Evaluating Site Quality in Subtropical Montane Forests in North Western Argentina

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Abstract

Evaluation of site quality represents an important prerequisite for sustainable and economically efficient forest management. Few generally applicable methodologies for mixed forests with indeterminate ages are known and their implementation is often limited by regional variations of factors determining tree growth. Site quality evaluation was carried out by means of classification based on various approaches in subtropical moist forests in north western Argentina. Different site characteristics were compared according to findings based on growth data obtained from stem analysis, soil characteristics and inventory data.

Growth analysis was carried out based on samples obtained from the valuable timber producing genus *Cedrela* and average growth rates were related to site factors. Predominant soil groups were identified and respective chemical properties were related to stand characteristics as obtained from inventory of the corresponding area. Further, canopy parameters were assessed using consumer grade digital photography. The variables of computerized imagery analysis were validated by crown related parameters obtained from stand inventory and compared according to various site factors.

Growth of *Cedrela spp.* was partially explained by identifying correlated site factors such as inclination of slope or exposition. Soil assessment allowed for assignment of explanatory variables to distributions of quantitative stand parameters and species composition. An analysis of variances identified certain trends with regard to distribution of variables of quantitative and qualitative stand parameters within two areas with distinct history of intervention.

Keywords: Site quality evaluation, *Cedrela spp.*, *Yungas*, north western Argentina

Abbreviations

The following notation will be used throughout the entire document, unless otherwise indicated:

A = area (m^2)

asl = above sea level

D_c = mean crown diameter, as projected to ground (m)

D_h = diameter (cm) at height h (m)

D_i = diameter at breast height (1.3 m above ground) (cm), outside bark, of tree i

D_j = diameter at breast height (1.3 m above ground) (cm), outside bark, of competitor j

G = total basal area (m^2 ha^{-1})

G_i = basal area at breast height (m^2) of tree i

H = relative height of tree (%)

H_c = height at crown base (m)

H_i = height i along bole (m)

H_t = total height of tree (m)

H_{top} = height of 20% of the strongest trees (m)

LAI = leaf area index

r = radius (m)

V_c = commercial volume, up to crown base (m^3)

Institutions and locations

FPC = *Finca Pintascayo*

GMF = *Gestion Manejo Forestal Latinoamericana S.A.*

FSC = *Forest Stewardship Council*

INTA = *Instituto Nacional de Tecnologia agropecaria*

NGO = non-governmental organization

SNC = *San Carlos*

1 Introduction

The classification of different stands according to their potential to grow trees can be regarded as a cornerstone for efficient and sustainable forest management, since reforestation or enrichment plantings can only be economically sound and successful if precise information on the dominant characteristics that govern tree growth in a specific area is available and taken into account. Information about existing site factors which determine the productive potential with regard to tree growth is usually hard to gain, but of extremely high value. (Vanclay, 1992; Gadow, 2004).

In countries with traditionally intensive forestry the valuation of site quality (German: "*Bonitierung*") has a long history of being subject to investigation and was easily studied since most areas have been subject to various cycles of clear cutting, planting and replanting. Thus, the quality of sites was empirically valuated by continuous record of prevailing tree heights of monocultures established in different plantations (Gadow, 2004; Laar and Akça, 1997).

In most tropical countries however, data on site quality is usually not available because little focus has been put so far on the productive potential of a site as cleared areas are only very occasionally subject to post harvest reforestation efforts (Vanclay, 1994). Thus, valuable empirical data is lacking and few studies exist on valuation of site quality in tropical forests, especially in natural forests with trees of many species and indeterminate ages (Vanclay, 1992).

Such a situation is given in northwestern Argentina, where vast forest areas (known as *las Yungas*) have been subject to destructive timber harvest and land conversion. During the last seven decades 75% of the once forested area have disappeared (Brown et al, 2005) in the provinces of Salta and Jujuy.

The data used for this Master-thesis was obtained during a stay of three months at the company "GMF Latinoamericana S.A." in Salta, Argentina in the winter of 2006.

