte Carlo Permutation Tests (MCPT)).

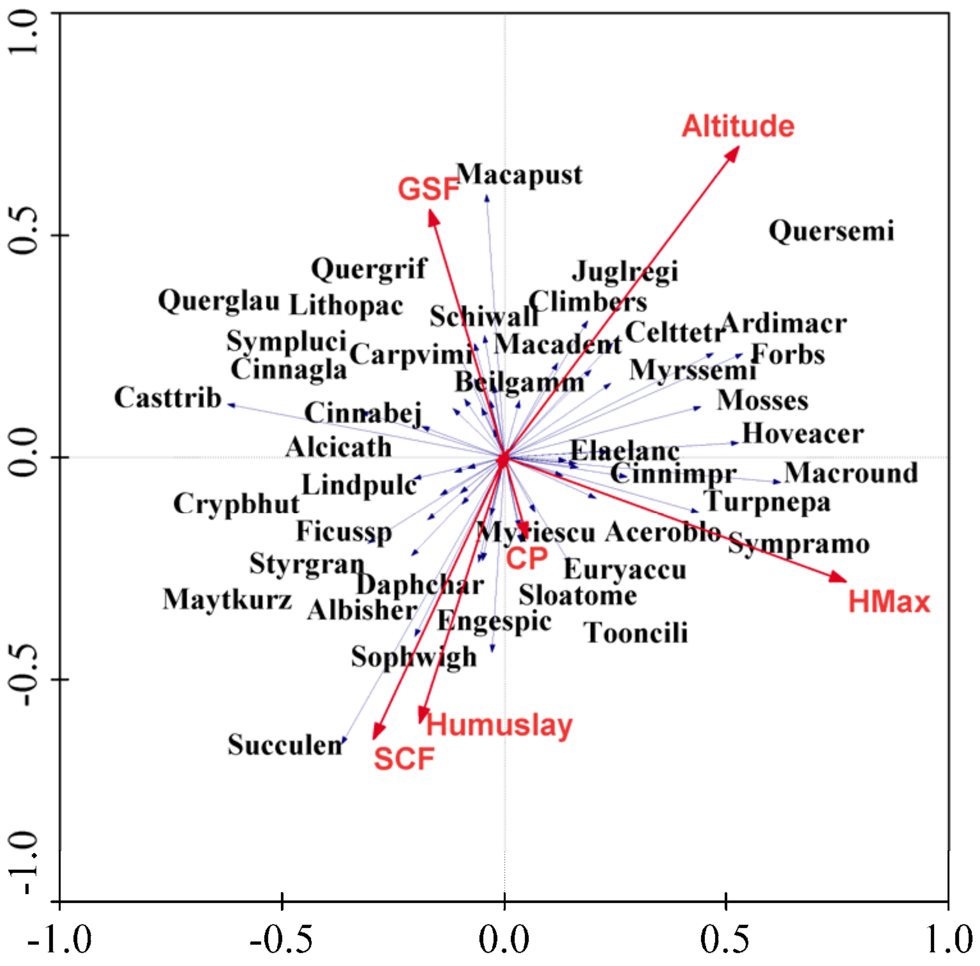


Figure 6.1-24: Biplot ordination diagram produced with redundancy analysis (RDA) of regenerating species with light and other site factors at the regional level (pooled exploratory plots). For species acronyms see Table 6.1-21.

However, at the regional level altitude, height of the ground vegetation (Hmax) and light (GSF) were significantly correlated with species occurrence (Monte Carlo Permutation Test; F, 4.18, p-value=0.002; F=3.42, and p-value = 0.002, F, 2.44, p-value = 0.04). It showed that some species were positively correlated with altitude, e.g. climbers (lianas), *Juglans regia*, *Quercus semiserrata, Celtis tetrandra.* Likewise, GSF was positively correlated with *Macaranga pustulata*; *Quercus griffithi*, *Juglans regia* and *Schima wallichi*, indicating that these species may occur in environments with higher light intensity. Species located opposite to GSF were *Turpinia nepalensis, Acer obl ongum, Eurya accuminata etc. (* Figure 6.1-23). The maximum ground vegetation height (Hmax) showed positive correlation with *Symplocos ramosissima*, *Acer oblongum, Eurya accuminata* etc, indicating that seedlings and saplings of these species m ay occur together with ground vegetation at m ore open places w ithin the stands. Castanopsis tribuloides, for instance, tends to be clea rly negatively correlated with Hmax indicating that this species may have a different regeneration strategy.

Table 6-21: Species acronym as used in ordination diagrams (Figures 6-22 and 6-24).

Acronyms	Species	Acronyms	Species
Acerlaev	Acer laevigatum	Querglau	Quesrcus glauca
Aceroblo	Acer oblongum	Queraccu	Quercus accuminata
Albisherr	Albizia sherriffii	Quersemi	Quercus semiserrata
Alcicatc	Alcimandra catcarthii	Schiwall	Quercus griffithii
Ardimacro	Ardisia macrophylla	Sloatome	Schima wallichii
Beilassa	Beilschmiedia assamica	Sophwightii	Sloanea tomentosa
Beilgamm	Beilschmiedia gammieana	Styrgrad	Sophora wigthii
Buddcrip	Buddleja crispa	Sympramo	Styrax grandiflorus
Carpvimi	Carpinus viminea	Syzycumi	Symplocos ramosissima
Casttrib	Castanopsis tribuloides	Tooncili	Syzygium cumini
Celttetr	Celtis tetrandra	Turpnepa	Toona ciliata
Cinnabej	Cinnamomum bejolghota	Climbers	Turpinia nepalensis
Cinnaglau	C.glaucescens	Graminoi	General lianas
Cinnaimpr	C. impressinerium	Ferns	Grass species
Crypbhut	Cryptocarya bhutanica	Forbs	Ferns species
Daphbhol	Daphne bholua	Mosses	Forbs species
Daphchar	Daphniphyllum chartaceum	Succulent	Mosses speecies
Desmreni	Desmodium renifolium		Succulent species
Dichfebr	Dichroa febrifuga		
Docyindic	Docynia indica		
Ehrewall	Ehretia wallichiana		
Elaeagnu	Elaeagnus		
Elaelanc	Elaeocarpus lanceifolius		
Engespic	Engelhardtia spicata		
Euryacum	Eurya accumunata		
Ficussp	Ficus sp		
Hovecerb	Hovenia acerba		
Ilexking	Ilex kingiana		
Juglregi	Juglans regia		
Lindpulc	Lindera pulcherrima		
Lithpach	Lithocarpus pachyphyllus		
Macadent,	Macaranga denticulate		
Macapust	Macaranga pustulata		
Macrpana,	Macropanax undulatus		
Maytkurz,	Maytenus kurzii		
Mussroxb	Mussenda roxburghii		
Myriescul	Myrica esculenta		
Myrssemi	Myrsine semiserrata		
Quergrif	Quercus griffithii		

6.2 Biomass relations of young trees growing below canopy

6.2.1 Biomass partitioning

The studied species were sapling stages to poles sizes and their height ranged from 1.0 meters and 6.0 meters and the average height was 3.98 meters with standard deviation (sd) of 1.11. Likewise the mean dbh of those species ranged from 1.41 to 4.10 cm (Table 6.2-1) and age range from 4 to 16 years with the mean age of 8.88. The differences among the species with regards to their mean height mean DBH and mean ages were tested (ANOVA, Posthoc test of Bonferroni test). The results showed no significant differences in their height and DBH ($p<0.05$) however there were significant differences in age between Macaranga pustulata (Mp) and the other three species ($p<0.05$) but there were no differences in mean age between the other three species.

Table 6.2-1. Basic biometric attributes of biomass sample trees, Cb = Cinnamomum bejolghota, Ct = Castanopsis tribuloides, Mp = Macaranga pustulata, and Sr = Symplocos ramosissima.

Species	Height [m]				DBH [cm]			Age [years]			
	n	mean	min	max	mean	min	max	n	mean	min	max
Cb	20	3.58	2.0	6.0	2.31	1.4	4.1	19	9.1	6.0	13.0
Ct	20	4.15	3.0	6.0	2.79	1.5	4.1	17	10.53	5.0	16.0
Mp	20	4.49	2.0	6.0	2.77	1.4	4.7	20	6.35	4.0	10.0
Sr	20	3.69	3.0	6.0	2.41	1.4	3.8	19	9.68	6.0	14.0
Total	80	3.98	2.0	6.0	2.57	1.4	4.7	75	8.88	4	16

The total above ground biomass (TDW) of these tree species ranged from 1194.44 to 2108.78 g, and the mean TDW was 1644.29 g with standard deviation around the mean of 133.29 g. Table 6.2-2 and 6.2-3 as well as Figure 6.2-1 show the biomass compartments for each species. Generally the mean oven-dried stem biomass was almost equal among the four trees except *Symplocos ramosissima* (Sr) which was higher compared to the other three species (Figure 6.2-1). The mean branch biomass was highest in *Castanopsis tribuloides* (Ct) followed by Sr, *Macaranga pustulata* (Mp) and *Cinnamomum bejolghota* (Cb). The mean leave biomass was highest in Cb, followed by Mp, Ct and Sr (Figure 6.2-1).

Table 6.2-2. The biomass compartments of four selected tree species.

species		SDW [g]			BDW [g]			LDW [g]		
	n	mean	min	max	mean	min	Max	mean	min	max
Cb	20	957.3	106.7	2727.3	184.5	150.1	556.8	299.61	100.2	1059.8
Ct	20	1334.5	476.0	2899.2	563.9	111.6	2060.6	210.33	49.9	598.8
Mp	20	843.2	107.1	2029.8	167.8	20.8	543.1	183.38	14.8	522.8
Sr	20	1253.9	392.8	5734.7	464.5	94.8	1708.4	114.10	25.5	465.7

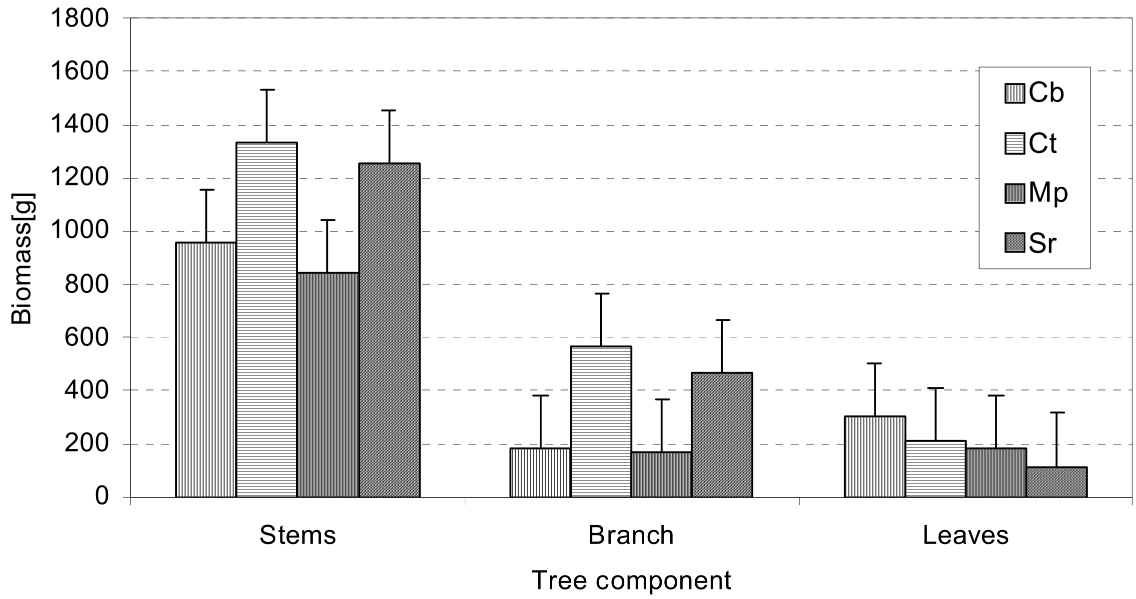


Figure 6.2-1: Distribution of mean above ground oven-dried biomass by tree component of four co-occurring tree species in broad leaved forests of Rimchu. The error bar represents standard deviation from mean.

Table 6.2-3: Biomass partitioning as proportion of total biomass (leaves, branches and stem) in four species in Rimchu. The differences were analysed with an ANOVA using species as factor, comparisons are based on Post hoc Bonferroni test. Different letters in () show significant difference at alpha = 0.05. *Ct = Catanopsis tribuloides, Cb= Cinnamomum bejolghota, Sr = Symplocos ramosissima, Mp = Macaranga pustulata.*

Species	Leaves (%)	Branches (%)	Stem (%)
Cb	23 (b)	12 (a)	65 (a)
Ct	11 (a)	25 (b)	64 (a)
Mp	17 (b)	15 (a)	68 (a)
Sr	7 (a)	25 (b)	68 (a)

The difference in the aboveground oven dried biomass partitioning between, stem, branches and leaves across species are shown in Table 6.2-3. The stem accounted for 60-70% of the biomass. The branches account for 12-25% of the biomass and leaves 7-23 % across species respectively. Some significant differences were observed in proportion of leaves biomass between species. Sr had the lowest leave biomass fraction (7%), followed by Ct (11 %). The leave mass fractions of these two species were not significantly different from each other (Bonferroni p>0.05). Significant differences in leaves mass fraction and branch mass fraction (Post Hoc Bonferroni test p<0.05) were observed between species. There were significant differences both in leaves and branch mass fraction of Mp and Sr, between Cb and Ct. The differences were not observed between Sr and Ct in all the tree components (Posthoc Bonferroni test, p>0.05). There was no significant difference in the stem mass fraction between the tree species (Table 6.2-3).

6.2.2. Regression functions for biomass components

As a first step the correlations between the biomass compartments and potential predictor variables were analyzed. The results are presented in Table 6.2-4. The correlations were significantly positive for all species between the tested independent variables and stem biomass (SDW) and total biomass (TDW) respectively. Weaker correlations, partly non-significant for MP, Sr and Ct, were found for branch and particularly leaf biomass compartments. The crown width (CW) was weakly correlated with stem biomass (SDW) in all species compared with other predictor variables. Interestingly, there was a negative correlation of height of Mp with branch (BDW) and biomass of leaves (LDW).

Table 6.2-4: Correlation matrix of dependent (column) and independent (rows) variables from the analyzed species in Rimchu. ** = correlation is significant at 0.01 level (2-tailed), * = correlation is significant at 0.05 level (2-tailed); rp = Pearson correlation, rs = Spearman correlation coefficient. Species codes: Ct = *Castanopsis tribuloides*, Cb = *Cinnamomum bejolghota*, Mp = *Macaranga pustulata*, Sr = *Symplocos ramosissima*. SDW = Stem oven dry weight [g], BDW = branch dry weight [g], LDW= leaf dry weight [g], H = height [m], Dcoll = collar diameter [cm], D10 = diameter 10 cm above ground [cm], dbh = diameter at breast height [cm], CL = crown length [m], CW = crown width [m].

Species	Variables	SDW		BDW		LDW		TDW	
		rp	rs	rp	rs	rp	rs	rp	rs
Ct	H	0.82**	0.77**	0.59*	0.67*	0.11	0.22	0.76*	0.81**
	Dcoll	0.81**	0.78**	0.71**	0.69**	0.35	0.39	0.82**	0.82**
	D10	0.80**	0.76**	0.67**	0.64**	0.3	0.3	0.80**	0.78**
	DBH	0.88**	0.78**	0.80**	0.80**	0.37	0.36	0.90**	0.87**
	CL	0.74**	0.73**	0.77**	0.76**	0.29	0.26	0.77**	0.77**
	CW	0.52*	0.57*	0.4	0.51*	0.45	0.49*	0.52*	0.61**
Cb	H	0.91**	0.85**	0.71**	0.78**	0.66**	0.68**	0.89**	0.85**
	Dcoll	0.88**	0.90**	0.79**	0.81**	0.75**	0.75**	0.91**	0.91**
	D10	0.84**	0.85**	0.79**	0.80**	0.76**	0.80**	0.89**	0.89**
	DBH	0.90**	0.93**	0.84**	0.89**	0.84**	0.84**	0.96**	0.96**
	CL	0.64**	0.45	0.46	0.57**	0.54*	0.58**	0.63**	0.58**
	CW	0.54*	0.64**	0.69**	0.72**	0.58**	0.74**	0.62**	0.69**
Mp	H	0.77**	0.80**	-0.34*	-0.22	-0.43*	-0.34*	0.42	0.58**
	Dcoll	0.90**	0.93**	0.13	0.14	0.18	0.15	0.83**	0.84**
	D10	0.90**	0.92**	0.12	0.1	0.2	0.13	0.82**	0.80**
	DBH	0.90**	0.87**	0.06	0.06	-0.03	-0.08	0.70**	0.69**
	CL	0.26	0.2	0.67**	0.61**	0.29	0.23	0.45	0.36
	CW	0.07	0.16	0.65**	0.60**	0.74	0.80**	0.36	0.52*
Sr	H	0.82**	0.74**	0.77**	0.68**	0.67**	0.65**	0.84**	0.77**
	Dcoll	0.51*	0.57**	0.39	0.33	0.37	0.4	0.49*	0.54*
	D10	0.53*	0.59**	0.41	0.36	0.39	0.44	0.52*	0.57**
	DBH	0.75**	0.86**	0.62**	0.62**	0.65**	0.74**	0.75**	0.84**
	CL	0.65**	0.59**	0.67**	0.59**	0.55**	0.54*	0.68**	0.62**
	CW	0.56**	0.46*	0.33	0.33	0.46*	0.39	0.49*	0.39

In building the regression models for biomass compartments two approaches had been chosen. Firstly, regression models were tested with DBH as only predictor variable.

Secondly, the models were extended by alternative tree size predictor variables. The results of the regression using the allometric equations (12) and (13) (see section 5.2.1) showed differences in predicting the biomass of different components of the tree species when only DBH was used compared with models with alternative independent variables. For the species Ct and Cb DBH explained a relatively high share ($r^2 > 0.70$) of the variance in total biomass (TDW) (Table 6.2-4). However, the inclusion of crown length (CL) further increased the r^2 slightly. For Mp and Sr DBH alone did not explain much of the biomass variation compared with the other two species. The r^2 improved by either using additional predictor variables or using another variable instead of DBH (Table 6.2-6). For instance, for Sr the use of H and CW instead of DBH improved the share of explained variation in TDW to $r^2 > 0.68$ (Table 6.2-6). The regression models for leaves biomass were the weakest of all biomass compartments for all species, compared with branch and stem components which indicates higher sensitivity and faster response to increased competition. The standardised predicted values and resulting standardized residuals for each regression model were plotted to judge the behaviour of the models and analysed for normality. The analysis did not show violation of normality assumptions. The scatter plots of predicted variable and residuals for each of the tree compartments were similar across the species and did not indicate problems with heteroscedasticity or bias. As an example the residual plots for *Castanopsis tribuloides* are shown as Figure 6.2-6.

Table 6.2-5: Regression using DBH as predictor variable in regression models of the form ln (y)=a + b*ln (x) where a and b are model parameters. Ct = Castanopsis tribuloides, Cb= Cinnamomum bejolghota, Mp= Macaranga pustulata, and Sr = Symplocos ramosissima. (Significant at alpha =0.05) SDW = Stem dried weight [g], BDW = Branch dried weight [g], LDW = Leaves dried weight [g] and TDW = Total dried weight [g], Ln = natural logarithm.

Species	Dependent variables	Independent variable	a	b	Adjusted R^2	(P-value)
Ct	Ln SDW	Ln DBH	5.50	1.58	0.76	.000
n=20	LnBDW	LnDBH	4.24	1.89	0.63	.000
	LnLDW	LnDBH	4.32	0.85	0.09	0.10
	LNTDW	LnDBH	5.91	1.64	0.81	.000
Cb	Ln SDW	Ln DBH	4.97	2.08	0.80	0.000
n=20	LnBDW	LnDBH	2.41	2.92	0.68	0.000
	LnLDW	LnDBH	4.31	1.53	0.69	0.000
	LnTDW	LnDBH	5.48	1.99	0.92	0.000
Mp	Ln SDW	Ln DBH	4.61	1.93	0.79	0.000
	LnBDW	LnDBH	4.92	-0.14	0.003	0.81
n=20	LnLDW	LnDBH	4.95	-0.06	0.001	0.91
	LnTDW	LnDBH	5.83	1.14	0.46	0.001
Sr	Ln SDW	Ln DBH	5.43	1.73	0.54	0.001
	LnBDW	LnDBH	4.45	1.68	0.35	0.003
n=20	LnLDW	LnDBH	3.24	1.51	0.39	0.002
	LnTDW	LnDBH	5.83	1.72	0.54	0.001

Table 6.2-6: Regression using alternative input variables and the regression model was of the form $\ln(y) = a_0 + b_i \cdot \ln(x_i)$ where a_0 and b_i are model parameters x_i is independent variables. *Ct = Castanopsis tribuloides, Cb= Cinnamomum bejolghota, Mp= Macaranga pustulata, and Sr = Symplocos* ramosissima. The predictors were selected keeping collinearity to its minimum indicated by variance inflation factor (VIF) and improvement in coefficient of determination (r^2). If inclusion of variables kept the VIP ≤2 and if r^2 increased then variables were included in the model. SDW = Stem dried weight [g], BDW = Branch dried weight [g], LDW = Leaves dried weight [g] and TDW = Total dried weight [g], Ln = natural logarithm.

Tree species	Dependent variables	Independent variables (xi)	a_0	b_1	b_2	b_3	adj. r^2
Ct	LnSDW	Ln (DBH, CL)	5.41	1.27	0.39	-	0.78
(n=20)	LnBDW	Ln (DBH, CL,H)	4.92	2.05	1.17	-1.46	0.76
	LnLDW	Ln (CW,CL)	4.44	0.86	0.36	-	0.23
	LnTDW	Ln (DBH, CL)	5.80	1.29	0.44	-	0.84
Cb	LnSDW	Ln (H, CW)	3.49	2.46	0.28	-	0.81
(n=20)	LnBDW	Ln (DBH, CW, CL)	2.59	2.12	1.01	0.18	0.70
	LnLDW	Ln (DBH, CL, CW)	4.26	1.28	0.27	0.18	0.68
	LnTDW	Ln (DBH,CL)	5.36	1.81	0.37	-	0.94
Mp	LnSDW	Ln (Dcoll, CL,CW)	2.67	3.17	0.05	-0.43	0.81
(n=20)	LnBDW	Ln (CL, H)	5.97	1.07	-0.99	-	0.57
	LnLDW	Ln (CW,Dcoll, CL)	4.59	1.84	0.03	-0.14	0.55
	LnTDW	Ln (Dcoll,CW, CL)	4.52	1.93	0.16	0.16	0.68
Sr	LnSDW	Ln (H, CW)	3.87	2.27	0.39	-	0.67
(n=20)	LnBDW	Ln (H, CW)	2.08	2.99	-0.18	-	0.55
	LnLDW	Ln (DBH, CW, CL)	3.13	1.10	0.49	0.38	0.42
	LnTDW	Ln (H, CW)	4.07	2.46	0.18	-	0.68

The models from easily measurable trees attributes such as DBH and height with biomass of the tree components are illustrated in Figures 6.2-3 to 6.2-6. The results show that the TDW per specific DBH size was highest in Sr, followed Cb, Ct and lowest in Mp. However, significant differences in TDW were observed between Mp and other three species (Bonferroni, p-value <0.05, data not shown). When DBH was used as predictor variable TDW (Figure 6.2-4) higher per unit increased in DBH in Cb followed by Sr, Ct and Mp.

There were significant differences in mean TDW between Mp and other three species (Bonferroni, p-value <0.05, data not shown). The figures illustrate different biomass allocation pattern for the analysed tree species under similar site and environmental conditions. The component-wise allocation of biomass as a function of DBH is shown in Figures 6.2-5 to 6.2-7. The mean estimated values for components biomass were tested for their differences by ANOVA between species and the results showed there were no significant differences in mean estimated values of SDW (Bonferroni p>0.05,data not shown) between species. However, significant differences exist in mean estimates of BDW between Cb and Ct and between Ct and Mp (Bonferroni, p-value <0.05). Significant differences were also observed in mean estimated LDW between Cb and Mp (Bonferroni; p<0.05), Cb and Sr (Bonferroni, p<0.001, data not shown).

Cb showed highest stem biomass (SDW) gain per unit increase in DBH, followed by Sr and Ct, Mp and Ct showed similar pattern in SDW with DBH (Figure 6.2-5). The branch biomass

(BDW) was high in Ct and Sr compared with other two species. The branch biom ass of Mp was distinctly smaller compared with other three species (Figure 6.2-6) and was indifferent to its DBH size. The leaves biom ass per unit DBH was higher in Cb com pared with other three species. The leaves biomass of Mp was lowest compared with other three species (Figure 6.2-7) and it was constant for the whole range of DBH.

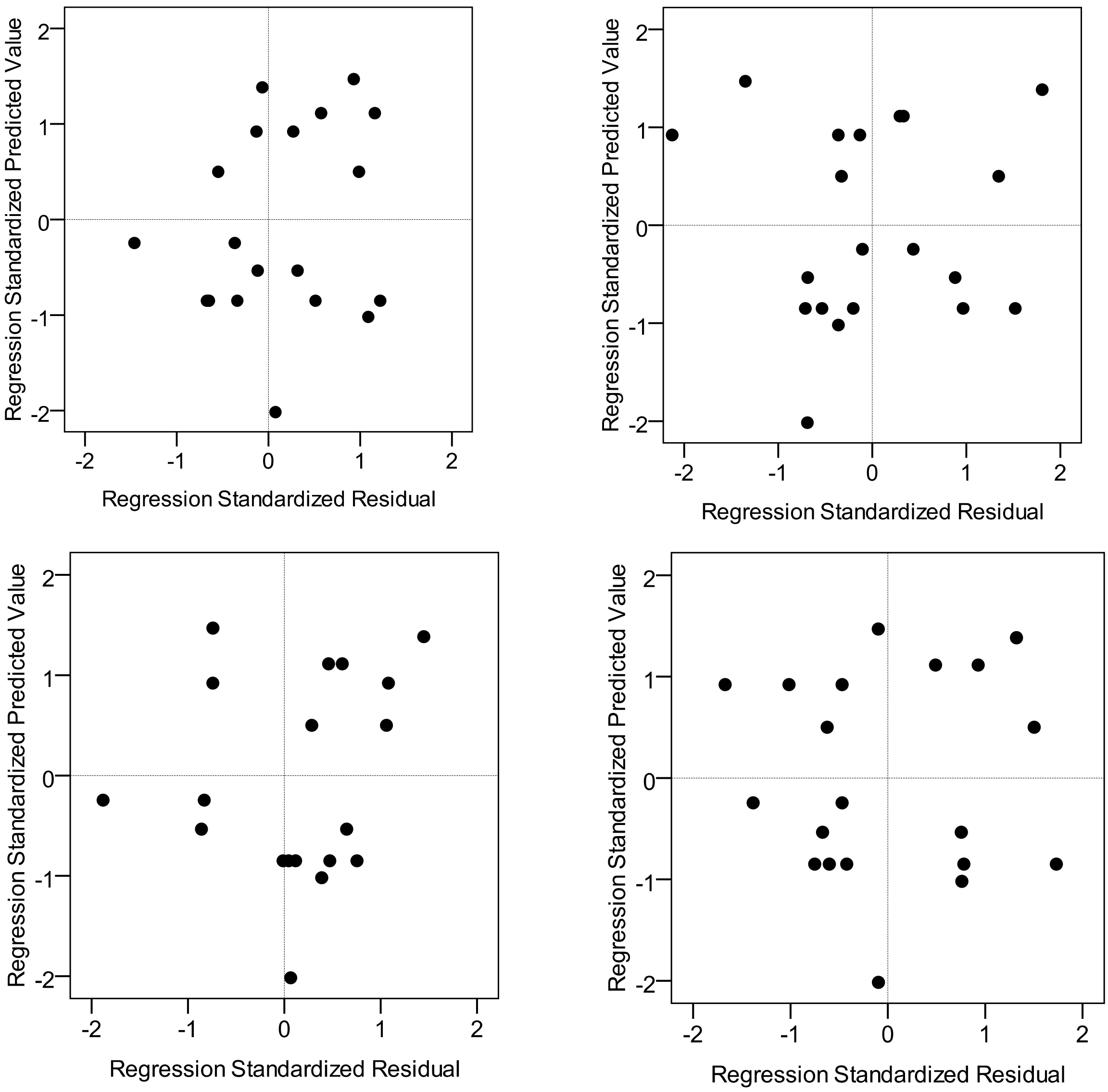


Figure 6.2-2: Scatter plot of the standardized predicted values of *C.tribuloides* at Rimchu for ln (SDW) (upper left) ln (BDW) (upper right), ln (LDW) (lower left) and ln (TDW) (lower right).

Table 6.2-7: The parameters of regression models used to estimate TDW as function of height and DBH separately. a_0 and $a_1$are regression parameters of the equation $Y = a_0 \cdot X^b$.

Species	TDW-H			TDW-DBH		
	a0	a1	r^2	a0	a1	r^2
Cb	63.91	2.33	0.79	240.84	1.99	0.93
Ct	213.07	1.55	0.58	367.35	1.64	0.81
Mp	342.66	0.75	0.18	340.15	1.15	0.49
Sr	51.15	2.6	0.69	341.13	1.72	0.58

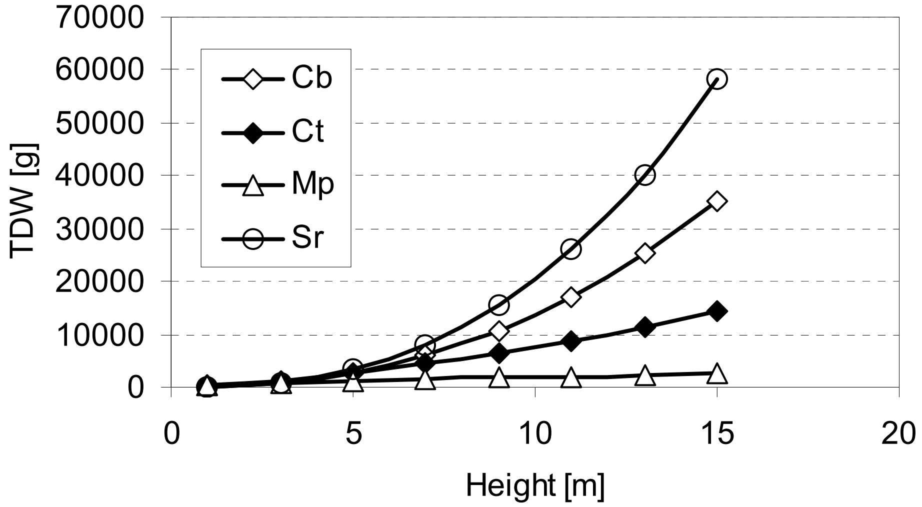


Figure 6.2-3: TDW of saplings of four br oadleaved tree species in Rim chu as function of height. Cb = *Cinnamomum bejolghota*, Ct= *Castanopsis tribuloides*, Mp = *Macaranga pustulata* and Sr = *Symplocos ramosissima***.** The equation used was $TDW = ao * Height^{a1}$ respectively. The parameters of regression lines and its r^2 are shown in Table 6.2-7.

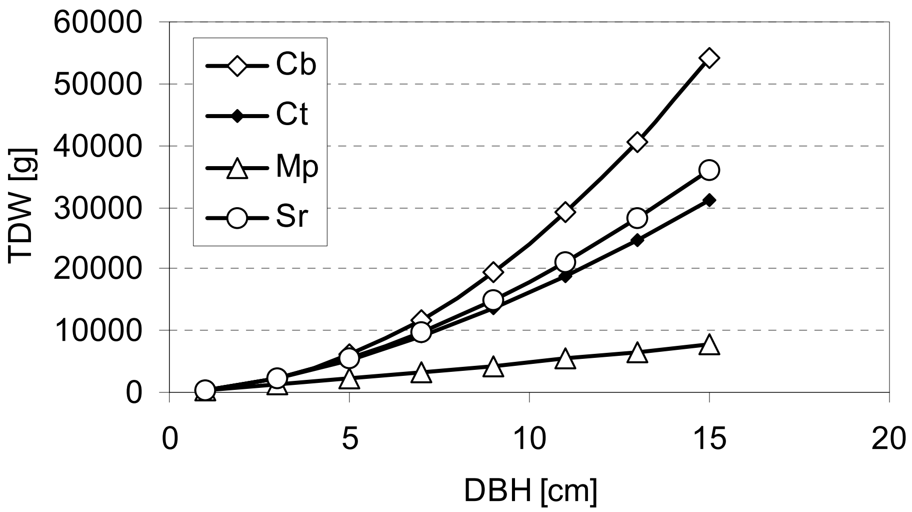


Figure 6.2-4: TWD of saplings of four broa dleaved tree species in R imchu as a function of DBH. Cb = *Cinnamomum bejolghota*, Ct= *Castanopsis tribuloides*, Mp = *Macaranga pustulata* and Sr = *Symplocos ramosissima*. The equation used was $TDW = ao * DBH^{a1}$ respectively. The parameters of regression lines and its $r^2$are shown in Table 6.2-7.

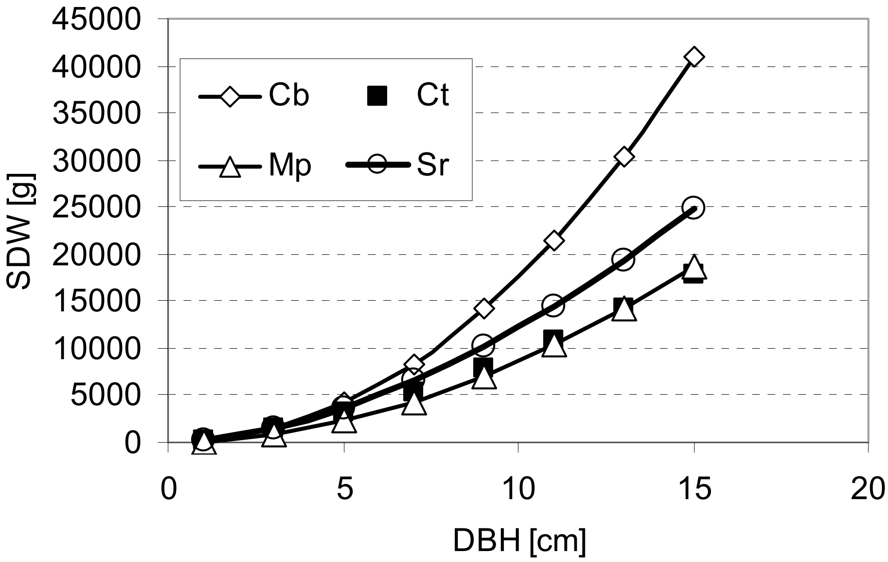


Figure 6.2-5: Stem dry weight (SD W) as funct ion of DBH. The equation was of the for m $SDW = ao * DBH^{a1}$ **(**see Table 6.2-8 for parameters and r^2 of fitted curves).

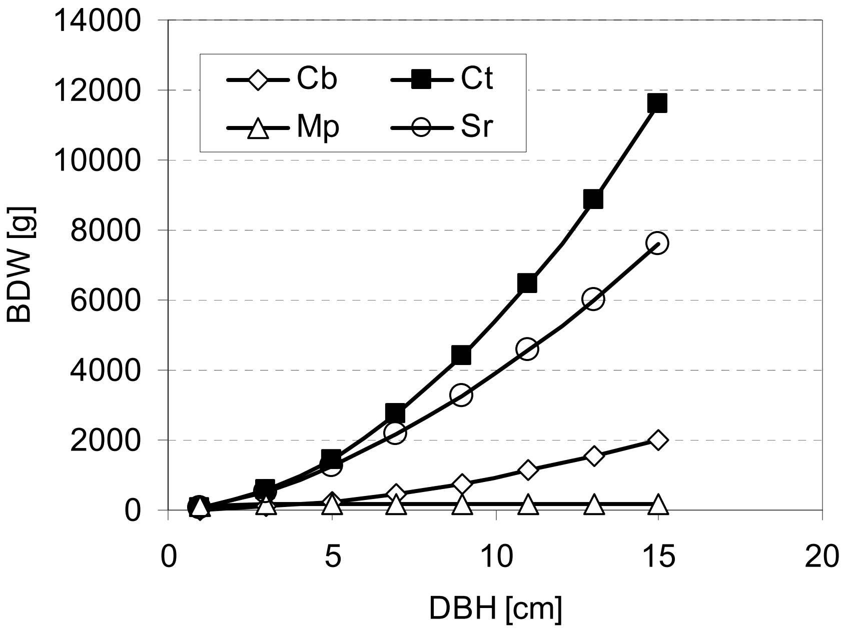


Figure 6.2-6: Branch biomass of s aplings of four broadleaved tree species in Rim chu as function of DBH. The e quation was of the for m $BDW = a_0 * DBH^{a_1}$. The parameters of the regression models are shown in Table 6.2-8.

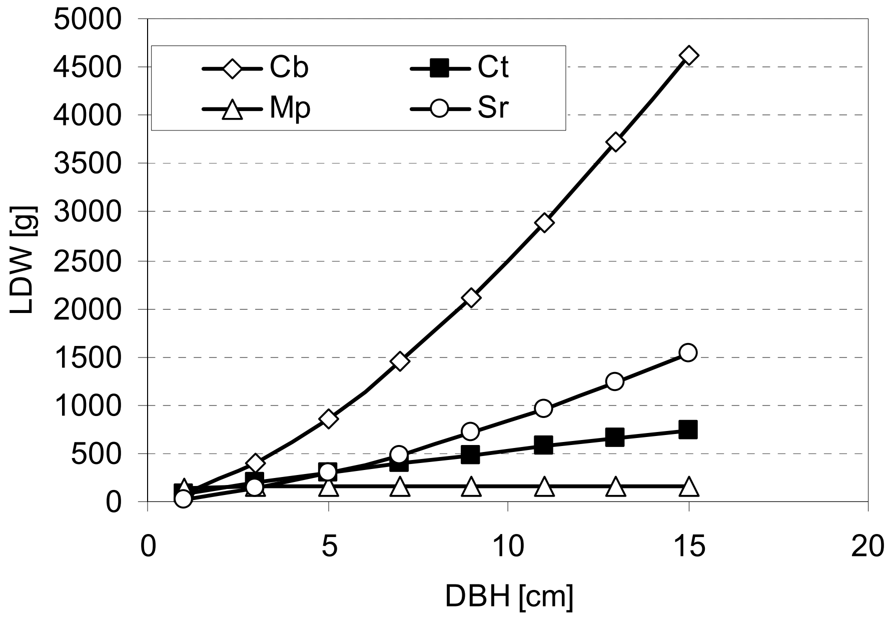


Figure 6.2. -7: Leaves biomass of saplings of four broadleaved tree species in Rimchu as function of DBH. The equation had the form $LDW = a_0 * DBH^{a_1}$ .The parameters of the regression models are shown in Table 6.2-8.

Table 6.2-8: The estimated parameters to predict the biomass components (stem dry weight (SDW), branch dry weight (BDW) and leaves dry weight (LDW) when DBH was used as predictor in regression equations of the form $y = a_0 * X^{a_1}$.

Species	SDW-DBH			BDW-DBH			LDW-DBH		
	a0	A1	r^2	a0	a1	r^2	a0	a1	r^2
Cb	144.35	2.08	0.81	11.16	2.92	0.69	74.09	1.53	0.71
Ct	245.79	1.58	0.77	69.44	1.89	0.63	75.17	0.84	0.13
Mp	100.78	1.93	0.80	136.54	0.12	0.01	141.69	-0.06	0.00
Sr	228.00	1.73	0.57	85.28	1.69	0.39	25.56	1.51	0.42

The biomass fraction relative to total dry weight (TDW) is shown in Figure 6.2-8. As mentioned earlier the stem biomass (SDW) constituted 60-80 % fraction of the biomass and did not differ between the species. Although branch and leaves fraction constituted less than 30% of the biomass fraction, they differed between species (Figure 6.2-8). At small size, the LDW of Cb was high compared to branches, however as biomass increased (size of the tree) decreased to a level of about 10% and branch fraction increased to a level of about 15 % and remained constant (Figure 6.2-8, upper left). Whereas in Ct both branch and leaves started at about 18 % of the mass fraction and divergences as Ct increased in size, in fact branch fraction constituted above 30 % level at higher size, leaves biomass decreased drastically (Figure 6.2-8, upper right panel).

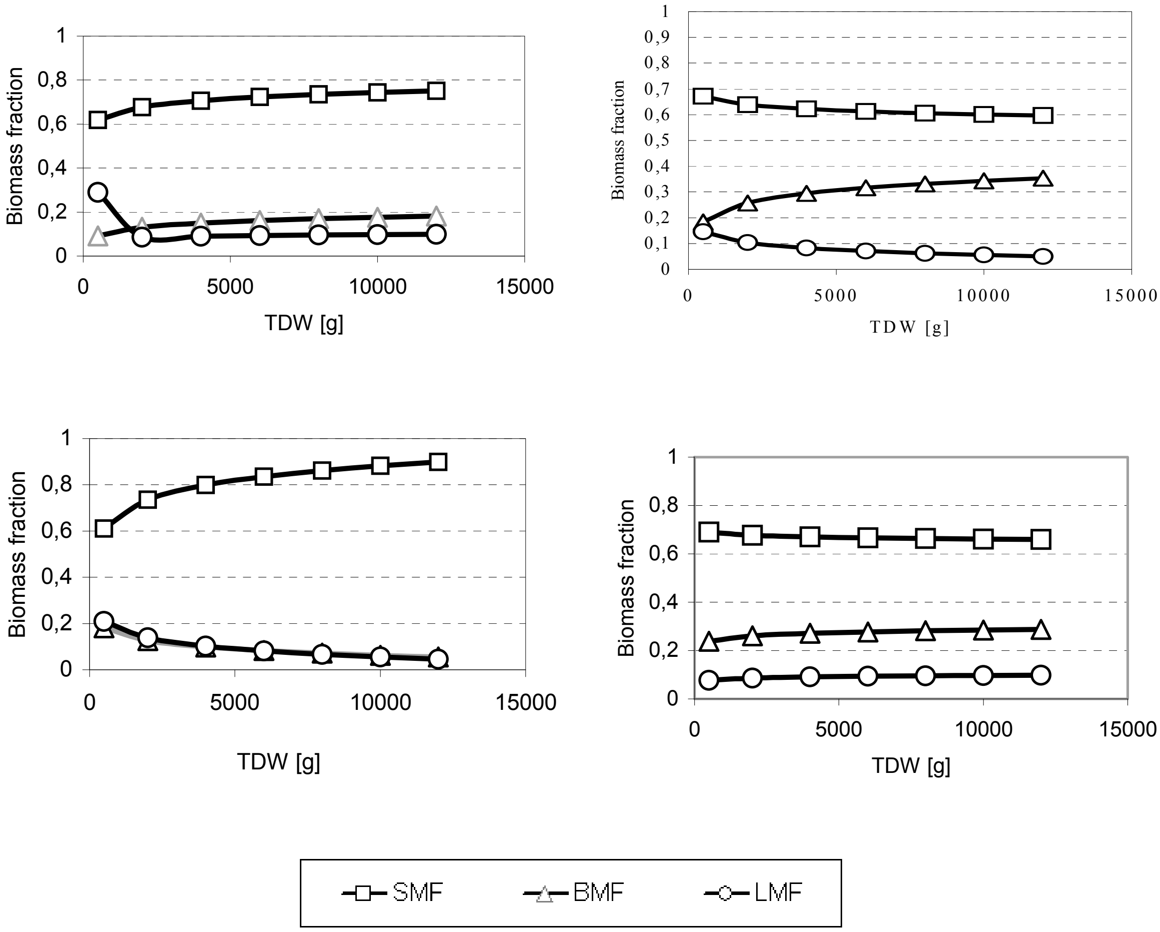


Figure 6.2-8: Biomass components as fraction of the total dry weight (TDW) in stem mass fraction (SMF), branch mass fraction (BMF), leaves mass fraction (LMF) of four young broadleaved trees in Rimchu. Upper left is Cb, upper right is Ct, lower left is Mp and lower right is Sr. The equation used to draw regression was of the form $Ln(Y) = a0 + a1 * \ln(X)$.

In Mp both branch and leaves fraction decreased as size increased and was compensated by increase of biomass in stem mass (Figure 6.2-8, lower left). Interestingly, Sr maintained a balance of all three components from small to bigger sizes (Figure 6.2-8, lower right). The differing biomass allocation to different components shows different adaptation strategy of these tree species.

6.2.3 Dimensional relationships of young trees

The height was largest in Cb for a given DBH compared with other three species (Figure 6.2-9). At the lowest DBH, the height of Sr was smallest, Mp and Ct had similar height-DBH relation up to 5 cm DBH, after which Mp seems to increase its height, however the growth rates both for height and DBH were much faster compared with other three species beyond 5th year (Figure 6.2-10 and 6.2-11). Both height and DBH were smallest in Cb at the younger age, however as it grew older it overtook Ct and Sr indicating different plasticity of species under same environmental conditions.