GMF was founded by a group of forestry and finance professionals from Switzerland and Germany in 2003 and is dedicated to the integration of extended properties in north-western Argentina in a comprehensive forest management scheme. GMF provides management structures based on European standards, which focus on sustainable management and conservation of existing forests. The establishment of a sound forest resource management scheme which can foster the long term conservation of the *Yungas* and help to solve regional socio-economic conflicts is the main objective of GMF, for which it has currently been certified to comply with the criteria of the *FSC* (Smartwood, 2007). This

management scheme poses a valuable alternative to existing devastating land use patterns that have led to vast forest degradation throughout the region (Brown et al, 2005).

Young companies like GMF constantly face various constraints concerning accessibility, transport, information and available resources. Therefore, optimization of applied inputs within low information scenarios is indispensable, especially with regard to silvicultural management, transport or harvesting practices.

Considering the above described situation, it becomes obvious that prior to the implementation of silvicultural actions, thorough consideration of the given situation and detailed assessment of missing variables is a crucial matter. In order to gain information about the suitability of specific sites for afforestation or enrichment plantings, an evaluation of different parameters affecting tree growth was carried out. With the objective to determine the most significant parameters indicating site quality, different areas of intervention were investigated and compared.

GMF is currently managing approximately 50,000 ha of forest (*Finca Pintascayo*) in the province of Salta in northwestern Argentina (Fig. 1):

Figure 1: Location of the study area Finca Pintascayo.

Within the area, two sites were selected for investigation. The main criterion for selection of the sites was of practical nature, namely accessibility. The complicated topography found in the study area (Fig. 2) combined with the low intensity forest road network, strongly restricted the number of possible areas to investigate. With regard to the urgent need of GMF to obtain data of practical value, two sites were selected that were a) easily accessible and b) displayed

typical conditions as expected for the majority of sites present in *Finca Pintascayo*. Further, the two areas also constitute the focus of current silvicultural interventions by GMF in terms of afforestation or enrichment planting.

Area one consists of a flat plain (locally referred to as *San Carlos*) at an altitude ranging from 800 to 950 m asl which has been subject to intensive logging in the past, due to its location within close proximity to human settlements (GMF, personal communication). As these stands would realize an immense increase in terms of value if proportions of commercial tree species are increased, it was regarded as decisive to evaluate productivity of these sites.

The second area comprises higher elevations (700 – 1050 m asl) among the rather mountainous regions of *Finca Pintascayo* varies significantly from the former in terms of topography and degree of sloping. This area does not only lie within short distance of recent logging operations and can thus be easily accessed, but was further assumed to exhibit typical conditions found within *Finca Pintascayo*.

With the aim to optimize future yields from silvicultural actions, a survey on site quality for tree growth in the two areas was carried out. The evaluation of the characteristics of these sites and the subsequent comparison based on parameters that reflect performance of tree growth, focused on the following aspects:

1. General assessment of site quality with regard to tree growth;
2. Classification of stand attributes according to topographic features;
3. Identification of the *in situ* potential for growth of commercial tree species, based on findings related to the on site performance of *Cedrela spp.*;

1.1 *Site productivity assessment in tropical forests*

Although investigation on forest site productivity has come a long way in European forestry, (e.g. Mitscherlich, 1961; Flury, 1929, as cited in Gadow, 2004) little is still known about procedures and techniques applicable in tropical forests (Wenk et al., 1990, as cited in Gadow, 2004, Vanclay, 1992). Multi-species composition and distributions over broad age classes usually characterize these forests and pose difficulties for the forest researcher when it comes to potential assessment of a defined species to produce timber on a certain site (Gadow, 2004; Kramer and Akça, 2002, Laar and Akça, 1997; Vanclay, 1992).

Although some feasible techniques have been reported, they are most likely to require a broad and proper base of information and the probability of success is not always unambiguous. According to Vanclay (1992), the applied measure for forest site evaluation should bear the following characteristics:

i) reproducibility and consistency within a long term spectrum;

ii)   indicative of the site and not entirely influenced by stand condition or management history;

iii) the measure should be correlated with the site's productive potential;

iv)   at least as good as any other productivity measure available.