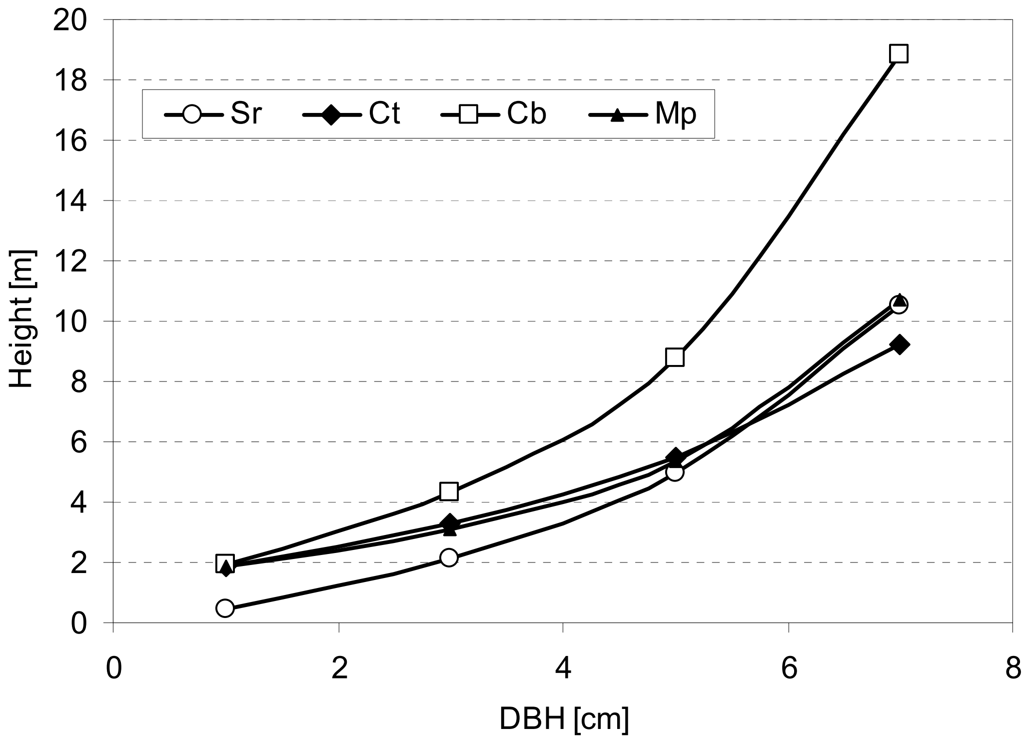


Figure 6.2-9: Height in relation to DBH, the equation used was of the form $h = d^2/(a_0 + a_1 + a_2 d^2) + 1.3$ (Prodan). Large extrapolation was avoided as data were from limited ranges. The DBH and Height parameters and r^2 of the regression models are shown in Table 6.2-9.

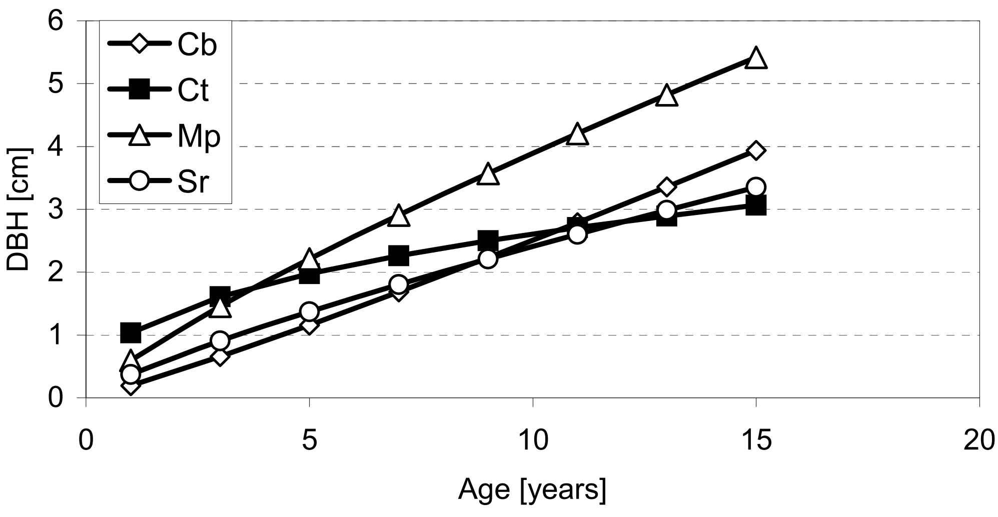


Figure 6.2-10: DBH as function of the age in four young trees in Rim chu. The equation was the form $DBH = a_0 \cdot Age^{a1}$. The parameters and r^2 of the regression models are shown in Table 6.2-10.

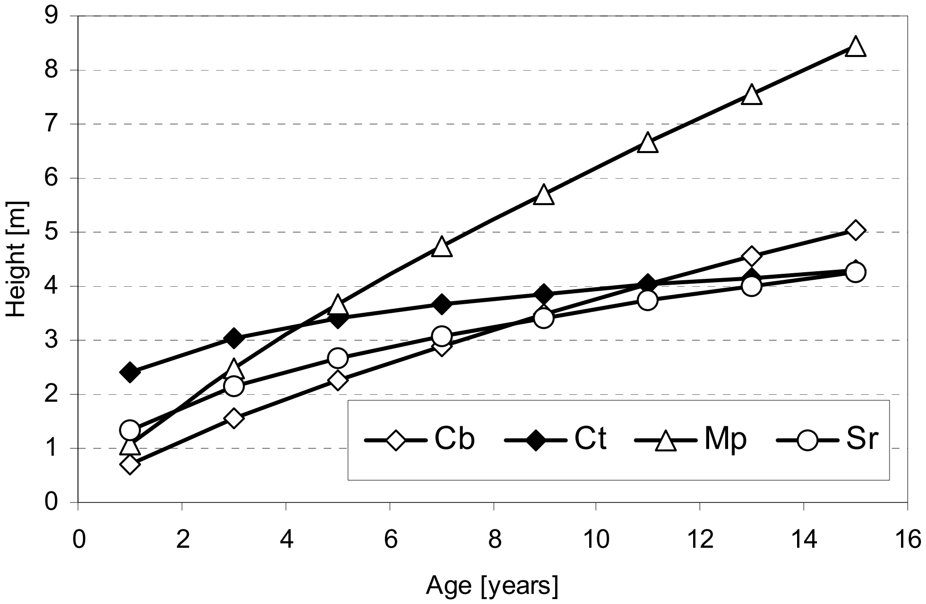


Figure 6.2-11: Height as function of the age in four young trees in Rimchu. The equation had the form: $DBH = a_0 \cdot Age^{a1}$. The parameters and r^2 of the regression lines are shown in Table 6.2-9.

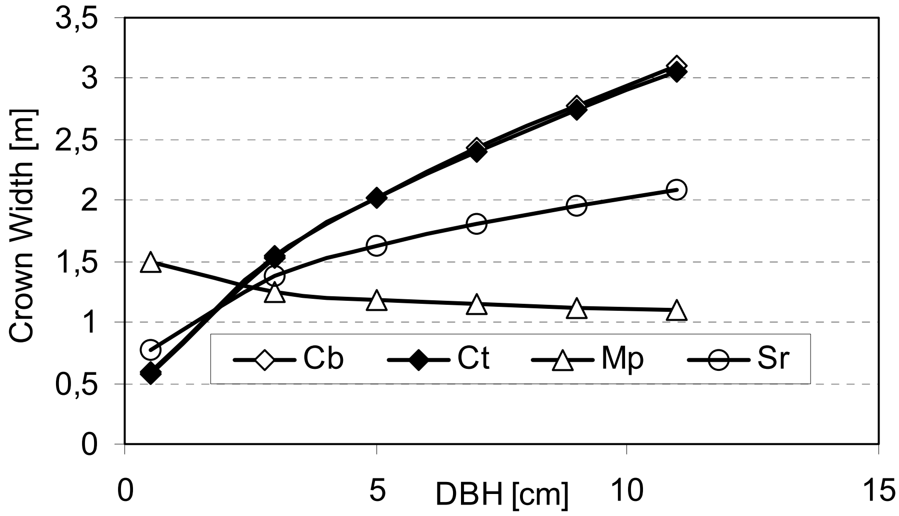


Figure 6.2-12: Crown width as function of DBH. The fitted equation was of the $CW = a_0 \cdot DBH^{a1}$. The parameters and coefficient of determination (r^2) are given in Table 6.2-9.

Cb and Ct had similar pattern of crown expansion which was highest compared with other two species. The lowest crown width in relation with DBH was observed in Mp (Figure 6.2-12).

Table 6.2-9: Estimated parameters and r^2 of height as function of DBH using Prodan equation as shown in Figure 6.2-10 and Crown width as function of DBH as shown in Figure 6.2-13.

	H-DBH relation (Prodan)				CW-DBH Relation		
Species	a0	a1	a2	r2	a0	a1	r2
Sr	0.82	1.57	-0.15	0.51	0.79	0.61	0.39
Ct	-0.18	2.03	-0.16	0.69	0.85	0.56	0.17
Cb	0.55	1.61	-0.12	0.71	1.15	0.02	0.04
Mp	-0.59	2.65	-0.26	0.67	0.95	0.37	0.10

6.2.3.1 Effective Height

Saplings of Mp were on average the talles t for a given am ount of TDW (Figure 6.2-14) compared with the o ther three species. This gap between the species became narrower with increasing biomass, especially between Ct, Mp and Cb. The effective height of Sr rem ained lowest compared with other th ree species (Figure 6.2-14). The differences were tested for significance with ANOVA. Ther e was no significant difference between species in their effective height (Bonferroni, p-value >0.05, data not shown).

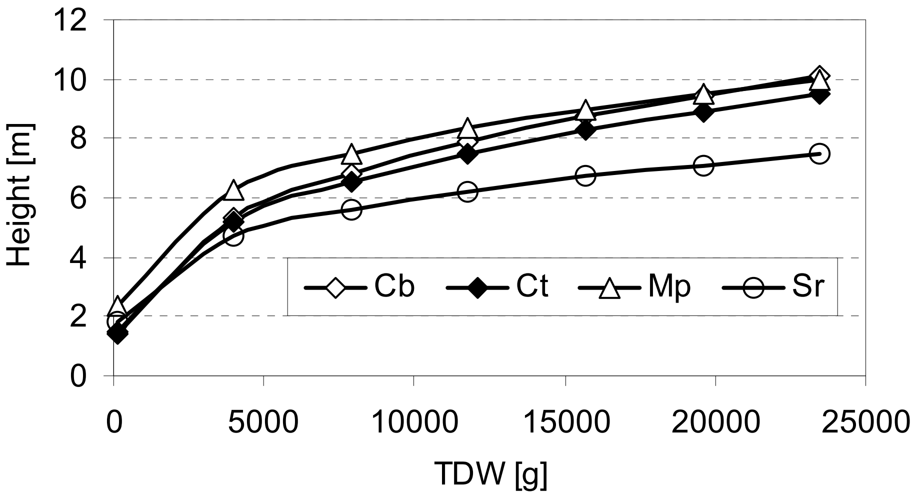


Figure 6.2-13: Height in relation to TDW using regressions equation $H_{eff} = a_0 \cdot TDW^{a1}$ where Heff = effective height, a and a1 are the parameters of the equation, TDW is the total dry biomass. The parameters a0, a1 and r^2 of each species are given in Table 6.2-10.

Table 6.2-10: Estimated coefficients for models to estimate the effective height with equation $H_{eff} = a_0 \cdot TDW^{a1}$ where H_{eff} is effective height and TDW is total aboveground oven dry biomass of trees species. The model of the age-DBH relation used the same model equation.

Species	H_{eff}			age-DBH relation			age-height relation		
	a_o	a_1	r^2	a_o	a_1	r^2	a_o	a_1	r^2
Cb	0.32	0.34	0.79	0.19	1.11	0.65	0.71	0.73	0.41
Ct	0.25	0.37	0.58	1.04	0.40	0.20	2.42	0.21	0.07
Mp	0.84	0.24	0.18	0.59	0.82	0.39	1.07	0.76	0.39
Sr	0.51	0.27	0.70	0.37	0.81	0.42	1.33	0.43	0.29

6.2.4 Morphological response of young trees to shading and lateral competition

It is general knowledge that the deciduous species and even the evergreen could lose leaves during winter due to dry spells in the study area. Since hemiview photographs were taken in a single point in time it is important to acknowledge certain assumptions. It was assumed that the gap fraction did not change considerably throughout the year and DSF (the direct light) obstructed by the canopy was uniform throughout the year. Generally, the light levels within the three exploratory plots varied from a minimum of 0.02 to a maximum of 0.40 with the mean of 0.09 and a standard deviation of sd = (-+0.06) in the study area. The complete range of GSF of all samples per species is shown in Figure 6.2-14.

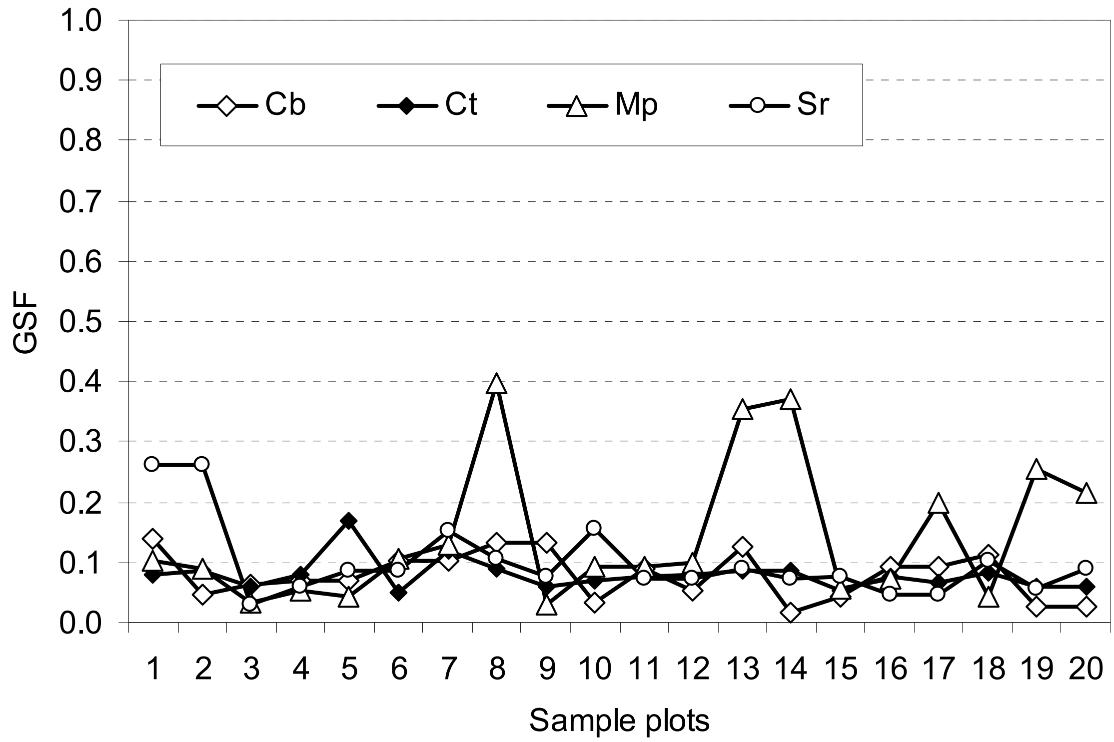


Figure 6.2-14: The range of GSF estimated through hemiview analysis of all biomass sample plots.

However, the lateral competition indices (CPA1, CPA2, CPA3, CPA4 and CPA5, see section 4.6.2 and Table 4.2 for definitions) were significantly different (Bonferroni, p-value <0.05, data not shown). Significant differences were observed between Sr and Cb in CPA1 and CPA3. Further significant differences were observed in CPA1, CPA3 and CPA4 between Cb and Ct. There was no significant difference in all lateral competition indices between Mp and the other three species.

The GSF was positively correlated with several measured morphological attributes. It was significantly correlated with DBH (p-value <0.05, rs =0.59) in Cb, none of the morphological attributes were significantly correlated with GSF in Ct indicating indifferent response in growth and plasticity to light, respectively. Interestingly, in Mp height and DBH (not significant) were negatively correlated with GSF indicating the sensitive plasticity of its morphology to varying degrees of light. In Sr a positive correlation was observed between height and GSF, in Cb DBH was positively correlated with GSF (Table 6.2-11).

Table 6.2-11: Pearson correlation (rs) between morphological attributes of saplings and GSF. * = significant at alpha = 0.05, ** = significant at alpha =0.01. H = height [m], DBH = diameter at breast height [cm], CL = crown length, CW= crown width [m], GSF = global site factor.

Species	Variable (light)	Morphological attributes			
		H	DBH	CL	CW
Cb	GSF (fraction)	0.30	0.59*	0.04	0.01
Ct	GSF (fraction)	-0.16	0.19	-0.06	0.01
Mp	GSF (fraction)	-0.61*	-0.36	0.00	0.31
Sr	GSF (fraction)	0.47*	0.24	0.31	0.34

Table6.2-12: Pearson correlation (rs) between biomass components and GSF. GSF = global site factor, SDW = stem dry weight, BDW = branch dry weight, LDW = leaves dry weight, TDW = total dry weight, LBDW = aggregate of leaves and branch dry weight. * = significant at alpha =0.05, ** = significant at alpha =0.01.

Species	variable (light)	biomass components				
		SDW	BDW	LDW	TDW	LBDW
Cb	GSF (fraction)	0.58*	0.33	0.51*	0.59*	0.47*
Ct	GSF (fraction)	0.15	0.68*	0.55*	0.42	0.66*
Mp	GSF (fraction)	-0.29	0.46*	0.61*	-0.02	0.56*
Sr	GSF (fraction)	0.55*	0.64*	0.71**	0.60*	0.67*

In Cb all the biomass components were positively correlated with GSF, SDW and LDW significantly (p-value <0.05, Table 6.2-12. A similar pattern was found for Ct. There was a weak negative correlation (trend) in SDW with GSF in Mp, however its BDW and LDW were positively correlated (p-values <0.05) indicating its plasticity under full light conditions. All the biomass components of Sr were positively correlated with GSF (p-value < 0.05, Table 6.2-12). Interestingly, none of the species showed any correlation of DeltaH with GSF.

Table6.2-13: Pearson correlation (rs) between morphological indicators (see Table 4.3 for definitions of variables) and lateral competition indices. Heff = effective height, RCL = relative crown length, HDR = Height/DBH ratio, DGR = mean diameter growth rate, HGR = mean height growth rate, DeltaH = last year's terminal height increment. * = significant at alpha =0.05, ** = significant at alpha =0.01.

Species	Lateral competition	Morphological indicators					
		H_{eff}	RCL	HDR	DGR	HGR	DeltaH
Cb	GSF (fraction)	0.50*	-0.20	-0.61*	0.40*	-0.23	-0.09
Ct	GSF (fraction)	0.16	0.07	-0.44*	0.10	-0.13	-0.13
Mp	GSF (fraction)	0.03	0.34	-0.33	0.03	-0.22	-0.19
Sr	GSF (fraction)	0.60*	-0.06	-0.19	-0.19	-0.18	0.18

The H_{eff} and DGR were positively (significant at alpha = 0.05) correlated with GSF in Cb, while Height/DBH ratio was negatively correlated with GSF in Ct. In Sr only H_{eff} was positively correlated (Table 6.2-13). None of the morphological indicators were significantly correlated with GSF in Mp.

Furthermore, the morphological responses of theses species were scrutinised through correlation with lateral competition indices via crown projection area of neighbouring saplings. Firstly, correlation analysis amongst the explanatory variables in each species was conducted (Table 6.2-14). The results showed that there was no significant correlation between light variable and lateral competition indices except in Sr where there was positive significant correlation between GSF and CPA1 and CPA3. However, upon closer look at the lateral competition indices (Table 6.2-15) themselves, the density of competing species was relatively low (maximum of one sapling/m^2)

Table 6.2-14: Correlation between GSF and lateral competition indices. * = significant at alpha =0.05.

Species	Variable	Lateral competition indices				
		CPA1	CPA2	CPA3	CPA4	CPA5
Cb	GSF	-0.22	0.05	-0.20	0.31	0.31
Ct	GSF	0.07	-0.19	0.05	-0.16	-0.16
Mp	GSF	-0.26	0.06	-0.26	-0.45	-0.45
Sr	GSF	0.67*	-0.20	0.64*	0.07	0.05

Table 6.2-15: The mean value of explanatory variables by species. CPA1 = total crown projection area of trees taller 130cm and smaller then (height of biomass tree + 15cm) per unit plot area (plot radius = 4m); CPA2 = total crown projection area per unit plot area of trees between 10cm and 130cm height (plot radius = 2.0m), CPA3 = CPA1+CPA2; CPA4 = total crown projection area per unit plot area of all saplings >130cm height and < 5cm DBH within 4 meter radius including individuals taller than in CPA1; CPA5 = CPA4+CPA2.

Species	GSF	Lateral competition indices [m^2/m^2]				
		CPA1	CPA2	CPA3	CPA4	CPA5
Cb	0.08	0.11	0.02	0.12	0.85	0.87
Ct	0.08	0.22	0.01	0.23	1.41	1.42
Mp	0.15	0.19	0.02	0.21	1.91	1.93
Sr	0.10	0.26	0.03	0.28	0.50	0.53

The species wise Pearson correlation coefficients (rs) for the lateral competition indices and measured morphological tree attributes and biomass components are shown in Tables 6.2-16 to 6.2-18.

Table 6.2-16 Pearson correlation (rs) between tree variables and lateral competition indices. CPA1 = total crown projection area of trees taller 130cm and smaller then (height of biomass tree + 15cm) per unit plot area (plot radius = 4m); CPA2 = total crown projection area per unit plot area of trees between 10cm and 130cm height (plot radius = 2.0m), CPA3 = CPA1+CPA2; CPA4 = total crown projection area per unit plot area of all saplings >130cm height and < 5cm DBH within 4 meter radius including individuals taller than in CPA1; CPA5 = CPA4+CPA2. * = significant at alpha = 0.05, ** significant at alpha = 0.01.

Species	Lateral competition	Morphological attributes			
		H (m)	DBH (cm)	CL (m)	CW (m)
Cb	CPA1 ($m2/m^2$)	0.40*	0.39	0.55*	0.74**
	CPA2 ($m2/m^2$)	0.35	0.34	0.28	0.19
	CPA3 ($m2/m^2$)	0.47*	0.45*	0.59*	0.76**
	CPA4 ($m2/m^2$)	-0.13	-0.09	0.11	-0.11
	CPA5 ($m2/m^2$)	-0.13	-0.08	0.12	-0.10
Ct	CPA1 ($m2/m^2$)	0.15	0.43*	-0.11	0.53*
	CPA2 ($m2/m^2$)	0.08	-0.02	0.28	0.12
	CPA3 ($m2/m^2$)	0.17	0.43*	-0.08	0.55*
	CPA4 ($m2/m^2$)	-0.13	-0.14	0.05	0.01
	CPA5($m2/m^2$)	-0.13	-0.14	0.05	0.01
Mp	CPA1 ($m2/m^2$)	0.45*	0.39	0.16	0.18
	CPA2 ($m2/m^2$)	-0.27	-0.51*	-0.39	-0.26
	CPA3 ($m2/m^2$)	0.42*	0.33	0.12	0.15
	CPA4 ($m2/m^2$)	-0.21	-0.46*	-0.05	-0.12
	CPA5($m2/m^2$)	-0.21	-0.47*	-0.06	-0.12
Sr	CPA1 ($m2/m^2$)	0.71**	0.39	0.47*	0.58*
	CPA2 ($m2/m^2$)	-0.08	-0.03	-0.17	0.07
	CPA3 ($m2/m^2$)	0.70**	0.39	0.45*	0.60*
	CPA4 ($m2/m^2$)	-0.10	-0.15	-0.27	-0.13
	CPA5($m2/m^2$)	-0.10	-0.14	-0.27	-0.12

In Cb positive significant relationships of CW and DBH with CPA1 and CPA3 were observed (Table 6.2-16). Also all biomass compartments with the exception of the leaves were positively correlated with CPA1 and CPA3 respectively (Table 6.2-17). Effective height and the recent shoot increment (DeltaH) were also positively correlated with the same lateral competition indices (Table 6.2-18). In short, Cb appears to be a shade tolerant species which can adjust its growth either in crown width or in height and allocates biomass accordingly when faced with competition.

Table 6.2-17: Pearson correlation between trees biomass components with light and lateral competition indices. CPA1 = total crown projection area of trees taller 130cm and smaller then (height of biomass tree + 15cm) per unit plot area (plot radius = 4m); CPA2 = total crown projection area per unit plot area of trees between 10cm and 130cm height (plot radius = 2.0m), CPA3 = CPA1+CPA2; CPA4 = total crown projection area per unit plot area of all saplings >130cm height and < 5cm DBH within 4 meter radius including individuals taller than in CPA1; CPA5 = CPA4+CPA2. * = significant at alpha = 0.05, ** significant at alpha = 0.01.

Species	Lateral competition	Biomass components				
		SDW	BDW	LDW	TDW	LBDW
Cb	CPA1 ($m2/m^2$)	0.40*	0.65*	0.26	0.45*	0.46*
	CPA2 ($m2/m^2$)	0.29	0.45*	0.03	0.29	0.22
	CPA3 ($m2/m^2$)	0.45*	0.73**	0.26	0.50*	0.50*
	CPA4 ($m2/m^2$)	-0.09	-0.15	-0.10	-0.11	-0.13
	CPA5($m2/m^2$)	-0.09	-0.15	-0.10	-0.11	-0.13
Ct	CPA1 ($m2/m^2$)	0.22	0.23	0.47*	0.28	0.29
	CPA2 ($m2/m^2$)	0.09	-0.13	-0.19	-0.02	-0.15
	CPA3 ($m2/m^2$)	0.24	0.21	0.45*	0.29	0.28
	CPA4 ($m2/m^2$)	-0.04	0.04	0.09	0.00	0.05
	CPA5($m2/m^2$)	-0.04	0.04	0.09	0.00	0.050
Mp	CPA1 ($m2/m^2$)	0.40*	-0.09	-0.11	0.32	-0.10
	CPA2 ($m2/m^2$)	-0.43*	-0.39	-0.39	-0.57*	-0.41*
	CPA3 ($m2/m^2$)	0.35	-0.14	-0.16	0.25	-0.16
	CPA4 ($m2/m^2$)	-0.32	-0.29	-0.29	-0.42*	-0.30
	CPA5($m2/m^2$)	-0.32	-0.29	-0.29	-0.42*	-0.30
Sr	CPA1 ($m2/m^2$)	0.79**	0.75**	0.83**	0.81*	0.79**
	CPA2 ($m2/m^2$)	0.07	-0.12	-0.01	0.02	-0.10
	CPA3 ($m2/m^2$)	0.81**	0.74**	0.83**	0.82**	0.78**
	CPA4 ($m2/m^2$)	0.13	0.02	0.18	0.11	0.05
	CPA5($m2/m^2$)	0.14	0.01	0.17	0.11	0.04

In Ct both CPA1 and CPA3 showed positive significant correlation to DBH and crown width (CW) indicating different plastic strategy to competition. The expansion of crown with could support more leaves and thus consequently LDW was positively correlated with CPA1 and CPA3 (Table 6.2-17). Height related indicators (mean height growth rate (HGR) and last year terminal shoot growth (DeltaH) were negatively correlated with the same competition indices indicating trade-offs between crown volume and height. In short, under relatively low light conditions (<15% GSF, Figure 6.2-14) and when exposed to lateral competition from its neighbours Ct invested more in crown expansion and in order to support heavier crowns it thus invested more biomass allocation to DBH to the cost of height growth.

Table 6.2-18: Pearson correlation between trees morphological indicators and lateral competition indices. CPA1 = total crown projection area of trees taller 130cm and smaller then (height of biomass tree + 15cm) per unit plot area (plot radius = 4m); CPA2 = total crown projection area per unit plot area of trees between 10cm and 130cm height (plot radius = 2.0m), CPA3 = CPA1+CPA2; CPA4 = total crown projection area per unit plot area of all saplings >130cm height and < 5cm DBH within 4 meter radius including individuals taller than in CPA1; CPA5 = CPA4+CPA2. * = significant at alpha = 0.05, ** significant at alpha = 0.01. All CPA indices in [m^2/m^2].

Species	Lateral competition	Morphological indicators					
		Heff	RCL	HDR	DGR	HGR	DeltaH
Cb	CPA1	0.47*	0.17	-0.17	0.24	0.07	0.82**
	CPA2	0.35	0.00	-0.16	0.29	0.07	0.08
	CPA3	0.53*	0.16	-0.20	0.29	0.08	0.81**
	CPA4	-0.17	0.32	0.04	0.19	0.16	-0.04
	CPA5	-0.16	0.33	0.04	0.19	0.13	0.04
Ct	CPA1	0.20	-0.30	-0.49*	0.08	-0.14	-0.46*
	CPA2	0.11	0.30	0.24	0.35	0.40*	-0.22
	CPA3	0.21	-0.26	-0.47*	0.13	-0.09	-0.49*
	CPA4	-0.01	0.29	0.03	-0.27	-0.24	0.19
	CPA5	0.03	0.29	0.03	-0.27	-0.24	0.19
Mp	CPA1	0.32	-0.10	-0.03	-0.08	-0.09	0.40*
	CPA2	-0.62*	-0.23	0.50*	-0.46*	-0.13	-0.43*
	CPA3	0.25	-0.13	0.03	-0.14	-0.11	0.35
	CPA4	-0.52*	0.18	0.67*	-0.35	0.06	-0.02
	CPA5	-0.52*	0.18	0.67**	0.36	0.06	0.02
Sr	CPA1	0.77**	-0.14	-0.11	-0.11	-0.06	0.19
	CPA2	0.00	-0.26	0.13	0.13	0.15	-0.07
	CPA3	0.78**	-0.18	-0.08	-0.08	-0.04	0.18
	CPA4	0.00	-0.44	-0.19	-0.19	-0.13	-0.21
	CPA5	-0.01	-0.45*	-0.17	-0.11	-0.11	-0.21

In Mp height was positively correlated with CPA1 and CPA3 indicating a different morphological response to competition. Interestingly, most of its morphological attributes seemed to be negatively correlated (trend) when it had neighbours <130 cm (CPA2) indicating its plastic sensitivity to competition and type of neighbours. Mp was observed growing in wide range of light conditions (from 5 to 40 % GSF, Figure 6.2-15) and in each of those situations it showed plasticity in its morphology and biomass allocation pattern. In situations when Mp grows together with small neighbouring saplings (CPA2) it seems to invest in shoot growth, once it's above its neighbours it invests more in leaves. The latter seems to happen frequently in gaps where light conditions brighter compared to relatively closed forest conditions.

Sr seems to follow a similar pattern as Cb when exposed to competition by neighbouring saplings (Table 6.2-16). However, regarding to effective height (H_{eff}) it behaved more like Mp. Generally, this species was also growing in very low light as well as under gap conditions (2 to 26% GSF, Figure 6.2-14). However, from the present data the morphological plasticity in response to light and lateral competition was not clear.

In order to further extend the analysis of morphological response in dependence from light and lateral competition the correlation analysis was extended using multivariate techniques in CANOCO version 4.5 (Leps and Smilauer 2003). Firstly, the data were tested using detrended correspondence analysis (DCA) to ordinate the species by means of synthetic ordination axes. The results of the DCA showed a maximum length of gradients of 0.44. Therefore, employing a linear relationship between the explanatory variables in explaining the ordination axes is justified. In this case RDA, an extension of principle component analysis (PCA), was used to test the significance of available explanatory variables. Monte Carlo Permutation F-Test (MCPT) using forward selection procedures with 999 permutations was used to test the significance of explanatory power of these explanatory variables. The first three axes in DCA explained more than 90% of the cumulative variance in response and explanatory variables. However, none of the environmental variables contributed significantly to the explanation of these gradients. Table 6.2-19 shows the factors listed from the most important to the least important explanatory variable according to the Monte Carlo Permutation F-test. However, the triplots diagram (response, explanatory and species variables) was drawn to visualise interrelationships of these variables and species and to contribute to data interpretation.

Table 6.2-19 : The listings of factors in order of most important to least important extracted by Monte Carlo permutation F-test in RDA.

Variables	Lamda A	F-statistic	p-value
CPA1	0.35	2.76	0.20
GSF	0.33	2.13	0.25
CPA3	0.32	1.45	0.31
CPA2	0.27	0.56	0.45
CPA4	0.14	0.10	0.90
CPA5	0.14	0.00	1.0

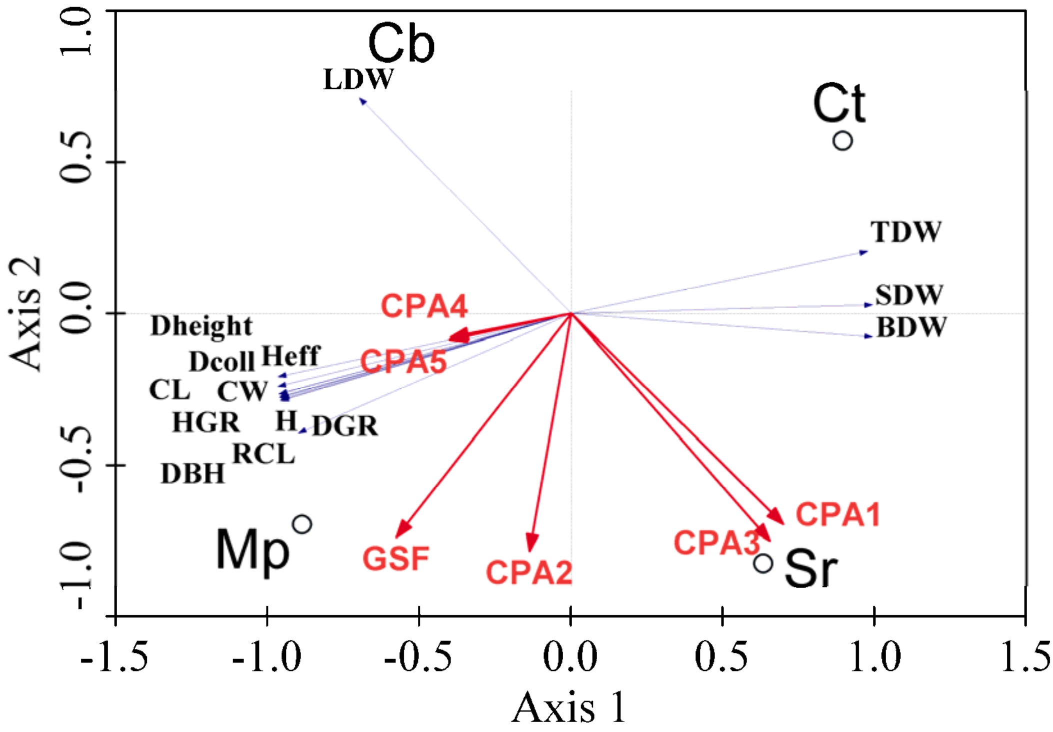


Figure 6.2-15: The ordination by redundancy correspondence analysis (RDA). The triplot diagram of tree species represented as *Ct (Castanopsis tribuloides), Cb (Cinnamomum bejolghota), Mp (Macaranga pustulata)* and *Sr (Symplocos ramosissima)*, explanatory variables in red letters and response variables in black letters (see section 4.6.1 for definition of each variable).

The responses of the species to lateral competition and light can be interpreted from Figure 6.2-15. The four species are spread over the entire diagram indicating different environmental requirements and related morphological plasticity. The occurrence of Mp was correlated with increasing GSF, Sr tended to mix with other seedlings and saplings (positive correlation with CPA1 and CPA3). Ct was ordinated opposite to Mp, and Cb was ordinated opposite to Sr. Ct was ordinated more towards stem and branch biomass indicating the tendency to allocate more of the biomass gain to structural elements which in turn shows the tendency of being negatively correlated with GSF. The leaves compartment showing higher affinity to Cb seems to be just weakly correlated with the environmental drivers. Mp was more correlated to size related morphological attributes indicating the plasticity of this species. Sr was again in a different position due to its tendency to maintain a balance between major biomass compartments which was consistent with earlier observations (e.g. Figure 6.2-8). CPA4 and CPA5, focusing more on the entire size spectrum of the neighbouring saplings, seem not to be the most influential competition indices. The relationships between the other lateral competition indices and tree structural parameters are fairly weak, which confirms somehow the results of the univariate correlation analysis.

6.3 Assessment of forest products demand through household survey

6.3.1 Basic household statistics

The information was collected using questionnaires (Annex 5). The survey covers about 9% (n= 39) of the households from the total of 477 households (PHC, 2005) in the administrative unit (geog) of Kabji under Punakha district. The respondents were 18 females and rest were male ranging in their age from 19 years old upto 67 years old (Table 6.3-1). The selections of the villages were done keeping the proximity to nearest possible from the study site (about 10-15 km). The interviewees were rice-based farmers who derived most of the income from rice and vegetables both for household consumptions as well as for cash income. These farmers used nearby forests for variety of purposes such as for timber for construction, poles for fencing, poles for hoisting prayer flags, leaf litters for fertilization and they also collect non wood forests products for household food supplements especially for vegetables.

Table 6.3-1: The respondent's gender distribution and their average age from the household survey of forest resources used assessment in 10 villages under Kabji geog of Punakha district (in case of single individual the absolute age is reflected).

Villages	Respondents		average age	
	Male	Female	Male	Female
Chotey Niku	3	2	45	38
Damchi	1	3	56	43
Khamena	1	1	50	51
Petari	3	2	33	47
Rangikha	2	1	42	64
Sirigang	2	4	45	44
Isukha	3	2	60	48
Tongsina	1	2	51	24
Wokuna	2	1	40	37
Zabesa	3	-	57	-
Total	21	18	-	-

6.4.2 Local demand of forest products

The household per capita timber products consumption/ demand was calculated using equation 11 (see section 5.4).

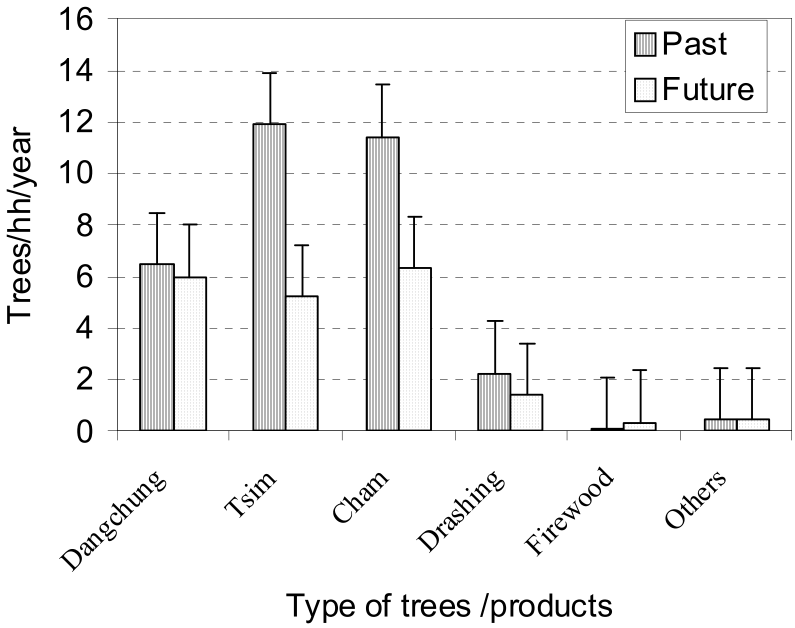


Figure 6.3-1: The average trees/forest products consumption pattern per households in 10 villages, (n=39 households) in Kabjisa geog in Punakha, these villages are close to the exploratory plots in Rimchu. The products are according to local measurement units for tree sizes (diameter) as Dangchung =<30 cm, Tsim =30-60 cm Cham = 90-120 cm, Drashing >120 cm approximately. Firewood and others are have no definite sizes and are indicative values.

Based on the consumption of timber for past 5 fives years the household consumptions of timber had been mostly concentrated more on tsim (30-60 cm diameter) and cham (90-120 cm diameter) and was about 11-12 trees per households per year. The bigger sized trees (drashing =sawing wood) was about 2 trees/hh/year, the firewood and other utilization remained very low about a tree per house hold/year indicating availability of alternative sources of energy and this observation was in conformity with non removal of coarse woody debris in exploratory plots reported earlier. The pole sized trees (dangchung) was used at the rate of 6 trees/hh/year (Figure 6.3-1). The pattern observed in exploratory plots (see section 6.1.6.1) of harvested stumps closely resembled the demand of trees by household. The per capita trees consumption and demands for next five years in those villages (Table 6.3-1) is shown in (Figure 6.3-2).

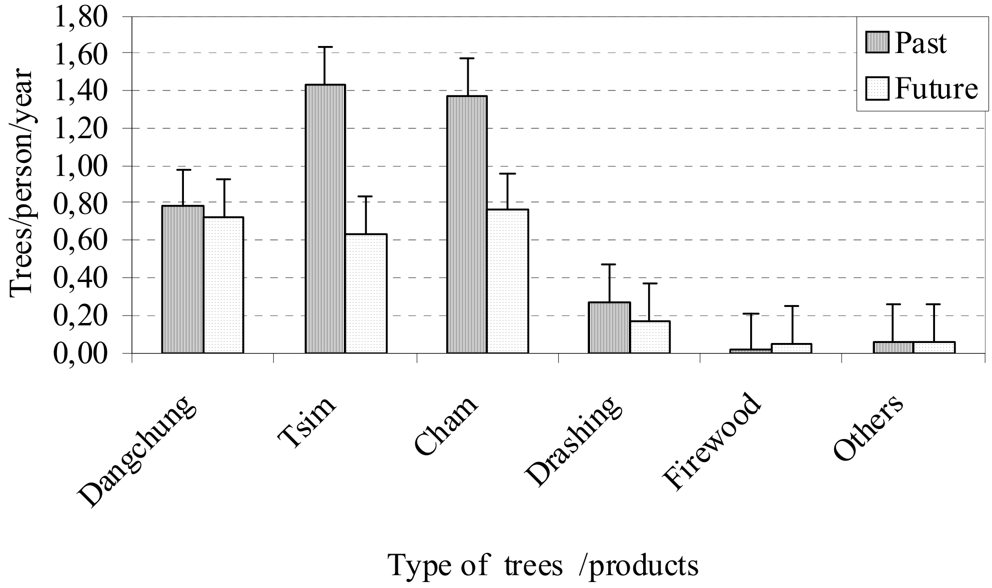


Figure (6.3-2): The average trees/forest products consumption pattern per persons in 10 villages, (n=328 people in 39 households) in Kabjisa geog in Punakha, these villages are close to the exploratory plots in Rimchu. The products are according to local measurement units for tree sizes (diameter) as Dangchung =<30 cm, Tsim =30-60 cm Cham = 90-120 cm, Drashing >120 cm approximately. Firewood and others are have no definite sizes and are indicative values.

The most preferred trees as tim ber species were *Castanopsis tribuloides, Schima wallichi, Symplocos spp, Betula alnoides, Macaranga spp, Ci nnamomum sp, Michealia spp Alcimandra spp etc. (Data not shown).* The timber remained one of the most important forests products (Table 6.3-2); 56 % of the total respondents ranked tim ber as most preferred forest products and 23% ranked second most preferred forest products, firewood was ranked second (36 % of the res pondents), fodder and non wood forest pr oducts were ranked third and forth respectively.

The non wood forests products were many different species of mushrooms, cane species both as raw materials for handicrafts and delicacies (tip proportion of the *Plectocomia himalayana* Griff is eaten as delicacies, see Photo 2), *Elastostema* spp, Namda (local name), fern species, etc. The consumption patterns of those non wood forest products by the sam pled households are indicated in Figure 6.3-4. The fern species (lo cally called nakay) are most sold and consumed nwfps in the region, followed by mushrooms, cane shoot and others (Figure 6.3-4).

Figure 6.3-3: Upper most panel trees harvesting by local residents Plates (lower left, mushroom), lower right was taken during field camp in December 2008 in Rimchu, the man in picture is carrying shoot of ***Plectocomia Himalayana*** (shoot of cane eaten as vegetable especially in special religious ceremonies in the villages).

Table 6.3-2: Ranking of forests products by residents of 11 villages under Kabjisa geog under Punakha district. 1 is highly preferred and 0 not all preferred n = number of respondents, % res = % respondents from total.

	Timber		Firewood		Fodder		NWFPs	
Rank	n	% res	n	% res	n	% res	n	% res
1	22	56.41	14	35.90	2	5.13	1	2.56
2	9	23.08	20	51.28	12	30.77	7	17.95
3	2	5.13	0	0	2	5.13	2	5.13
0	6	15.38	5	12.82	23	58.97	29	74.36
Total	39	100.00	39	100.00	39	100.00	39	100.00

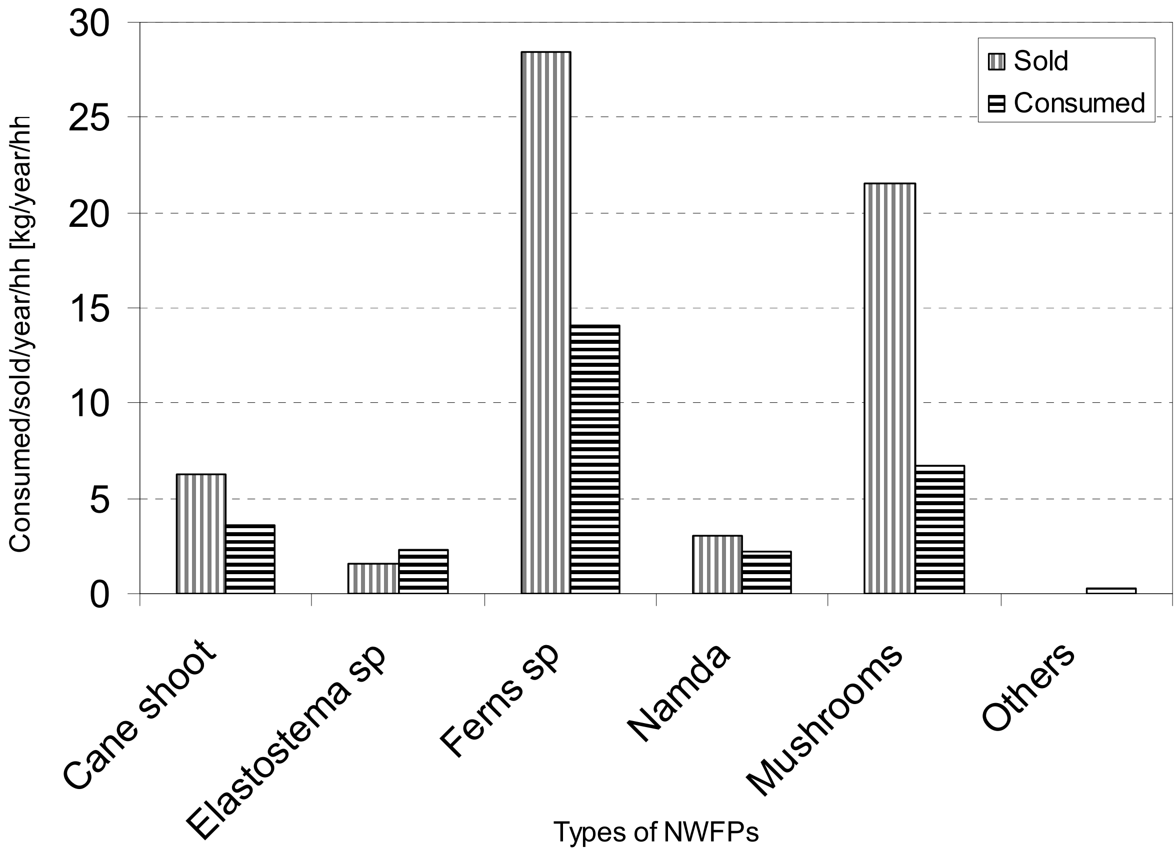


Figure 6.3-4: The consumption and sold quantities of nwfps by the local residents in Rimchu region. The conversion to standardised unit are base on assumptions that 1 bundle of ferns =0.5 kg, 1 bundle of Namda = 0.35 kg, 1 cane shoot = 0.5 kg, one bangchung of mushroom = 0.5 kg, 1 bundle of Elastostema =0.5 kg).