Two major approaches to assess site productivity can be distinguished. Measures focusing on the physical environment (i.e. soil properties, climate, topography, etc.) in which tree growth occurs, are ascertaining site evaluation from a *geocentric* viewpoint. On the other hand, measures that implement a *phytocentric* viewpoint, assume that vegetation is the best indicator for all site properties, since existing plants or trees reflect the sum of all physical factors that influence growth on the specific site (Vanclay, 1992).

Phytocentric methods for assessing site productivity can further be distinguished between two major approaches: the *classification* approach and the *ordination* approach.

a) Classification: classification approaches use the potential climax vegetation to stratify areas into different habitats or site types, which are considered to be efficiently uniform to allow classification (Gadow, 2004; Vanclay, 1994).

b) Ordination: the ordination approach is based on the classification of certain species into ecological groups which directly reflect different site properties. Two approaches are known. The more commonly applied method focuses on presence or absence of specific indicator species. The second approach is based on physiognomic characteristics such as height of indicator plants or shape and size of leaves (Gadow, 2004; Vanclay, 1994).

Geocentric methods are commonly applied to evaluate site productivity where suitable stand parameters cannot be assessed. In contrast to *phytocentric* methods, this approach focuses on the evaluation of existing site factors. Site factors include various components of the physical environment in which a site is located, that influence tree growth. Thus, site quality can be evaluated by comparison of existing soil characteristics, climatic conditions and topography (Vanclay, 1994).

1.2   Objectives of this study

The on hand study aims to facilitate silvicultural planning and forest management in the area of *Finca Pintascayo* by providing a base of information on factors which determine site quality in the specific region. To achieve the given objectives, forest stands at two disjoint areas with different land use histories were sampled and compared. Easily measurable site factors where assessed and analyzed.

2 Material and methods

2.1 Study area

2.1.1 Argentina

Argentina, the second largest country of South America, covers a total land area of 2,736,690 km^2. The diverse geophysical landscapes range from subtropical forests in the north to tundra in the far south and are divided into 23 provinces and 1 autonomous city (the federal district of *Buenos Aires*) (CIA World Fact book, 2007). In the subtropical northwest, bordering Chile to the west and Bolivia to the north, the provinces of Salta, Jujuy and Tucumán are the home of vast wooded areas, known as *Las Yungas*.

This study was carried out in the province of Salta, which displays a diverse set of different ecosystems, ranging from dry forests which border the *Gran Chaco* to the east, to areas of higher altitude and low precipitation, which host vast deserts, but also hosts about 70% of the present extension of the subtropical moist forest, known as *Yungas* (Brown et al., 2005; Del Castillo et al., 1992).

2.1.2 Las Yungas – the subtropical moist forests of northwestern Argentina

2.1.2.1 Distribution and geography

The montane subtropical forests of northwestern Argentina (*Selva Tucumano-boliviana*) are located at two disjoint areas within 23° (Bolivian border) and 29° (province of *Catamarca*) southern latitude. They spread some 1500 km south along the eastern slope of the Andes and range from 400 m asl to 3000 m asl, but are at their widest longitudinal extension only around 100 km wide. Currently covered area is estimated to encompass a total of around 5,200,000 ha (Brown et al., 2005).

2.1.2.2 Vegetation

The tree flora of the *Yungas* is relatively well known (Digilio and Legname, 1966; Legname, 1982) and includes 167 tree species in 130 genera and 57 families (Morales et al, 1995).Changing with ascending altitudinal level, three types of ecological entities based on tree floristic composition have been described by Cabrera (1976) and Hueck (1966) and were further classified by Kappelle and Brown (2001):

400 – 700 m asl: Pre-montane forest *(Selva pedemontana)*. This easily accessible forest is the most heavily destroyed, due to great area losses caused by the intensive timber harvest and subsequent conversion to agricultural land for i.e. citriculture, sugar cane or soy bean

production (Brown et al., 2005). Among the dominant species are *Tabebuia spp.*, *Anadenanthera colubrina*, *Myroxylon peruiferum*, *Patagonula americana*, which are all considered valuable timber species (Tab. 2) (Brown, 1995; Morales et al., 1995; Del Castillo et al., 1992).