6.4 Equilibrium diameter distribution models for broadleaved forests in Rimchu

6.4.1 Model setup

In total stem discs from 26 trees were taken from the Rimchu sampling area and analysed in the tree ring laboratory. In order to represent all species present in the three exploratory plots six species groups were formed. The grouping was based on the timber use, the successional stage the trees represent as well as estimated attainable maximum diameter size (Table 6.4-1).

Table 6.4-1: Species grouping based on timber use, successional stage and maximum attainable diameter.

Species group	Timber use	Successional stage	Maximum DBH [cm] (appr.)
1	all sizes are used	mid successional species	130
2	Drashing	late successional species	200
3	Cham, Drashing	Pioneer species	120
4	Danchung	Pioneer species	50
5	Less frequently used	mid successional species	60
6	Relatively unknown	Relatively unknown	50

In Table 6.4-2 the number of trees available for each of the six species groups is listed. In order to increase the number of tree rings available for the development of diameter increment models the tree ring series of each tree was sampled in fixed periods of 10 years to reduce temporal autocorrelation in increment data. Group 6 was originally not represented by any tree, therefore and based on hypothesized ecological behaviour group 6 was represented by the mean of tree ring width of groups 1, 3 and 4.

Table 6.4-2: Number of trees and sampled annual rings used for the development of diameter increment models.

species group	number of trees	tree ring samples	model	Equation
1	15	120	Linear function	(17)
2	2	28	Mean	
3	4	8	Power function	(18)
4	4	9	Logarithmic function	(19)
5	1	4	Linear function	(20)
6	mean of groups 1, 3 and 4	137	Mean	

Diameter growth as function of DBH size class for species groups. For group 2 and group 6 no regression model could be established which was able to meet the statistical requirements and represented plausible ecological behaviour. Here the annual DBH increment per size class is fixed at 2.93cm and 2.87cm respectively. In Equations (17) to (20) the resulting diameter increment is in [mm/a], the DBH is given in [cm].

$$dDBH = 1.461 + 0.0365 \cdot DBH \quad (17)$$

$$dDBH = 11.5 \cdot e^{(-0.0427 \cdot DBH)} \quad (18)$$

$$dDBH = 0.6247 + 0.5825 \cdot \ln(DBH) \quad (19)$$

$$dDBH = 0.1418 + 0.0995 \cdot DBH \quad (20)$$

Figure 6.4-1 shows all diam eter increment models for the species groups. Group 3 clearly showed decreasing tree ring width with increa sing DBH and was therefore represented by a descending power function.

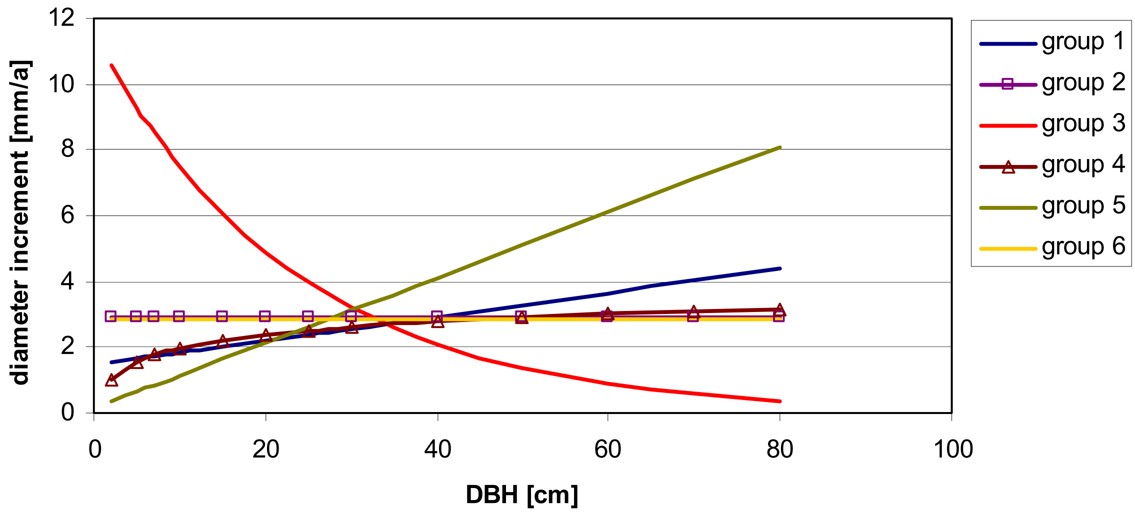


Figure 6.4-1. Diameter increment models for six species groups in Rimchu (see Table 6.4-1).

Mortality rates in the DBH categories were inferred from the number of snags in all exploratory plots (Figure 6.4-2). Assuming that 15 years after tree death snags wont be visible anymore (personal communication by field foresters in Rim chu), the num ber of snags as recorded in the exploratory pl ots and the stem numbers annual mortality rates can be derived. In Figure 6.4-3 m ortality rates over the DBH classes for the six species groups as well as for all species in total are shown.

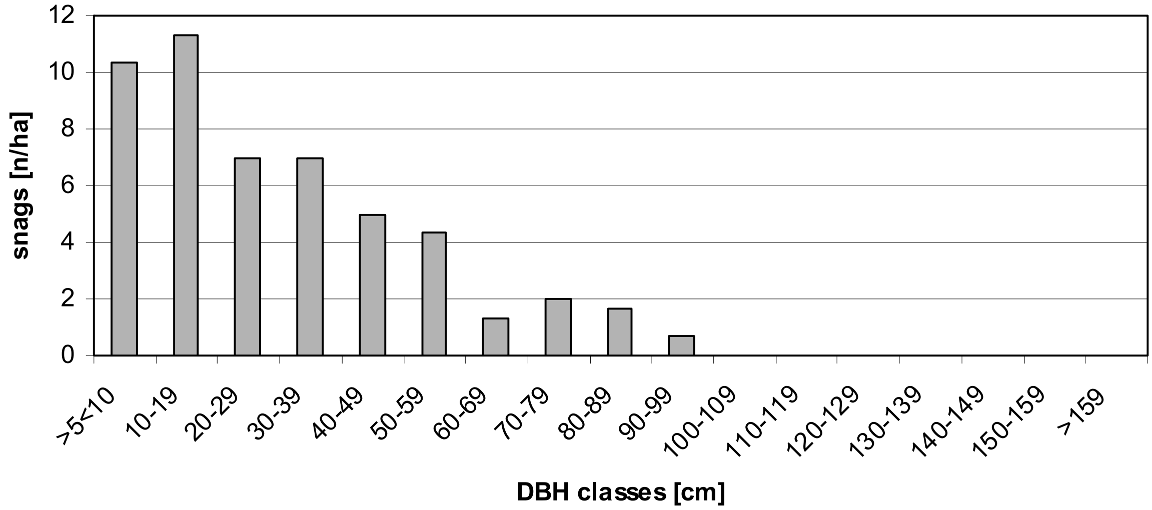


Figure 6.4-2: Number of snags per hectare as mean value from all three exploratory plots.

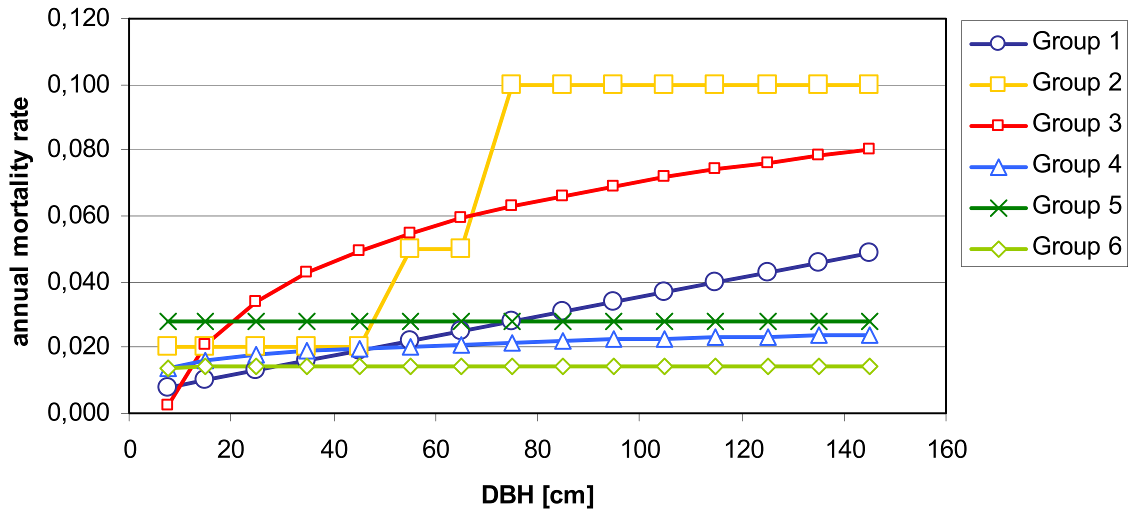


Figure 6.4-3: Mortality rates for species groups (see Table 6.4-1) in Rimchu derived from mortality data.

Harvesting rates in the DBH categories and species groups were derived from the number of stumps in all exploratory plots (Figure 6.4-4). Assuming that 10 years after harvest stumps are not visible anymore (personal communication by field foresters in Rimchu), the number of stumps as recorded in the exploratory plots and the annual harvesting rates can be derived. In the exploratory plots all stumps were from species groups 1 to 4. In Figure 6.4-5 harvesting rates over the DBH classes for four species groups as well as for all species in total are shown.

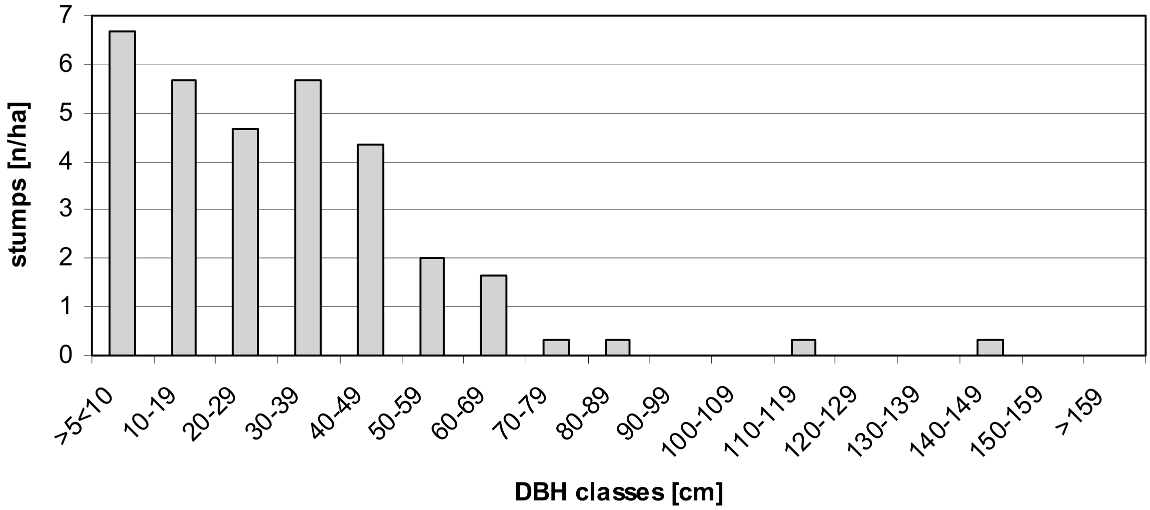


Figure 6.4-4: Number of stumps (species groups 1 to 4) per hectare as mean value from all three exploratory plots.

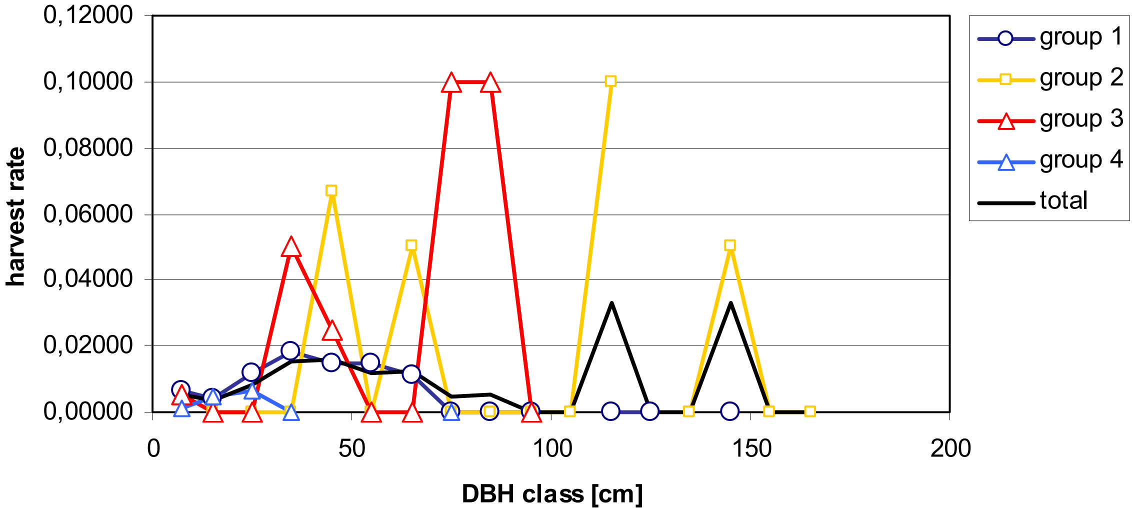


Figure 6.4-5: Annual harvest rates over the recent decade for four species groups and in total (see Table 6.3-1) as derived from the stump inventory in the exploratory plots Rimchu.

6.4.2 Scenario analysis

6.4.2.1 Equilibrium diameter distribution "current harvesting"

The equilibrium diameter distribution model approach as described in section 5.5 was employed to analyse the combined effect of growth rates, mortality and harvests as recorded in the three exploratory plots in Rimchu. The initial forest composition data in the three plots were pooled and used as starting condition for the analysis (Figure 6.4-6).

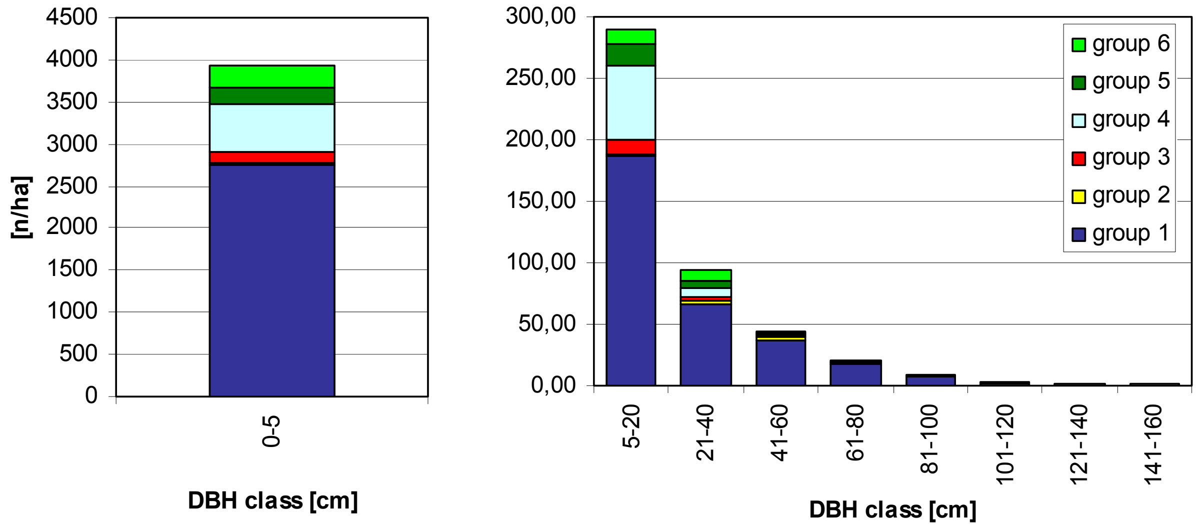


Figure 6.4-6: Initial state of the forest for the analysis of sustainable unevenaged forest structure.

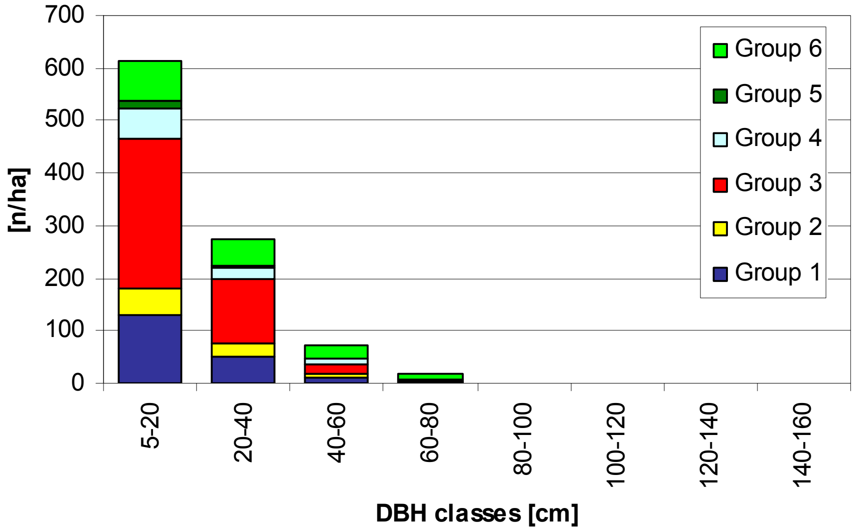


Figure 6.4-7: Equilibrium diameter distribution fo r the steady state forest "curren t harvesting".

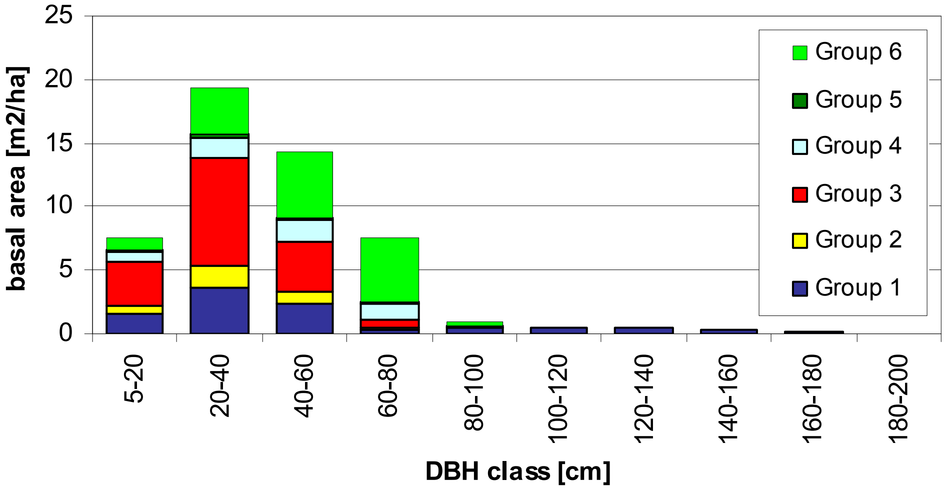


Figure 6.4-8: Basal area distribution per species group in the steady state forest "current harvesting" in Rimchu.

After an initial decrease in stem numbers the stem density (982 stems per hectare) and the species composition stabilizes after 200 years (not shown). Figures 6.4-7 and 6.4-8 display forest composition and diameter structure in the steady state. Overall, species group 3 contributes the largest share in basal area (33%) followed by species group 6 (30%), group 1 (19%), group 4 (11%), group 2 and group 5 (7% and 1% respectively). Compared to the initial forest state as recorded in 2009 the quadratic mean diameter in the steady state forest is smaller (27.1cm versus 33.3cm).

This equilibrium for the current growth rates, harvest and mortality rates has been established under the assumption that per species group 10 saplings per year are recruited into the lowest diameter class (DBH 5-20cm). Given the total basal area of 51.3 m^2/ha accumulated over the equilibrium diameter distribution this recruitment rate appears plausible. Under conditions represented by the exploratory plots in 2009 a total of 3921 saplings over the six species groups became established at a basal area of 40.32 m^2/ha (compare Table 6.1-1). Should the recruitment rate be higher than those 10 trees per ha and year than stem density needs to be reduced by a tending operation.

If the ingrowth would be reduced by 50% (5 saplings per species group and year) the equilibrium stem number (> 5cm DBH) would decrease to 657 stems per hectare. The basal area in the steady state would be reduced to 35.4 m2/ha which is below the basal area of the exploratory plots but in general still in line with the forest state in 2009. This test shows that the overall steady state diameter distribution can be quite sensitive to changes in the recruitment rate.

Another important indicator to assess the implications of the steady state model are the harvesting rates which are required to maintain the steady state. Figure 6.3-9 indicates the importance to consider explicitly the trade-offs between natural mortality and the harvest rate. The higher the harvest rates the lower the natural mortality by self thinning within the sapling layer and from shading by the main canopy. Table 6.3-3 presents the details and shows from where in the diameter range and from within the species groups the harvested trees originate.