700 – 1500 m asl: Low-montane forest *(Selva montana)*. On this altitudinal level the highest precipitations are realized. More than 2000 mm a^{-1} account for the southernmost extension of tropical species such as *Ficus maroma*, *Cinnamomum porphyrium*, *Nectandra pichurim* and *Ocotea puberula*. The hindered access to this region might account for the relatively extensive timber extraction that has been carried so far on this level (Brown et al, 2005; Morales et al., 1995; Del Castillo et al., 1992).

1500 – 3000 m asl: High-montane forest *(Bosque montano)*. The highest level is decisively influenced by certain characteristics of its high altitude, i.e. cloud stripping, low temperatures or fires. These disturbances result in structural heterogeneity, where species such as *Podocarpus parlatorei*, *Alnus acuminate*, or even *Juglans australis* or *Fuchsia boliviana* of boreal origin can be found (Del Castillo et al., 1992; Grau and Brown, 1995; Grau and Veblen, 2000).

2.1.2.3 Climate

The climatic conditions found within the *Yungas* are strongly characterized by a high amount of annual precipitation with a strong seasonal variance (Arias and Bianchi, 1996). Five months of dry and cool weather from May to September during which monthly precipitation hardly exceeds 50 mm are followed by wet and hot conditions from November to March, with the months April and October being transitional months (Tab. 1). Precipitation averages vary considerably among altitudinal levels, ranging from 800 to 1000 mm a^{-1} in pre-montane forests up to more than 3000 mm a^{-1} and 1300 mm a^{-1} in the low-montane and high-montane forests, respectively. Rainfall is highly concentrated, as almost 80% of annual precipitation occurs during the wetter months (November till March) (Grau and Veblen, 2000; Arias and Bianchi, 1996).

However, the presence of fog throughout a great part of the year decisively increases humidity even during drier periods, as horizontal precipitations, due to fog and cloud stripping are realized. Total amount and distribution of rainfall are highly influenced by exposition and altitude and are thus highly variable even within short distances (Dohrenbusch and Häger, 2006; Brown et al., 2001; Grau and Veblen, 2000).

Further, mean annual temperature also varies considerably between altitudinal levels. In pre-montane forests an annual mean of 21.2 °C is realized, whereas mean annual temperature is 11.7 °C in the high-montane forest (Arias and Bianchi 1996).

2.1.2.4 Geology and soils

The Andes were formed by the subduction of the Nazca plate beneath the South American plate that led to the rise of the longest mountain cordillera on earth. Being situated on the eastern slope of the Andes, the area of *FPC* is part of a sub-Andean geological unit that was formed by sequences of sedimentations during the Ordovician, the Cambium and Tertiary (Nadir and Chafatinos, 1990).

Most locally available soil maps are presented in a scale (1:500000) of little practical value for detailed soil classification within the area. Consequently, detailed soil analysis had to be carried out to determine soil potential of the investigated stands.

2.1.2.5 Biology and ecology of *Cedrela spp.*

Cedrela spp. of the subfamily *Cedreloides*, which belongs to the family of the *Meliaceae* is represented by several species in the Argentinean and Bolivian *Yungas*. Different species, such as *C. fussilis*, *C. lilloi, C. odorata* among others, are known to represent this common deciduous tree known as '*Cedro*' in the subtropical montane forests of South America (Villalba et al., 1985; Del Castillo et al., 2005).

The genus *Cedrela* occurs along an altitudinal belt between 400 and 2000 m asl (Zapater et al., 2003; Cabrera, 1976) and is considered to be a fast growing canopy tree, capable of reaching heights of up to 40 m and diameters of 1.5 m at breast height in northwestern Argentina (Grau, 2000; Villalba, et al., 1985).

In the provinces of Salta and Jujuy, the exact identification of all species of the genus *Cedrela* yet remains ambiguous (Lamprecht, 1990), as up to now three different species have been identified with specific distributions corresponding to the ecological entities described earlier (cpt. 2.1.2.2). In the pre-montane forest, *C. balensae* is commonly found, whilst *C. saltensis* and C. *lilloi* are more abundant in the low-montane and high-montane forest, respectively (Del Castillo et al., 2005).

The most widely spread species *C. lilloi* is known to be a gap opportunist, benefiting from successive openings in the canopy (Grau, 2000). According to Brown and Grau (1993) the genus *Cedrela spp.* is regarded as one of the most important timber species in the *Yungas* of northwestern Argentina.

The pinnate leaves are shed between June and August (dry winter). The bark is rather grayish with longitudinal channels, while the inside can be found to be reddish, dispensing a

characteristic cedar-like scent. The timber, with its reddish sapwood and brown to pink hardwood, shows a medium to coarse texture with an accentuated and straight grain. Although it is not completely prone to shrinking, its lightness and moderate hardness make it excellent construction wood (Zapater et al., 2003).

Cedrela spp. produces visible and reliable annual tree rings (Schweingruber, 1993), which according to Villalba et al. (1985) and Grau (2000) allow very well for dendrochronological studies.

2.1.3   Finca Pintascayo

The property of *Finca Pintascayo* encompasses a total of 48,186 ha and is situated within the eco-region of the Andean subtropical moist forests, about 70 km northeast of the city of *San Ramon de la Nueva Oran*. The area comprises altitudinal levels from 500 - 2000 m asl, thus including all ecological entities discussed in chapter 2.1.2.2 (GMF, 2006).

The *Finca* is located within the department of Iruya of the province of Salta in the northwestern corner of Argentina, which borders Chile to the west and Bolivia to the north (Fig. 1). Its position of 22º54'02" southern latitude and 64º39'49" western longitude (point of reference: the adjoining settlement of *Isla de Cañas*) lies within the ecological region of the neo-tropical moist forests, also known as *Yungas* (GMF, 2006).

The entire property is partitioned as follows: 39,545 ha are comprised by the area of Pintascayo, 5,218 ha of partly deforested area situated the alluvial plain called *San Carlos* and 3,423 ha consist of marginal areas surrounding rivers, such as the *Río Pescado* which are excluded from any harvesting activities (GMF, 2006).

2.1.3.1   Topography
The Finca is situated at an altitudinal level between 600 m and 2000 m asl. The predominant topography is very heterogeneous with partially very high degrees of sloping (>50%). Further, hilly to undulating terrain is very common (Fig. 2). According to the management plan of GMF, terrain with slope gradients of more than 30% impedes timber harvest; above 50% harvest becomes impossible, as operations in this area would be too destructive. Up to 8% of productive area cannot be harvested, due to extreme inclination (GMF, 2006).
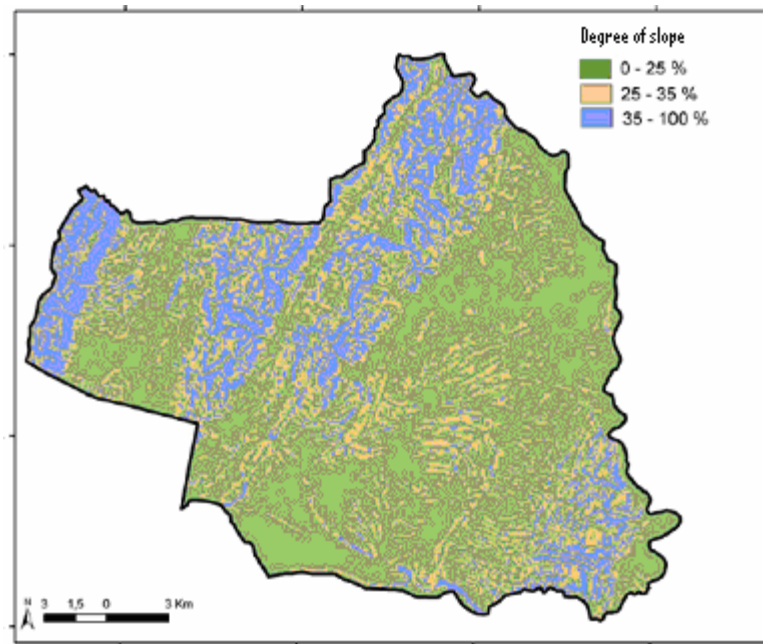
Figure 2: Different degrees of sloping on Finca Pintascayo, according to GMF, 2006