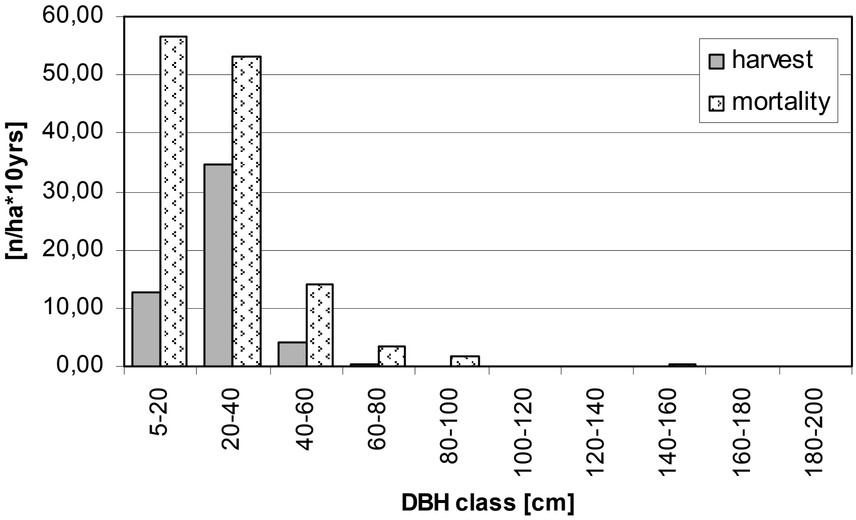


Figure 6.4-9: Total decadal harvest and mortality from the steady state forest “current harvesting”.

Table 6.4-3: Decadal h arvest and mortality in DBH cl asses and species group s from the steady state fo rests "current harv esting" (top) and "alternative harvesting" (bottom).

Species group		DBH class [cm]										Total
		5-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	160-180	180-200	
1	Harvest	4.55	4.67	0.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.19
	mortality	9.10	5.19	1.48	0.13	0.12	0.11	0.10	0.22	0.14	0.00	16.59
2	Harvest	0.00	0.00	0.66	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.83
	mortality	25.59	12.69	2.20	0.34	0.04	0.00	0.00	0.00	0.00	0.00	40.86
3	Harvest	7.75	29.38	2.50	0.15	0.00	0.00	0.00	0.00	0.00	0.00	39.78
	mortality	4.18	25.27	5.50	0.47	0.02	0.00	0.00	0.00	0.00	0.00	35.44
4	Harvest	0.30	0.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.01
	mortality	4.66	2.16	0.93	0.44	0.21	0.01	0.00	0.00	0.00	0.00	8.42
5	Harvest	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	mortality	2.16	0.53	0.16	0.06	0.05	0.01	0.00	0.00	0.00	0.00	2.98
6	Harvest	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	mortality	10.72	7.25	3.68	1.82	1.41	0.00	0.00	0.00	0.00	0.00	24.87
total	Harvest	12.60	34.77	4.13	0.32	0.00	0.00	0.00	0.00	0.00	0.00	51.82
	Mortality	56.42	53.09	13.95	3.27	1.85	0.10	0.10	0.22	0.14	0.00	129.16

Species group		DBH class [cm]										Total
		5-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	160-180	180-200	
1	harvest	30.35	8.46	0.00	0.08	0.29	0.52	0.26	0.14	0.09	0.00	40.18
	mortality	8.50	0.00	2.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.61
2	Harvest	0.00	11.24	2.72	0.00	1.34	0.48	0.06	0.00	0.00	0.00	15.84
	mortality	2.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.59
3	harvest	75.07	34.27	9.25	0.99	0.13	0.01	0.00	0.00	0.00	0.00	119.71
	mortality	37.54	13.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	51.25
4	harvest	11.78	1.58	0.00	0.26	0.01	0.00	0.00	0.00	0.00	0.00	13.62
	mortality	2.36	0.79	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.74
5	harvest	0.00	0.94	0.00	0.08	0.05	0.00	0.00	0.00	0.00	0.00	1.08
	mortality	3.46	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.65
6	harvest	13.16	7.25	3.88	0.33	0.00	0.00	0.00	0.00	0.00	0.00	24.62
	mortality	9.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.21
total	harvest	130.36	63.74	15.85	1.73	1.81	1.01	0.32	0.14	0.09	0.00	215.05
	mortality	86.66	14.50	2.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	104.06

6.4.2.2 Equilibrium diameter distribution "alternative harvesting"

As an alternative scenario the harvesting rates were modified. General idea was (i) to actively regulate mixture and density of the recruits in the lowest diameter classes, (ii) to harvest some trees from intermediate DBH classes as to better guarantee the production of valuable large diameter trees, particularly from species group 2 which includes, inter alia, several valuable timber species, and (iii) to avoid overly frequent natural mortality in diameter classes which can already contribute timber for house construction.

Growth rates were left as in the Scenario "current condition". Assuming again ingrowth of 10 saplings per hectare from each species group results in the equilibrium diameter distribution presented in Figure 6.4-10.

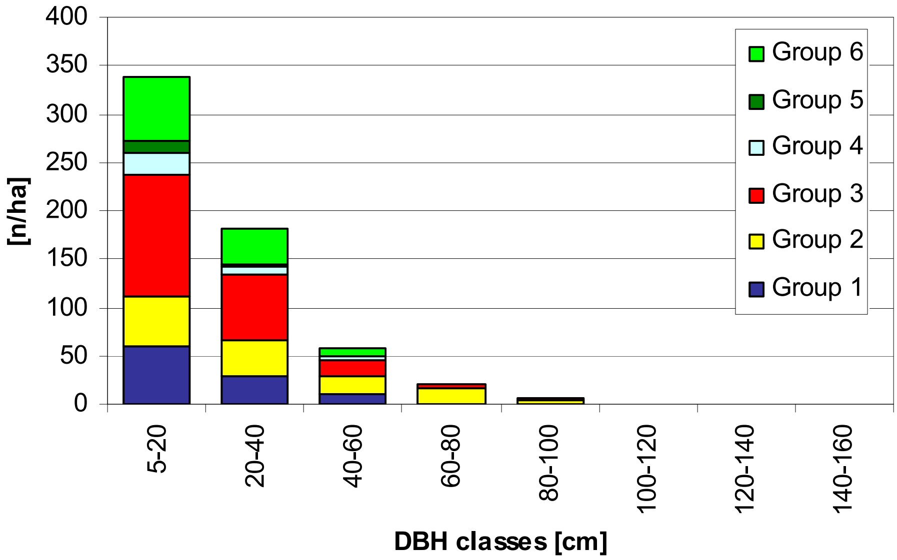


Figure 6.4-10: Stem numbers in diameter classes per species group in the steady state forest "alternative harvesting" in Rimchu.

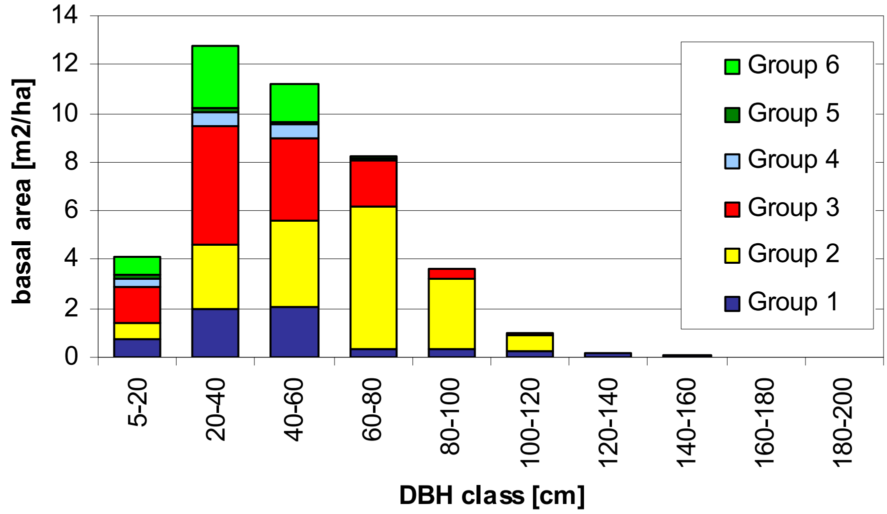


Figure 6.4-11: Basal area distribution per species group in the steady state forest "alternative harvesting" in Rimchu.

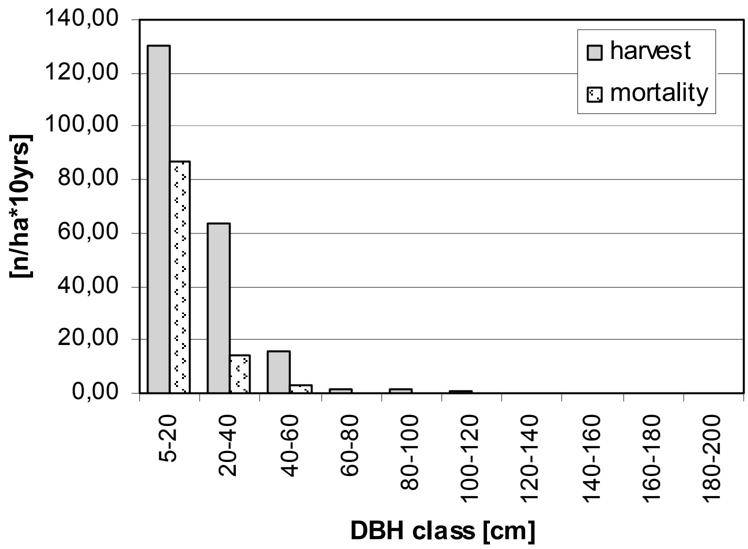


Figure 6.4-12 Total decadal harvest and mortality from the steady state forest "alternative harvesting".

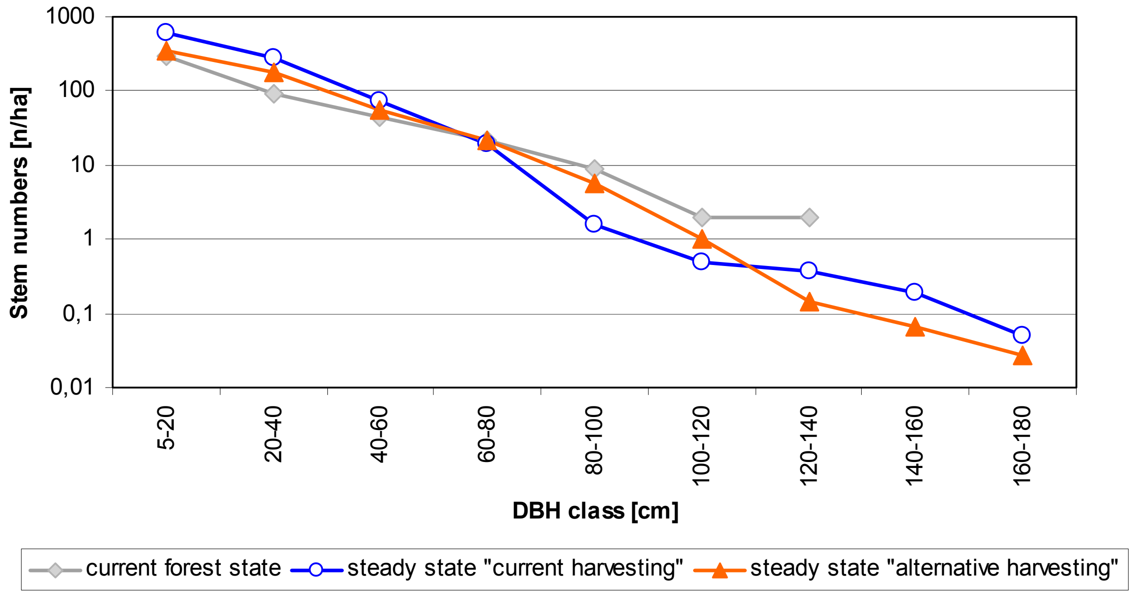


Figure 6.4-13: Comparing current state of the forest with two equilibrium diameter distributions resulting from different harvesting strategies.

Overall the steady state under above mentioned requirements accumulates 604 stems per ha (> 5cm DBH). Compared to the equilibrium diameter distribution “current harvesting” the stem numbers in low and intermediate DBH classes are substantially reduced by silvicultural management and in turn several species groups, particularly groups 2 and 3 are grown into larger dimensions (compare also the initial state in 2009 and the two analysed steady state forests in Figure 6.3-13 in logarithmic paper). The distribution of species groups’ basal area over the diameter distribution is shown in Figure 6.4-11. Total basal area in steady state under “alternative harvesting” is 41.5 m^2/ha, thus almost 10 m^2/ha less than under “current harvesting”. This should overall allow for sufficient recruitment into the lowest diameter class. Figure 6.4-12 presents and overview on total harvests and natural mortality within the steady state framework “alternative harvesting”; details are included in Table 6.4-3.

7 Discussion

7.1 The study approach

Not much research has been done so far on broadleaved forests in Bhutan. Norbu (2002) reported that unregulated and uncontrolled grazing and its related activities (lopping, clearing of under brushes) has led to undesirable consequences such as elimination of some tree species, change in tree species composition and overall reduction in tree density and warned that such uncontrolled cattle grazing practices in broadleaved forests would be detrimental both ecologically and economically and emphasized a systematic planning and integration of grazing in forest management planning at various levels of management units. Lately Buffum et al. (2008) had shown that moderate grazing of broadleaved forests and timber production was possible (0.4 cattle/ha, and timber of 4.64 m^3/ha/year) in late successional broadleaved forests of eastern Bhutan. One of the few available studies on forest structure and composition is the large scale gradient analysis by Wangda and Oshawa (2006) who sampled broadleaved forests along a geographical transect. While this study is informative with regard to general compositional pattern along gradients it does not provide sufficient operational detail necessary to inform management decisions. Therefore, the current study set focus on a specific region within the broadleaved forest zone in Bhutan.

In Rimchu experience is available from management operations in the 1980s where stripwise clear cuts along skyline tracks had been used to harvest broadleaved forests. Natural regeneration was not successful and subsequently these logged over areas had to be artificially regenerated with few successional intermediate species. Similar harvesting regimes are ongoing on other broadleaved FMUs. In Rimchu small scale single tree selection harvesting activities were ongoing to supply local population with construction timber and other products such as poles. In this context the current study sets out to analyse stand structural and compositional features with a focus on tree regeneration to improve the knowledge base for silvicultural decision making in broadleaved forests in Bhutan.

Three exploratory 1ha plots have been established as permanent monitoring plots and tree, deadwood, regeneration and microsite attributes have been measured. The plots were located along an altitudinal transect ranging from 1610m asl (Plot A) to 1970m asl (Plot C). This altitudinal gradient is intermixed with a harvest intensity gradient that is based on the notion that Plot A was situated below the new forest road, Plots B and C above. Furthermore, even when timber harvests have been limited and mainly took place since the new road construction, the effect of grazing is difficult to estimate. Thus, the interpretation of differences in stand characteristics as effect of altitude is limited and the main value of the plots is exploratory and indicative.

The size of the plots is well suited to study forest structure and composition and allows to cover gap formation processes, the hypothesized prevailing disturbance regime in broadleaved forests in Bhutan. A challenge was the large number of tree species occurring in these forests at very small scale. In all three exploratory plots the species number was between 27 and 35. Thus, intermingling of species could not be studied in detail due to the shier species diversity. Rather species were grouped according to different characteristics and these groups used in plot comparisons. For instance, species were grouped with regard to their importance as timber species within a regional context (Chapter 6.1). Another perspective was the assignment of the individual species to functional groups according to their role in the canopy formation processes, while another approach was taking the relative height within the plots as grouping variable (Chapter 6.1). The latter two approaches were used to shed light on the vertical composition in the exploratory plots.

A minimum of 16 sub plots was established within each exploratory plot. All together 48 sub plots with detailed information on regeneration structure and composition as well as a selection of microsite attributes including Hemiview photographs were available to analyse the occurrence of seedlings and saplings in broadleaved forests. The regeneration data set was complemented by a separate study on biomass allocation pattern and morphological attributes of saplings from four selected tree species. The species had been selected in order to represent contrasting behaviour and ecological roles in broadleaved forests: *Castanopsis tribuloides* as one of the dominating species in Rimchu forests, *Cinnamomum bejolghota* as sub-canopy, *Macaranga pustulata* as pioneer species and *Symplocos ramosissima* as an ecologically versatile species. The sample size of 20 saplings per species may be considered small. However, considering the effort required to measure the biomass compartments and to record the regeneration status in the immediate neighbourhood of the biomass trees the study provided promising material to explore growth and biomass allocation pattern of tree regeneration below the main canopy.

To study the sustainability of single tree harvesting regimes required additional data collection efforts. The equilibrium diameter distribution approach (e.g. Schütz 1989), an analysis approach which is well established in Central European uneven-aged forest management, was employed to study potential management implications in broadleaved forests in Bhutan. This required information on periodic diameter growth. A total of 26 trees and stumps were sampled for tree ring chronologies. The tree ring data set together with mortality and harvest data inferred from an inventory of stumps and snags in the three exploratory plots allowed for the first time the preliminary parameterization of equilibrium diameter distribution models sensu Prodan (1949) and Schütz (1989) for broadleaved forests in Bhutan.

Summarizing, the study concept was targeted towards the exploration of management – related features and processes in broadleaved forests: forest composition and structure, regeneration in relation of shading and lateral competition as well as the synthesizing attempt to analyze the implications of single tree selection harvests on the sustainability of forest structure and composition. In the following selected methods and related results will be discussed in detail.

7.2 Species composition and diversity

There were 34 species in Plot A, 27 species in Plot B 35 in Plot C and the species which occurred just in one plot constituted 12%, 33% and 23% of the tree species composition >5cm DBH in each plot respectively. The species level similarity indices differed between the plots. The observed differences were mainly due to the occurrence of species which were recorded once. There were four such species in Plot A, nine in Plot B and eight in Plot C. As mentioned earlier, there were 52 tree species >5 cm DBH in three plots, out of which 22 were common in all three plots and these 22 species constituted more than 90% of the stem densities in the study stands.

The differences in species composition could be due to altitude, moisture regimes and other site conditions unaccounted for in this study. Many studies on evergreen broadleaved forest elsewhere have established that habitat heterogeneity (Manabe and Yamamoto 1997; Manabe et al. 2000; Arévalo and Fernández-Palacios 2003), canopy openings (Cornelissen et al. 1994; Enoki and Abe 2004), and density-dependence (Grau 2000) are important for the coexistence of different trees species in broadleaved forest. Similarly, Luo et al (2009) reported environmental heterogeneity and seed dispersal limitation as mechanisms controlling the distribution patterns of tree species in evergreen broad leaved forests of eastern China.

For the Rimchu exploratory plots it has been ruled out the possibility of tree composition differences due to aspect, as the plots were all oriented towards Northeast. It is a known fact that species composition in Bhutan changes along altitudinal and moisture gradients. A study covering the altitudinal gradient from 1520 masl to 2500 masl (Wangda and Ohsawa, 2006) had shown that there were changes not only in species composition, there were altogether different forest types partition along the temperature, moisture and soil nutrient gradients. In Rimchu, many species that were present on low altitude plots (1610-1710) were absent in 1900-2000m asl plots and vice versa indicating partitioning of species along the altitudinal gradient. Another possible cause for differences in species composition may be natural as well as man-made disturbances. Many studies have recognized the role of natural and man-made disturbances in the forests as an agent of change of species composition, structure and density (Pickett and White 1985, Oliver and Larson 1990, Young and Hubell 1991, Burslem and Whitemore 1999, Hubbel et al 1999, Sheil 1999). However, there were no signs of large scale disturbances, for instance from windstorm, visible in the region. Harvesting did take place since the construction of the local forest road about 10 years ago. Before the area of the exploratory plots was considered as inaccessible for timber harvesting (personal communication by local foresters). Timber harvests since then can all be tracked via the stump inventory.

As reported elsewhere in Bhutan, the grazing by local cattle could change forest structure and composition significantly (Norbu 2002, Davidson 1999). However, despite the long grazing history in the region, the grazing pressure was not considered high in Rimchu. The grazing was done on rotational basis and lasted for few months only during winter (field interviews with cattle herders, 2008). Thus, the observed differences in species composition could not be explained by past human utilization nor by large scale natural disturbances as there were no evidences of heavy used of forests by humans as well as big scale natural disturbances in the past on the study plots. It is speculated that the small scale disturbances (Denslow 1987), both natural and anthropogenic (single tree fall, single tree harvesting), in combinations with environmental factors, inter and inter species competition, seed production and dispersal mechanism, may have been decisive for the recruitment of new individuals and species in the study plots. In the regeneration layer in the exploratory plots a few species dominate (e.g., *Castanopsis tribuloides, Symplocos sp*.). Assuming that at observed stand densities natural regeneration seems to be possible throughout the forest the composition of the regeneration layer may partly be synchronized in space due to seed production processes but may change over time, thus generating continuous shifts in species composition. This view is supported by the fact that in the current regeneration layer, though abundant over large parts of the forest, just 55 % of the species present in the main canopy was also represented in the regeneration layer.

The data of the three plots on the structural pattern of the forests revealed that all sites were mainly dominated by *Castanopsis tribuloides* and few prominent under-storey species such as *Symplocos spp and Turpinia nepalensis.* The present classification of broad leaved forests types based on precipitation and altitude by Grierson and Long (1983) did not match well with the study data from Rimchu. The current classification seems too broad to accommodate stand level characteristics by functional groups or successional groups of tree species. It was observed that there was clear dominance of a single species, *Castanopsis tribuloides,* with admixed other species from sub-tropical to temperate forests in all study plots. However, it was difficult to fit the observed species data into any of the forests types reported in Grierson and Long (1983). Within that scheme according to altitude Rimchu forests should belong to the warm broadleaved forest type. The current species mixture in the exploratory plots indicates cool as well as warm broadleaved forest types. Therefore a sub-classification scheme employing species functional groups or dominance groups may be required for better understanding and management of the broad leaved forests.

In addition to the tree species a significant number of lianas, orchids, tree ferns and other epiphytes and hemi-epiphytes were observed on most of the trees in the exploratory plots which certainly adds to diversity of the plant species in the study area. However, the understanding of their ecological role is completely missing in the Bhutan Himalayan forests, yet they occur extensively especially in broadleaved forests. The recent advances in studying lianas in the tropics have shown that they can play an important role as gap fillers and also as tree killers (Schnitzer and Bongers 2002).

7.3 Stand structure

The overall density (stems/ha) in the exploratory plots was higher compared to forests with similar human impact both from within Bhutan as well as from other countries. Norbu (2002), for instance, reports stem numbers/ha from cool broadleaved forests in Bhutan of ca. 200 stems/ha. The general diameter structure in all plots in Rimchu was inverse j-shaped. In all the plots the highest numbers of individuals occurred between 5-20cm DBH and the frequency of stems in larger DBH classes (>100cm) dropped sharply in all plots, more so above the forest road (Plot B and Plot C).

The harvested basal area was higher in Plot B and Plot C compared with Plot A. The observed differences in basal area removal could be explained in terms of accessibility by forests road and topography of the area. As mentioned earlier, the study plots fall under single tree selection where there are no clear guidelines to mark the trees based on structure of the existing stand. The trees are felled according to the demand of the client. In this case the removal of larger trees occurred from areas above the road; this was necessary as the harvesting method with single tree selection (STS) is not mechanised, people transport logs by gravity (rolling and dragging down hill) till the road head and then transport by tractors, power tillers and trucks to their respective villages. The minimal basal area removal in Plot A showed that only small sizes trees such as poles were harvested from below the road, the manual transportation of heavier logs is not feasible up the slope. It is evident from this study that topography and accessibility factors play an important role for human utilization of these forests. In a study of disturbed and undisturbed sites in Mt. Elgon in Kenya, Hitiman et al (2004) had shown that removal of small sizes trees by residents close to the accessed forests roads and big trees removal by timber company with mechanised logging.