2.1.3.2 Geology and soils

According to Nadir and Chafatinos (1990), two major soil groups can be distinguished in the area of *FPC*. Along streams and rivers mollisols occur, whereas areas of higher elevation are reportedly composed of inceptisols for the most part. These denominations comply with US soil taxonomy and correspond to chernozems and cambisols according to the FAO classification system (FAO, 2006). However, this rather coarse categorization does not allow for detailed site division according to pedogenic site factors.

2.1.3.3 Vegetation and wildlife

FPC is situated within an UNESCO Wildlife Reserve (*Reserva de la Biosfera de las Yungas*) and almost completely surrounded by protected areas. The Baritú national park, (72,000 ha) adjoins to the north, while the neighboring area (13,000 ha) to the east has recently been declared a provincial reservation (*Reserva Provincial Laguna Pintascayo*). Consequently, the Finca can be regarded as highly important for the conservation of migrating fauna and various endangered species, such as the Jaguar (*Panthera onca*) and the Lowland Tapir (*Tapirus terrestris*). The pressure on these species is very high as strong demands for timber or farmland have led to a vast decline of habitat area in recent years (Brown et al., 2006).

2.1.3.4 Climate

The climate of the region surrounding *FPC* is characterized by an annual precipitation of around 930 mm a^{-1} of which 657 mm (72.5%) are distributed during four months from October to April (Arias and Bianchi, 1996). Since no detailed data on climatic conditions at

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FPC was available, the climatic conditions of *San Ramon de la Nueva Orán* serve as data basis (Tab. 1):

Table 1: Climatic characteristics of San Ramon de la Nueva Orán (adapted from GMF, 2006).

Units	Category	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Year
km/h	mean wind speed	6	6	5	5	4	4	5	6	7	7	7	7	6
°C	absolute maximum temperature	41.5	42.1	39.6	35.8	34.5	31.5	35.4	38.9	40.8	42.4	43.6	44.4	44.4
°C	mean maximum temperature	32.4	31.2	29.2	26.2	23.9	21.1	22.4	25.8	28.3	31.5	32.3	32.9	28.1
°C	absolute minimum temperature	12.7	12.6	10.8	5.1	0.4	-0.4	-3.6	-3.4	-0.5	4.0	8.5	11.5	-3.6
°C	mean minimum temperature	21.5	20.8	20.3	18.0	14.4	10.8	9.3	11.2	13.5	17.4	19.7	21.1	16.4
°C	mean temperature	25.9	25.0	23.5	20.8	18.1	14.7	14.5	17.0	19.7	23.6	24.8	25.8	21.1
mm	precipitation	192	164	147	83	22	9	6	7	11	51	92	154	938
%	mean relative humidity	80	82	85	86	86	84	78	69	62	63	70	76	77
days	number of rainy days	13.3	12.3	15.0	11.7	6.7	4.3	3.3	2.5	3.0	7.0	10.7	12.3	102
days	number of days with frost	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.4	0.0	0.0	0.0	0.0	1.4

2.1.3.5 Exposition

Exposition of a site is a decisive factor determining plant growth (Gadow, 2004; Otto, 1994), especially in the subtropical moist forests of northwestern Argentina (Bava, 1990). Local topography and prevailing wind directions result in great variability of growing conditions within different aspects of slope and sites. As the Finca Pintascayo is situated on the eastern slope of the Andes, most precipitation is brought in from the east, when dry air masses coming from the great Chaco plains ascend and thus precipitate along the slopes of the Andes (Arias and Bianchi, 1996).

2.1.3.6 Hydrology

Due to the geographic position of this eco-region, it can be presumed that the forested areas along the eastern slope of the Andes have a decisive influence on water related aspects for the entire region. As water influxes increase with altitude, these forests serve as watershed and supply for most agricultural areas and settlements further downstream (Brown et al., 2005). Since most borders of Finca Pintascayo are defined following the natural course of two important rivers and the area further contains a high number of various smaller rivers and streams, its hydrological importance can be regarded as very high (Brown et al., 2006; Fundación Proyungas, 2005).

2.1.3.7 Existing land use types

The area has been subject to selective logging of few valuable timber species since the early 50s of the last century (GMF, 2006; Brown et al., 2005). By selective extraction of few individuals of valuable timber species like *Cedrela*, *Myroxylon*, *Amburana* and *Anadenanthera*, the ecosystem is disturbed on various levels (Pinazo et al., 2003; Brown, 1995). A summary of commercial timber species currently harvested by GMF (Tab.: 2) that were classified according to timber quality with regard to market value (GMF, 2006; Minetti, 2005).

Table 2: Commercial trees harvested at Finca Pintascayo (adapted from GMF, 2006).

No.	Scientific name	Common name	Timber quality
1	*Anadenanthera colubrina*	Cebil colorado	B
2	*Cedrela spp.*	Cedro	A
3	*Cordia trichotoma*	Afata	B
4	*Enterolobium contortisiliquum*	Pacará	B
5	*Lonchocarpus lilloi*	Quina blanca	C
6	*Myroxylon peruiferum*	Quina colorada	A
7	*Parapiptandenia excelsa*	Horco cebil	B
8	*Patagonula americana*	Lanza blanca	B
9	*Ruprechtia laxiflora*	Virarú	B
10	*Tabebuia spp.*	Lapacho	A
11	*Terminalia triflora*	Lanza amarilla	C
12	*Tipuana tipu*	Tipa Blanca	B

In general, a steady decline in volumes of produced timber can be observed throughout the last two decades, due to continuous overexploitation of wooded areas and the subsequent conversion into agricultural land (Brown et al., 2005; Minetti, 2005; Brown, 1995). Further, lack of proper data and information led to poorly adapted forestry and resulted in destructive harvesting techniques and unsustainable management, which accounts for the ongoing decrease of areas occupied by the *Yungas* (Brown et al., 2005; Brown, 1995).

As further land use type, cattle grazing can be observed throughout the entire area. By unknown numbers the local population allows cattle to graze freely inside the forests. This has led to the formation of cow populations that live, breed and forage within the area (GMF, 2006).

2.2 Data acquisition

2.2.1 Selection of sample area

The areas investigated for comparison of site quality were selected primarily according to practical suitability, since accessibility poses a major hindrance to field work in the area and time constraints had to be considered, too. Thus, potential sample areas had to be reasonably accessible and should not be too far apart in order to minimize traveling time. Low intensity of human disturbance, homogeneity stand appearance and presence of characteristic conditions for the majority of stands found at *FPC* were further regarded as decisive criteria. Consequently, two distinct areas with the following characteristics were chosen and assessed (Fig. 3):

Area 1: Heavily logged over forest on flat terrain (*San Carlos*)

This area is situated on an alluvial plain within walking distance of the adjoining human settlement (*Isla de Cañas*) and has been subject to intensive logging in the past whose impacts are still clearly visible (GMF, 2006). Easy access in combination with a convenient flat terrain obviously fostered the exploitation of these stands. The area consists of 5,218 ha of open forest with a patchy canopy at low height. Nearly all commercial timber has been extracted and only trees of inferior timber or low stem quality seem to be left. Cows have been grazing frequently within the area but are now held off by a fence recently established by GMF (GMF, 2006).