In the context of current management scenarios for these forests a practice like the one illustrated above may result in changes in species composition, structure of forests above and below the transport boundaries on the long term. This might lead to undesirable consequences regarding loss of biodiversity and forest degradation as more and more open spaces created by selective logging and transportation downhill by gravity could lead to soil erosion.
The height of the trees and size (DBH) of the trees indicates stand development phases of the forests, the forest in Rimchu did not show very distinct development stage, in all the investigated

plots there were trees with heights up to 49 m and diameters up to 215cm indicating a late successional stage. At the same time considerable numbers of young small trees were also present indicating recent recruitments of new individuals in the system, the system mimics almost like plenter forests.

Tall trees were found in all the plots (46 to 49 meter tree height) indicating presence of late successional species in all plots. The mean tree height was about 22 meters in Plot A, about 15 to 16 meters in Plot B and Plot C. The tallest individuals did not belong to the most dominant species in terms of stem numbers per hectare; however they contributed or represented significant proportion of basal area in the studied plots. For instance, *Alcimandra catcarthii* was common in all the plots but its frequency was low. However, its basal area was high. The analysis of the trees >35 meters tall showed that about seven species that were more than 35 meter high, contributed most of the basal area of the study plots; three of them (*Schima wallichi, Castanopsis tribuloides and Alcimandra catcarthii*) were the most harvested species in the study area. Therefore, any removal of bigger tree means higher biomass removal and creation of bigger gaps in the forest. It is evident that the height structure of the forests was impacted by harvesting of different size classes; it was observed that most small sizes removal occurred in Plot A and bigger sizes were removed from Plot B and Plot C respectively. The possible reasons as could be linked to accessibility and topographical factors as discussed earlier. Unlike in other parts of Bhutan where lopping of trees for fodder production is very common, lopping of trees was not observed within the Rimchu plots. The observed data did also not provide evidence that other human activities would have changed the height structure of these forests significantly.

Comparing the mean size of trees (cross sectional area at breast height) in functional canopy groups yielded interesting results. While the expected difference between understorey, subcanopy and canopy species within the three exploratory plots was confirmed by non-parametric tests also the mean basal area of trees within a functional canopy group was partly different between the plots. This was significant for canopy species as well as for subcanopy species while for the understorey species no significant differences between the plots could be found. In general, canopy species dominated the lowest relative vertical layer in all three plots indicating the role of canopy species in the regeneration process.

The present pattern of distribution of coarse woody debris (CWD) was correlated to accessibility and topography as discussed earlier. Generally, the CWD was continuously distributed from smallest to biggest sizes in Plot A whereas such pattern was absent in the other plots indicating possible use or removal by humans. The bigger volume of CWD occurred in Plot A. This suggests that removal of CWD was better above the road then below. However, the biggest share of the CDW was in advanced stages of decomposition (class 4) suggesting long term non-removal of CDW from the forest. It is a common practice for people of Bhutan to collect the CDW as fuel wood; however, that in Rimchu large portions of CWD remained in the forest indicated that CWD as source of fuel wood was not important for the local residents. They may have alternative places for firewood collection or alternative sources of energy. In Plot A there was more or less a balance of CWD across decay classes compared with the other two plots suggesting removal by humans in the former. The retaining of CWD in the forest was suggested in many of the recent literature on CWD, they are said to be habitat for host of insects and other useful fauna in the forests. However, no inference can be made from the present study on the actual ecological role of CWD, therefore a study investigation the ecological role of CWD is envisioned in future.

7.4 Stand quality

The quality of the trees in a stand is very important when it comes to human utilization and harvesting. Standard approach in current single stem harvesting regimes in Bhutan is that people usually tend to choose the best quality trees by species. In this study the trees have been classified into two categories. Generally about 68% of the standing trees were classified in the "good" category and rest were "poor". Overall, the distribution of tree categories both good and poor was multimodal indicating different regeneration and recruitment patterns. There was more basal area from poor trees in Plot A than in Plot B and Plot C. This could be due to the norms or current government harvesting rules that dead, diseased and dying trees must be removed first and which may have led to an upgrading due to more intense harvesting activities in Plots B and C. It may be argued that the "upgrading" of stand quality through the removal of these deformed trees may also have negative side effects. Old trees may serve many ecological functions such as habitat for insects, birds and host for dozens of epiphytes and other plant forms, their removal from the system will made the old tree dependent plants and fauna species homeless.

7.5 Regeneration pattern in broad leaved forests

Regeneration of broad leaved forests has been a topic of debate for several years in Bhutan. The ratio of the regenerating tree species (<5cm DBH) and canopy species (>5 cm DBH) was 0.58 in Plot A, 0.46 Plot B and 0.60 in Plot C, showing on average more than 50% of the species present as adult trees were also present in the regeneration layer. Many studies have shown that there are many reasons for differences in regeneration patterns of forest trees species. It could be differential requirements of species with regard to light, moisture or seedbed conditions in general (e.g. Huth and Wagner 2004), seed dispersal mechanism (Seidler and Plotkin 2006), sprouting timing, disturbances, inter and intra species competition (Oliver and Larson 1990, (Schnitzer and Bongers 2002), altitude (Wangda and Ohsawa, 2006).

Seedling and sapling numbers differed substantially between the exploratory plots, and so did also the origin (sprouting versus seed origin). Interestingly, Plot A with on average lowest light levels at the forest floor had seedling numbers (about 11600 per ha) while for instance Plot B with higher light levels showed just about recruits below 130cm height. The Plot C at the highest altitude had the highest seedling density with over 17000 individuals per hectare. Similar relationships between the plots existed also for sapling densities (between 1000 and 3400 per hectare). These numbers appear high and seem to indicate that regeneration under forest conditions of the exploratory plots does not seem to be a major problem. However, in species rich forests like Rimchu, the general stocks of regeneration alone may be misleading. A closer look at the species level would be necessary. Generally, the most dominant species such as *Castanopsis tribuloides*, some intermediate shade tolerant species *Symplocos spp*, and pioneers species like *Macaranga spp* were abundant in number; however some key late successional species such as *Alcimandra catcarthii* were present in very low numbers or none at all in some plots. Many canopy species did not have regeneration at all.

Although regeneration of tree species in Rimchu was higher compared with similar forest types in Bhutan (Norbu, 2002) it would be ecologically meaningful to explore the relationships between regeneration abundances and possible factors that control them. Such an approach will aid in developing sustainable forest management regimes. The relative light levels within the exploratory plots differed between the three plots. The range in light levels was clearly largest in Plot C, smallest in Plot A. However, it was evident from the results of the regeneration inventory in the exploratory plots that almost all species were present under most light conditions, thus, light was obviously not a strong decisive factor in contrasting the species composition among and within the plots. A further effect may have been relevant in this context. There is a seasonal signal with regard to leaf area density due to increased leaf shading during the winter season. Many species are able to utilize the increased light levels below canopy during winter to gain height and thus a relative advantage compared to other more dormant species. The magnitude of this "dilution" effect regarding to shade could not be analysed in the current study but may be an interesting task for follow-up activities.

The ordination of the plant species (both trees and others) with multivariate RDA techniques showed partitioning of species along the altitudinal and light gradients (i.e. GSF). The species that are more correlated towards higher GSF are shade intolerant species, the ordination diagram clearly identified them as *Macaranga spp, Carpinus viminea, Juglans regia etc* and the species directly opposite of GSF such as *Cinnamomum spp, Quercus glauca*, *Beilschmiedia gammieana* etc could be shade tolerantly, and those species which have weak correlation with GSF could be intermediate species. *Castanopsis tribuloides* in all plots showed such intermediate behaviour. Further study entailing detailed environmental conditions such as soil parameters, temperature soil moisture along with vital morphological indicators of the tree species are required to illustrate the species responses. In the analysis other recorded microsite attributes were not decisive for the establishment of regeneration.

The detailed analysis of biomass and morphological relations of saplings of four selected tree species was meant to further investigate functional relationships and processes relevant in understanding regeneration processes in Rimchu forests. In general, biomass partitioning pattern showed characteristic differences between the species. In general biomass compartments per species could be predicted well from DBH, height and other dimensional attributes of saplings. However, the leaf component yielded the lowest R^2 values of all biomass compartments for all four species. This indicates the sensitivity of the leaf compartment to differences in light and lateral competition conditions. Univariate correlation analysis and multivariate ordination techniques of sapling morphological attributes and light as well as lateral competition indices did not reveal a clear pattern for all four analysed species. *Macaranga pustulata* was more the exception than the rule in showing a distinct pioneer species response pattern to varying light and competition levels. Partially, the rather diffuse response pattern to light and lateral competition may be due to (a) the relative homogeneous light levels below canopy which did not exclude or favour very clearly any of the regenerating species, and (b) the absolute density of neighbouring seedlings and saplings around the biomass study trees was not high enough to significantly affect sapling morphology.

7.6 Steady state diameter distribution models

The steady state diameter distribution models (EDDM) established for the Rimchu plots were the first attempt to utilize this technique for broadleaved forests in Bhutan. The method is attractive as it allows with relatively low input to estimate potential consequences of single tree selection harvesting strategies. As long as the limitations of the method are clearly acknowledged the results from EDDM provide valuable support in analysing and designing silvicultural alternatives within single stem selection approaches. Clearly, the missing feedback relation of stand structure and density on growth and mortality rates is a limitation of the method. However, in Rimchu the initial stand conditions in all three exploratory plots were quite close to the potential steady state conditions. Thus, using the empirical diameter increment models and mortality rates from the exploratory plots seemed justifiable. Nevertheless, it has to be clearly pointed at the work by Prodan (1949) and (Schütz 1989) who state that a resulting EDDM always has indicative character, needs to be updated periodically and should be taken as guideline not as operational cutting plan itself.

In the "alternative harvesting" scenario the overall basal area is approximately the same as recorded under current state, thus tree growth rates should be comparable. In the scenario "current harvesting" 51m^2/ha basal area are accumulated in the steady state which is higher than what has been observed in 2009. Thus, growth rates for intermediate and low diameter classes may be overestimated compared to what has been derived from the tree ring analysis. A suitable means to circumvent this inherent limitation would be a diameter increment model similar to the one presented by Monserud and Sterba (1996) for Austrian forests. Such an equation could be developed at relatively low cost from an inventory in broadleaved forests and then be used to adjust growth rates as the stand structure is changing due to assumptions about harvesting and mortality rates (e.g. Nenning 1999). A matrix model approach (e.g. Solomon et al. 1986) could then be a further step towards a fully developed suitable growth model for broadleaved forests.

Analysis showed that continuing with current harvesting rates would result in an increase in basal area by about 10%. Whether this would substantially reduce the recruitment of new trees into the lowest diameter class remains open. To account for such a possible feedback loop in the analysis the assumed ingrowth rates in the lowest diameter class had been set to values of 8-10 trees per ha and year, which is substantially lower then what can be inferred from the regeneration inventory. Important finding from the analysis is that harvesting strategies can be used to shift the shares of species and species groups towards more stakeholder oriented targets. In the scenario "alternative harvesting" increased emphasis was put on increasing the shares of species groups 1 and 2 providing the most preferred timber species from local user perspective.

It is interesting to compare the results of the household survey on current and future demand in timber and fuelwood in the Rimchu region with the production of the two analysed steady state harvesting strategies. As we do not know the absolute demand of local and non-local stakeholders the forest area required to satisfy the demand of an average household was calculated under both harvesting scenarios (Table 7-1). Under the "current harvesting" scenario the future demand for timber (exclusive the small amounts of firewood) could be met with a forest area of 0.7ha (Dangchung), 2.3 ha (Tsim), 30.4 (Cham) and 22.0 ha (Drashing). Compared to the output of the "alternative harvesting" scenario this requires for most of the assortments substantially larger areas (compare Table 7-1).

Table 7-1: Area required to meet the demand of an average household under "current harvesting" and "alternative harvesting" regimes.

Scenario	Demand	Area demand for timber assortments [ha]			
		Dangchung	Tsim	Cham	Drashing
Current harvesting	current	0.7	5.5	55.8	43.9
	Future	0.7	2.3	30.4	21.9
Alternative harvesting	Current	0.8	6.4	38.9	37.1
	future	0.8	2.7	21.2	18.5

EDDM can provide valuable support in analysing the likely implications of silvicultural strategies. They do not provide ready solutions but an iterative approach to derive targeted harvesting measures as well as to check internally the validity of set assumptions.

7.7 Forest dynamics, management and future stand development

Considering the above discussions on different aspects of species compositions and stand structure a stand development framework for broadleaved forests in Rimchu is put forward and discussed.

The current studied forests are near natural forests (that is reproduction, seed production, seedling germination, saplings establishments and growth to maturity happened naturally) the conventional classification of these forests into stand structural developmental stages (e.g. Oliver and Larson, 1990) was difficult to implement. Firstly, the development was evidently continuous rather than a chain of discreet phases (Franklin et al, 2002) evident from the presence of all sorts of species (e.g. pioneers such as *Macaranga pustulata*) and late successional species (e.g., *Alcimandra catcarthii*). Secondly, the processes that created spatial heterogeneity seem to be operating throughout the life of the stand. Now some questions arise regarding the dynamics of these forests. What are the drivers and processes that have lead to the present structure of the forests? And how will they develop in the future?

The small scale natural stochastic gap forming events at random such as snags falls, tree falls due to unstable geological conditions or by wind throws, branch breakages etc, occasional single trees selection felling by humans and loss of tree leaves due to yearly seasonal variations (extreme of dry and wet periods due to monsoon type of climate) might have been responsible for shaping the these forests stand structures and compositions. These events are happenening randomly in space but more or less continuously in time. Since these forests bear considerable number of tree species, these species respond differently to each of those events mentioned previously.
The next question is what happens to these gaps? How are they filled? Many studies (e.g. Parish and Antos 2004, Whitmore 1989, Spies and Franklin 1990), a comprehensive review of gap dynamics and tree regeneration by Yamammoto (2000) presented various possibilities of gap fillings. The gap formations in forests and fostering of regeneration according to successional state of the trees species (pioneer and late successional) had been recognised fundamental natural processes (Brokaw, 1985). A simple model for these forest developmental stages was conceptualised after Franklin et al (2002).

The small disturbances seldom removes all structural elements from the previous stand (Franklin et al. 2002) depending on the scale of the disturbances many trees species survive and in fact almost intact vegetation remains in case of branch breakage or small tree mortality. When a new space or gap is created in a forest it provides microenvironmental conditions (Yamamoto, 2000) favouring establishment of shade intolerant plant species, it may happen that the gap was created just above existing advanced regeneration of shade tolerant trees. In that case these plant species immediately take the released space resulting in a small new stand of their own. In broadleaved forests of Rimchu, it was observed that *Macaranga pustulata* along with some other tree species such as Symplocos spp, clones of *Castanopsis tribuloides* covered most of the bigger gaps leading to the conclusion that these species may respond fastest to sudden opening of niche space. The smaller gaps may enhance the growth and development of already existing advanced regeneration of more shade tolerant species. Very often it had been observed that the density of regeneration especially of pioneers like *Macaranga pustulata* were abundantly present in bigger gaps. The other late successional species have never been seen in such quantities in any of the forests gaps, such observations are cited widely in gap dynamic literatures such as Brokaw (1985), Abe et al. (1995) and Carvalho et al. (2000).

Table 7-2: Factors responsible for creation of gaps in exploratory plots in Rimchu and their possible effects on the forest stand dynamics.

Events	Causal agents	Gap size	Possible resources availability
Branch breakage	wind, rain primates	Small (<20 m^2)	Increased sunlight availability on the forest floor
Natural tree fall	wind, landslides (due to fragile mountain geology)	Small to moderate	sunlight and release of nutrients
Natural tree death	Natural mortality due to maturity, due to insects and pathogens, self thinning	Small to moderate	Sunlight and release of nutrients
Single tree harvest and other forest products collection	humans for timber, firewood, fodder etc	Small to moderate	Sunlight and release of nutrients
Leaf losses	climatic seasons, Limited soil moisture, insect defoliation	small to large (depending on species distribution by types (evergreen or deciduous), soil types, insects and pest breakout	Increased sunlight available and release of nutrients

Although big gaps (created by felling of 4-5 trees) are not part of the study plots, on some of those gaps, in and around Rimchu forests it was found mostly covered by herbaceous vegetations such as Girardinia *diversifolia* (Link) Frisis, *Urtica spp*, *Elastostema spp* etc, while in some gaps bamboo thickets were observed. In gaps on the relatively wetter sites *Musa spp* (wild bananas) were abundant; still in other gaps different species of ferns constituted most of the ground vegetation. Nevertheless, the regeneration of tree species was present in small numbers either as sprout or from seed sources also in these gaps. In short, it is speculated that the gap sizes and frequency of gap formations could explain species richness and species establishment rate in such forests.

The gap phase regeneration becomes more complex when external factors such as grazing interact with the regeneration processes described earlier. Depending upon the size of the gaps livestock species such as cattle are attracted accordingly, larger the gaps are likely to attract more cattle than smaller ones. However, with the present set of data at hand more cannot be said about cattle grazing impact or influence on the stand developmental stages; nevertheless it is postulated that there is influence on forest dynamics and hence the overall forests stand structure due to cattle grazing in these forests. Further research detailing the cattle grazing on forest stands is warranted to clarify the postulation.

The climatic patterns determine the vegetation of any given location, obviously if there are changes in climate the response of vegetation to such changes may be different depending on the stages of stand development. Again more research is needed to clarify in which ways the tree species are responding to changing climatic conditions. The changes in climate conditions may have positive or negative feed back to the system, for example the pest and diseases may have increased or decreased due to climate changes which in turn may have influence on forests stand development. Further it is speculated that the responses of trees due to prolonged dry periods usually from mid September to May could be very influential for future species composition.

8 Conclusions

This study was conducted in broad leaved forests of western Bhutan where single tree selection has been practiced for at least the previous decade. The forest structure as recorded in 2009 resembles a "Plenter forest" with stem numbers in diameter classes following a reverse J shaped distribution. Analysis of potential steady state diameter distribution models indicated that it is likely that such a forest structure could be maintained given that harvesting rates are kept under control. Therefore it can be argued that a single tree selection system with proper harvesting guidelines may prove a working silvicultural strategy for the sustainable use of broadleaved forest resources in Bhutan. Given the observed failures in regeneration on logged over areas in broadleaved forests, it is evident that stripwise clear cuts along long distance cable yarding tracks are unlikely to succeed in maintaining species diversity of current broadleaved forests. The results of the current study do not provide a ready to use silvicultural guideline. However, it seems reasonable to conclude that single stem selection approaches as discussed in the context of this study could contribute to the maintenance of mandatory 60% forest cover "for all times to come" fostering the maintenance of biodiversity, soil and water conservation in the country while at the same time make wise and sustainable use natural resources.

From the current study it follows that there are some urgent research needs on many basic forests attributes, one of the most and urgent need is to classify the tree species according to their shade tolerance and to establish minimum required light levels for successful regeneration. Other studies such as knowledge on seed dispersal and the response of intermediate trees to release are urgently required on the was towards the design of science-based management concepts for broadleaved forests in Bhutan. Observational studies such as the one presented herein should be complemented by experimental approaches to target the required output with higher efficiency. Such future research should also be designed so as to contribute data required to develop and parameterize simulation models of forest dynamics. The current study has made a substantial first step towards this goal.

To make single stem and small scale harvesting approaches operational interdependencies with other landuses such as cattle grazing needs to be considered. Ultimately, as proof of usability possible implementation with skyline – based logging systems need to be tailored to the needs of sustainable management concepts for broadleaved forests.

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Table A1-1: Plot-wise raking of tree species > 5cm DBH in Rimchu) according to their cumulative relative density and species ID serve as entry along x-axis in Figure 6.1-4 upper panel) from most frequent to least frequent.

ID	PLOT A	PLOT B	PLOT C
1	Castanopsis tribuloides	Castanopsis tribuloides	Castanopsis tribuloides
2	C.bejolghota	Symplocos ramosissima	Elaeocarpus lanceifolius
3	Macaranga pustulata	Symplocos lucida	Quercus glauca
4	Quercus glauca	C.impressinervium	Symplocos ramosissima
5	Turpinia nepalensis	Cordia obliqua	Turpinia nepalensis
6	Symplocos lucida	Hovenia acerba	Cinnamomum bejolghota
7	Sloanea tomentosa	Daphniphyllum chartaceum	Styrax grandiflorus
8	Carpinus viminea	Elaeocarpus lanceifolius	Eurya acuminata
9	Elaeocarpus lanceifolius	Macropanax undulatus	Alcimandra cathcartii
10	Eurya acuminata	Albizia sherriffii	Macropanax undulatus
11	C.bhutanica	Eurya acuminata	C.glaucescens
12	Engelhardia spicata	Styrax grandiflorus	C.impressinervium
13	Styrax grandiflorus	Alcimandra cathcartii	Albizia sherriffii
14	Myrsine semiserrata	Beilschmiedia gammieana	Myrica esculenta
15	Symplocos ramosissima	Macaranga pustulata	Beilschmiedia gammieana
16	Alcimandra cathcartii	Rhus succedanea	Engelhardia spicata
17	D.chartaceum	Carpinus viminea	Lithocarpus pachyphyllus
18	Ficus sp	Celtis tetrandra	Lyonia ovalifolia
19	Hovenia acerba	Eriobotrya dubia	Q.griffithii
20	Lindera pulcherrima	Juglan regia	Quercus lanata
21	L. pachyphyllus	Michaleia valutina	Schima wallichii
22	Schima wallichii	Myrica esculenta	Acer laevigatum
23	Acer laevigatum	Prunus undulata	Symplocos lucida
24	B.gammieana	Quercus glauca	Myrsine semiserrata
25	Casearia glomerata	Symplocos sumuntia	Carpinus viminea
26	C. glanduliferum	Turpinia nepalensis	Celtis tetrandra
27	Macropanax dispermus	--	Daphniphyllum chartaceum
28	Syzygium kurzii	-	Ehretia wallichiana
29	Talauma hodgsonii	-	Exbucklandia populnea
30	Albizia sherriffii	-	Glochidion acuminatum
31	Brassaiopsis hispita	-	Hovenia acerba
32	Choerospondias axillaris	-	Ilex kingiana
33	Prunus andulata	-	Macaranga pustulata
34	-	-	Unknown

Table A1-2: Plot-wise raking of tree species > 5cm DBH in Ri mchu) according to their cumulative relative basal area density and specie s ID serve as entry along x-axis in Figure 6.1-4, lower panel, the ranking is based on the most dominant = 1 to 34 the least dominant.

Species ID	PLOT A	PLOT B	PLOT C
1	Castanopsis tribuloides	Castanopsis tribuloides	C.tribuloides
2	Alcimandra cathcartii	Cordia obliqua	A. cathcartii
3	Engelhardia spicata	Alcimandra cathcartii	E. lanceifolius
4	Sloanea tomentosa	Michaleia valutina	Q. glauca
5	Elaeocarpus lanceifolius	Beilschmiedia gammieana	C.glaucescens
6	Schima wallichii	Hovenia acerba	A. sherriffii
7	C.bhutanica	Elaeocarpus lanceifolius	S. wallichii
8	Turpinia nepalensis	Cinnamomum impressinervium	C. bejolghota
9	Quercus glauca	Daphniphyllum chartaceum	Q.griffithii
10	Cinnamomum bejolghota	Albizia sherriffii	Q. lanata
11	Macaranga pustulata	Rhus succedanea	T.nepalensis
12	Carpinus viminea	Symplocos lucida	L. pachyphyllus
13	Cinnamomum glanduliferum	Symplocos ramosissima	D. chartaceum
14	Eurya acuminata	Juglan regia	B. gammieana
15	Lithocarpus pachyphyllus	Quercus glauca	Lyonia ovalifolia
16	Symplocos lucida	Celtis tetrandra	M. undulatus
17	Acer laevigatum	Eriobotrya dubia	S. ramosissima
18	Beilschmiedia gammieana	Prunus undulata	E. spicata
19	Daphniphyllum chartaceum	Eurya acuminata	S. lucida
20	Prunus andulata	Turpinia nepalensis	A.laevigatum
21	Ficus sp	Macropanax undulatus	C. viminea
22	Talauma hodgsonii	Carpinus viminea	E.acuminata
23	Lindera pulcherrima	Symplocos sumuntia	S. grandiflorus
24	Styrax grandiflorus	Styrax grandiflorus	C. impressinervium
25	Casearia glomerata	Myrica esculenta	Celtis tetrandra
26	Albizia sherriffii	Macaranga pustulata	Ehretia wallichiana
27	Myrsine semiserrata		M. esculenta
28	Symplocos ramosissima		H. acerba
29	Hovenia acerba		Glochidion acuminatum
30	Syzygium kurzii		Ilex kingiana
31	Macropanax dispermus		Exbucklandia populnea
32	Brassaiopsis hispita		Unknown sp
33	Choerospondias axillaris		M. semiserrata
34			M. pustulata

Table A2-1: List of regeneration <5 cm dbh by height classes by species/ ha in exploratory PLOT A. The Height classes are in cm.

Species	<10	10-30	30-50	50-80	80-130	130-200	200-300	300-400	400-500	500-600	Total/ha	% Total
Castanopsis tribuloides	99.5	547.4	547.4	1144.5	1990.4	485.2	547.4	248.8	224	161.7	5996.1	41.44
Sophora wightii	49.8	149.3	149.3	149.28	298.56	62.2	12.44	0	0	0	870.8	6.02
Sloanea tomentosa	49.8	199	49.76	149.28	149.28	24.88	0	12.44	0	0	634.44	4.39
Symplocos ramosissima	99.5	49.76	99.52	99.52	199.04	12.44	12.44	12.44	0	12.44	597.12	4.13
Mussaenda roxburghii	0	49.76	99.52	149.28	248.8	0	37.32	0	0	0	584.68	4.04
Albizia sherriffii	0	199	49.76	99.52	99.52	0	12.44	24.88	0	0	485.16	3.35
Daphne bholua	0	49.76	149.3	99.52	49.76	12.44	0	0	0	0	360.76	2.49
Lindera pulcherrima	49.8	149.3	0	0	99.52	49.76	0	0	12.4	0	360.76	2.49
Macropanax undulatus	0	0	99.52	149.28	49.76	24.88	12.44	0	12.4	12.44	360.76	2.49
Styrax grandiflorus	0	99.52	49.76	0	149.28	24.88	12.44	0	12.4	0	348.32	2.41
D. chartaceum	0	99.52	0	99.52	49.76	12.44	0	49.76	0	12.44	323.44	2.24
Dichroa febrifuga	0	99.52	149.3	0	0	12.44	12.44	0	0	0	273.68	1.89
Engelhardtia spicata	0	0	49.76	99.52	99.52	0	12.44	0	12.4	0	273.68	1.89
Cinnamomum glaucescens	0	99.52	0	99.52	49.76	12.44	0	0	0	0	261.24	1.81
Eurya accuminata	0	49.76	0	49.76	99.52	37.32	24.88	0	0	0	261.24	1.81
Maytenus kurzii	0	49.76	49.76	49.76	99.52	12.44	0	0	0	0	261.24	1.81
Cinnamomum bejolghota	0	0	0	49.76	49.76	49.76	37.32	37.32	12.4	12.44	248.8	1.72
B. gammieana	49.8	49.76	0	49.76	49.76	12.44	12.44	0	0	0	223.92	1.55
Cryptocarya bhutanica	0	0	0	0	199.04	12.44	0	0	0	0	211.48	1.46
Alcimandra cathcartii	0	49.76	49.76	0	49.76	0	0	0	0	12.44	161.72	1.12
Ficus sp	0	99.52	0	0	49.76	12.44	0	0	0	0	161.72	1.12
Turpinia nepalensis	0	0	49.76	0	49.76	12.44	12.44	0	0	12.44	136.84	0.95
Carpinus viminea	49.8	0	0	49.76	0	12.44	12.44	0	0	0	124.4	0.86
C. impressinerium	0	0	49.76	49.76	0	0	12.44	0	0	0	111.96	0.77
Toona ciliata	0	0	0	49.76	49.76	12.44	0	0	0	0	111.96	0.77
Acer oblongum	0	0	49.76	49.76	0	0	0	0	0	0	99.52	0.69
Myrica esculenta	0	0	0	49.76	49.76	0	0	0	0	0	99.52	0.69

Continued ..Table B1-1.

Schima wallichii	0	0	49.76	49.76	0	0	0	0	0	0	99.52	0.69
Buddleja crispa	0	49.76	0	0	0	24.88	0	0	0	0	74.64	0.52
Acer laevigatum	49.8	0	0	0	0	12.44	0	0	0	0	62.2	0.43
B. assamica	0	0	0	0	0	37.32	0	0	12.4	0	49.76	0.34
Desmodium renifolium	0	0	0	49.76	0	0	0	0	0	0	49.76	0.34
E. lanceifolius	0	0	49.76	0	0	0	0	0	0	0	49.76	0.34
Ilex kingiana	0	0	49.76	0	0	0	0	0	0	0	49.76	0.34
Quercus glauca	0	0	0	0	0	0	12.44	0	12.4	24.88	49.76	0.34
Macaranga pustulata	0	0	0	0	0	12.44	0	0	12.4	0	24.88	0.17
Hovenia acerba	0	0	0	0	0	0	0	0	0	12.44	12.44	0.09
Total/Ha	498	2140	1891	2886.1	4279.4	995.2	796.2	385.6	323	273.7	14468	
% of the total	3.44	14.79	13.07	19.948	29.579	6.879	5.503	2.666	2.24	1.892	100	

Table A2-2: List of regeneration <5 cm dbh by height classes by species/ ha in exploratory PLOT C. The Height classes are in cm.

Species	<10	10-30	30-50	50-80	80-130	130-200	200-300	300-400	400-500	500-600	Total/ha	% Total
Castanopsis tribuloides	796.16	1293.76	1841.12	1492.8	1443	1007.64	435.4	136.84	111.96	447.84	9006.56	43.10
Symplocos ramosissima	99.52	447.84	547.36	646.88	298.56	149.28	149.28	24.88	62.2	87.08	2512.88	12.02
Beilschmiedia gammieana	199.04	696.64	49.76	99.52	49.76	49.76	0	0	0	12.44	1156.92	5.54
Macaranga pustulata	0	199.04	248.8	149.28	447.84	99.52	0	0	0	0	1144.48	5.48
Daphne bholua	49.76	398.08	49.76	149.28	49.76	37.32	12.44	0	0	0	746.4	3.57
Quercus semiserrata	49.76	298.56	149.28	49.76	99.52	24.88	0	0	0	0	671.76	3.21
Quercus glauca	99.52	149.28	99.52	0	99.52	99.52	37.32	12.44	0	12.44	609.56	2.92
Cinnamomum glaucescens	49.76	199.04	0	99.52	99.52	0	0	0	0	0	447.84	2.14
Engelhartia spicata	49.76	149.28	99.52	149.28	0	0	0	0	0	0	447.84	2.14
Cinnamomum impressinerium	0	99.52	99.52	49.76	0	49.76	24.88	0	0	74.64	398.08	1.90
Docynia indica	248.8	149.28	0	0	0	0	0	0	0	0	398.08	1.90
Macropanax undulatus	49.76	199.04	149.28	0	0	0	0	0	0	0	398.08	1.90
Ficus sp	0	0	248.8	49.76	0	49.76	0	12.44	0	0	360.76	1.73
Ardisia macrocarpa	0	149.28	99.52	0	0	0	0	0	0	0	248.8	1.19

Continued..Table B1-2.

Alcimandra cathcartii	49.76	149.28	49.76	0	0	0	0	0	0	0	248.8	1.19
Turpinia nepalensis	0	49.76	149.28	0	0	24.88	0	0	0	12.44	236.36	1.13
Cinnamomum bejolghota	49.76	149.28	0	0	0	0	0	0	0	0	199.04	0.95
Lithocarpus pachyphyllus	49.76	99.52	0	0	49.76	0	0	0	0	0	199.04	0.95
Lindera pulcherrima	0	49.76	49.76	49.76	0	12.44	12.44	0	0	12.44	186.6	0.89
Carpinus viminea	49.76	99.52	0	0	0	0	0	0	0	0	149.28	0.71
Pongpoma	0	149.28	0	0	0	0	0	0	0	0	149.28	0.71
Eurya accuminata	0	99.52	0	0	0	0	0	0	12.44	0	111.96	0.54
Schima wallichii	0	0	49.76	49.76	0	0	0	0	0	12.44	111.96	0.54
Macaranga denticulata	0	49.76	0	0	49.76	0	0	0	0	0	99.52	0.48
Quercus griffithii	0	99.52	0	0	0	0	0	0	0	0	99.52	0.48
Maytenus kurzii	0	0	0	0	49.76	0	24.88	0	12.44	0	87.08	0.42
Ehretia wallichiana	0	49.76	0	0	0	12.44	0	0	0	0	62.2	0.30
Styrax grandiflorus	0	0	49.76	0	0	12.44	0	0	0	0	62.2	0.30
Acer laevigatum	49.76	0	0	0	0	0	0	0	0	0	49.76	0.24
Celtis tetrandra	0	0	0	49.76	0	0	0	0	0	0	49.76	0.24
Daphniphyllum chartaceum	0	0	0	0	49.76	0	0	0	0	0	49.76	0.24
Myrica esculenta	0	0	49.76	0	0	0	0	0	0	0	49.76	0.24
Myrsine semiserrata	0	0	49.76	0	0	0	0	0	0	0	49.76	0.24
Symplocos lucida	0	49.76	0	0	0	0	0	0	0	0	49.76	0.24
Elaeagnus conferta	0	0	0	0	0	12.44	12.44	0	0	0	24.88	0.12
Engelhardtia spicata	0	0	0	0	0	24.88	0	0	0	0	24.88	0.12
Total/ha	1940.64	5523.36	4130.08	3085.12	2786.6	1666.96	709.08	186.6	199.04	671.76	20899.2	
Total % share	9.28571	26.4286	19.7619	14.7619	13.333	7.97619	3.3929	0.8929	0.9524	3.21429		

Table A3-1 : Descriptive statistics of morphological attributes of four young broadleaved tree species as studied for their biomass in Rimchu. Mp = Macaranga pustulata, Sr = Symplocos ramosissima, MSE = mean standard error around the mean, SD = standard error around the mean.

Species	Variables	n	Min	Max	Mean	MSE	SD	Variance
Ct	Height (m)	20	2.50	6.20	4.15	0.24	1.07	1.14
	Dcoll (cm)	20	2.70	5.00	3.78	0.16	0.70	0.49
	D10 (cm)	20	2.52	4.70	3.56	0.16	0.69	0.48
	DBH (cm)	20	1.50	4.10	2.79	0.18	0.79	0.62
	CL (m)	20	1.40	5.00	2.92	0.20	0.91	0.82
	CW (m)	20	0.80	2.60	1.54	0.10	0.45	0.20
Cb	Height (m)	20	2	6	3.58	0.22	0.99	0.99
	Dcoll (cm)	20	1.7	4.8	3.05	0.19	0.87	0.75
	D10 (cm)	20	2	4.6	3.32	0.22	0.98	0.97
	DBH (cm)	20	1.9	4.6	3.14	0.22	1.00	1.01
	CL (m)	20	1.4	4.1	2.31	0.19	0.83	0.69
	CW (m)	20	0.8	3.4	2.16	0.15	0.65	0.42
Mp	Height (m)	20	1.93	6.40	4.49	0.30	1.35	1.83
	Dcoll (cm)	20	2.30	4.80	3.46	0.18	0.81	0.65
	D10 (cm)	20	2.10	4.70	3.26	0.18	0.79	0.63
	DBH (cm)	20	1.00	4.70	2.77	0.21	0.95	0.90
	CL (m)	20	0.40	3.70	1.48	0.17	0.77	0.60
	CW (m)	20	0.40	1.80	1.24	0.08	0.37	0.14
Sr	Height (m)	20	2.5	5.6	3.69	0.18	0.78	0.61
	Dcoll (cm)	20	2.4	5.6	3.49	0.20	0.90	0.82
	D10 (cm)	20	2.2	5.3	3.28	0.20	0.91	0.84
	DBH (cm)	20	1.4	3.8	2.41	0.15	0.68	0.47
	CL (m)	20	1.2	3.7	2.47	0.15	0.67	0.45
	CW (m)	20	0.7	2.2	1.36	0.09	0.42	0.18

Table A3-2: Descriptive statisti cs of biom ass trees and their component dried weights (g) stem (SDW),branch (B DW) and leaves (LDW), Cb,= Ci nnamomum bejolghota, Ct = Castanopsis tribuloides, Mp = Macaranga pus tulata, Sr = Sym plocos ramosissima, MSE = mean standard error around the mean, SD = standard error around the mean.

Species	Variables	n	Minimum	Maximum	Mean	MSE	SD
Ct	STD (g)	20	476.01	2899.17	1334.51	160.66	718.51
	BDW (g)	20	111.45	2060.60	563.94	98.37	439.93
	LDW (g)	20	49.95	598.84	210.33	30.86	138.00
	TDW (g)	20	697.78	4825.72	2108.78	255.46	1142.44
Cb	SDW (g)	20	106.73	2727.27	957.35	153.31	685.63
	BDW (g)	20	5.07	556.80	184.47	37.14	166.09
	LDW (g)	20	100.17	1059.82	299.62	51.49	230.27
	TDW (g)	20	313.43	3625.87	1441.44	219.07	979.73
Mp	SDW (g)	20	107.09	2029.84	843.20	133.43	596.72
	BDW (g)	20	20.77	543.11	167.82	32.56	145.60
	LDW (g)	20	14.82	522.77	183.38	34.06	152.30
	TDW (g)	20	324.67	2705.92	1194.40	146.36	654.53
Sr	SDW (g)	20	392.84	5734.71	1253.94	270.07	1207.81
	BDW (g)	20	94.81	1708.37	464.516	87.35	390.63
	LDW (g)	20	25.49	465.73	114.104	21.43	95.82
	TDW (g)	20	601.58	7908.82	1832.56	366.36	1638.40

Table A4-1: Data collection form used to record general attributes of study plots (refers to 50 meters above and above 1 ha exploratory plot in CL = Clear cut forests, LU =local use only (single tree harvesting), VF = Virgin forests.

Name of the Recorder			**Date**			
Location	**CL**	**LU**	**VF**	**Altitude [m]**	**Aspect**	**Slope range**
Slope position	**Slope form (Straight/Cocave/Covex)**	**Longitude**	**Latitude**	**Forest types**	**If CL then year of logging**	**If CL then cable block name and line number**
Accessibility to area	(Road/ footpath)					
Who use these forests						
How many people use it?						
When it is used maximum						
What they used for?						
How many cattle are grazing these forests?						
What type of cattle?						
Who own these cattle?						
When is the maximum cattle go in these forests						
Are there any made disturbances?						
Natural disturbances	(landslides, wind throws, others specify)					
Any special functions	Religious/spiritual, special habitat for animals, biological, any other specify					
Any management activities	Nursery, plantation/ fencing etc.					
Any other observations						

Table A4-2: Data form used to record attributes on trees >5 cm DBH including stumps and snags. Types refers to quality in case of live trees (1 =good , 2= Poor, 3= Snags, 4= stumps).

Name of the Recorder:																		**Date:**				
Location		**Transect**		**Plot No**		**Quadrant No**		**Radius**				**CL**			**LU**			**VF**				
Tree No	Species	DBH [cm]	Ht [m]	Crown[m]				Co-ordinates			Crown Length [m]	Class	Supports other species	Uses	Damages	Types						
				up	down	left	right	Angle	Dist[m]	Ref												

Table A4-3:Data form used to record trees attributes < 5 cm >1.3 meter height**.**

Name of the Recorder:						**Date:**		
Location		**Transect**	**Plot No**	**Radius**		**CL**	**LU**	**VF**
Sl no	Species	Height [m]	DBH/Collar dia [cm]	Crown length [m]	Crown Width[m]	Status		Remarks

Table A4-4: Data form used to record attributes on trees species <130cm > 30 cm height

Name of the Recorder:						**Date:**		
Location		**Transect**	**Plot No**	**Radius**		**CL**	**LU**	**VF**
Sl no	Species	Height [cm]	Collar diameter [cm]	Crown length [cm]	Crown width [cm]	Vitality class (1 to 6)	Browsing intensity	Other damages

Table A4-5: Data form used to record attributes on trees species <30 cm height

Name of the Recorder:						**Date:**			
Location		**Transect**	**Plot No**	**Radius**		**CL**		**LU**	**VF**
Sl no	Species	Height [m]	Collar diameter [m]	Crown length	Crown width	Vitality class	Micro sites	Browsing intensity	Other damages

Table A4-6: Data recording form for recording attributes on coarse woody debris (CWD).

Name of the Recorder:						**Date:**			
Location		**Transect**	**Plot No**	**Radius**		**CL**	**LU**		**VF**
Sl no	Species	Bigger end diameter [cm]	Smaller end diameter[cm]	Total length [m]	Direction	X cord	Ycord	Nurse log/yes/ No	Decomposition class

Table A4-7: Data recording form used for recording sites attributes on regeneration sample plots.

Name of the Recorder:				**Date:**		
Location	**Transect**	**Plot No**	**Radius**	**CL**	**LU**	**VF**

Altitude		Humus depth		**Relief**	
Slope %		Litter depth		Ridge top	
Aspect		% Boulders		Middle slope	
Geology		Soil Type		Lower slope	
Longitude		Soil Texture		Slope Toe	
Latitude		Grazing Impact		Ditch	
				Valley bottom	
				Plain	
Ground vegetation		**% Cover**		**Height**	
Species				**Max and Min**	
					Dominant vegetation

Table A4-8: Data collection form used to record attributes and compartment of biomass samples ; L= Leaves, B= branch and S= stem biomass cs = composite samples.

Name of the Recorder:							**Date:**					
Location		**Transect**	**Plot No**	**Quadrant**	**Radius**		**Forest use type**					
							Fresh weights [g]					
Plot No	Species	Ht [m]	DBH [cm]	Crown Length [m]	Crown Width [m]	Sample Label	**Total Fresh weights**			Composite		
							L	B	S	Lcs	Bcs	Ssc

Table A4-9: Data form used for collection and recording of attributes related to tree ring data**.**

Name of the Recorder:						**Date:**		
Location		**Transect**	**Plot No**	**Quadrant**	**Radius**	**CL**	**LU**	**VF**
Plot No	Species	DBH [cm]	Height [m]	Disc diameter	Sample height [m]	Sample Label	Cores/ Disc from stumps/ Disc from Trees	Remarks

Annex 5

Questionaires for assessment of forest resources demand

Name of the interviewer: **Date:**

1. **Back ground information**

(a)Name of the Respondent :
(b)Age :
(c)Sex:
(d)Educational Background :
(e)Income type (low/ medium /high) tick appropriate one.
(f)Relation to head of the family :
(g)Village :
(h)Geog :
(i) Dzongkhag :

2. **Social information**

(a) Number of members in households :
(b) Number of dependent by types : (b1) old = (b2)Young = (b3) any other =
(c) Number of schooling going children:
(d) Number of hh family members working other than farming
(e) Number of hh members engaged in farming:

2.1 Household income sources

What are the most important income sources? Name them and rank according to priority.
(a) ----------(b)----------(c) --------(d) --------------(e)-----------------.

2.3 Household property holdings
2.3.1 Wetland (ac) 2.3.2 . Dry land

2.7.3 Pastures:

2.3. 4 any others land uses:

2.3.5. Number of livestock by types
a. Number of cattle (a1) Improved: (a2) Local:

b. Horses /mules/donkey)

c. Others

3. **Past Forest use trends**

3.1. Which were the most important forests products you have been using for the past 5 years? Rank which was most important forest products for you (Scale 1 to 4, 1 is very high and 4 is lowest)

3.1-1: Timber / Firewood/fodder / non wood forests products

Forest Products	Rank
Timber	
Firewood	
Fodder	
Non wood Forests Products	
Any other	

3.2. How many trees and which species did your household used for the past 5 years ? Give a ranking according to preferences for species and mention the locality of their collection?

Species	Number of trees used					Locality of collection
	Dangchung	Tsim	Cham	Drashing	Others	

3.3 What is the demand for the forests products now, compared to 5 to 10 years ago? Increasing or decreasing?

3.3.1 Reason for increase?

3.3.2 Reason for decrease?

3.4 Did you collect any non wood forest products in the past 5 years? How much did you sell and how much did you consume yourself in your household?

Name of NWFPs	Sold	Consumed	Price per unit	Rank

3.5 What is the trend in availability of non wood forests produces compared to 5-6 years ago? Increasing or decreasing? Which species?

3.5.1 Reason for Increasing:

3.5.2 Reasons for decreasing:

3.5.3 Species:

4. Future demand for forests resources

4.1. Which forests products (timber, firewood, fodder, nwfps, any other specify) will be important to you in future? and why?

4.1.1 Timber:

4.1.2 Firewood:

4.1.3 Fodder:

4.1.4 Non wood Forests produce:

4.1.5 Any Others:

4.2. How much of the forests produce would you require in another five years from now?

Species	Number of trees required					Purposes
	Dangchung	Tsim	Cham	Drashing	Others	

4.3 Do you think these resources will be easily available and why?
Why do you think otherwise?

5. Forest resources management

5.1. Do you think the present system of forests management by the government is good?
If so why? If not why?

5.2. How do you think that the management of the forests resources will be improved for future?

5.3 Do you think the community forestry is a good way of managing the forests?
If so why if not why?

5.4. Any other comments