Area 2: Forest on hilly terrain that has been subject to extensive logging

The second area is situated at a higher altitude within *FPC* and varies significantly from the former in terms of topography and degree of sloping. The area does not only lie within short distance of recent logging operations and is thus easily accessible, but it can also be regarded as typical for the predominate conditions of most stands found in *FPC*.
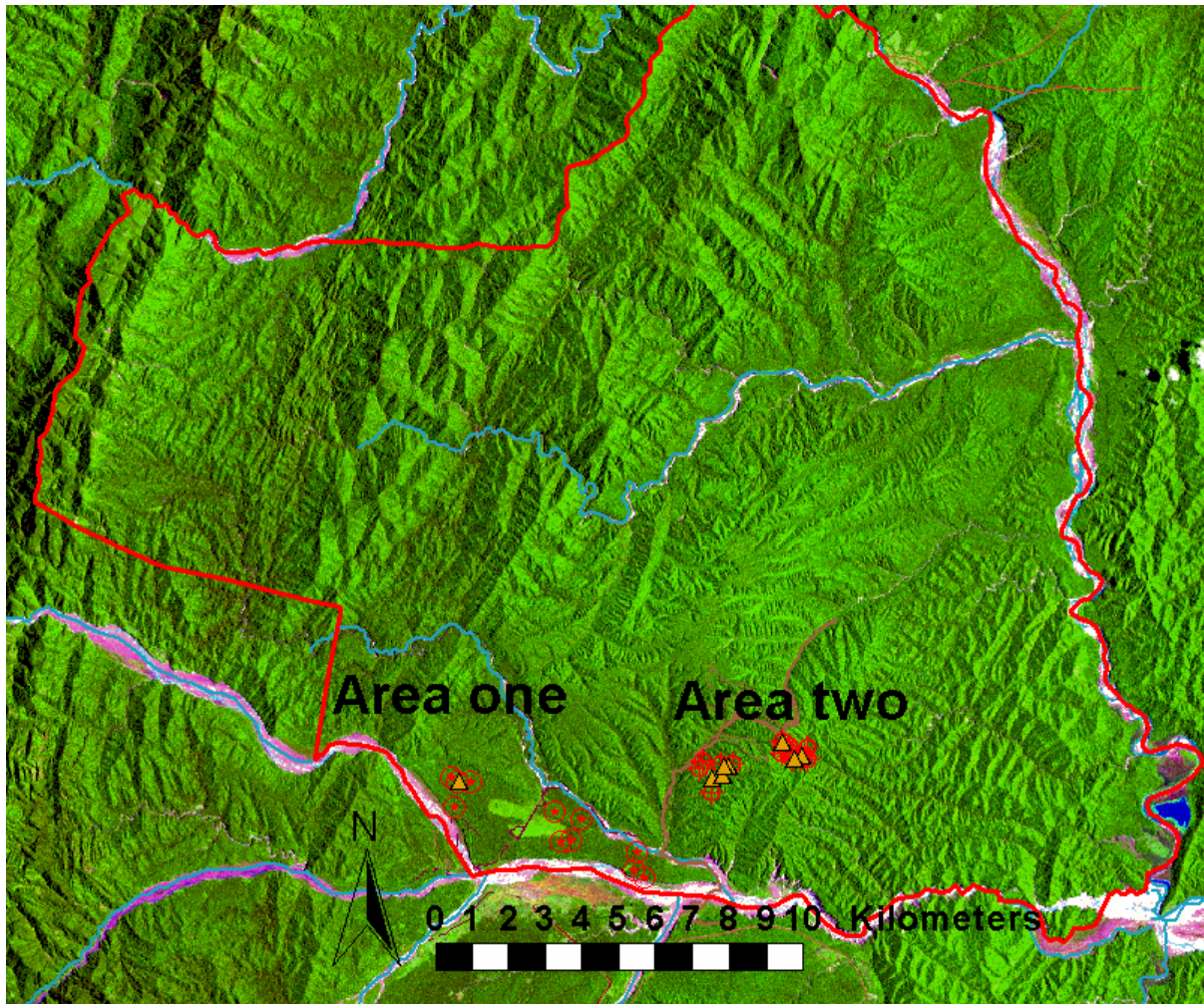
Figure 3: Finca Pintascayo and location of sample plots in area one and two (Δ indicate position of sample trees)

2.2.2 Stratification and sample design

Stratification of *FPC* was carried out with regard to elevation. Both areas were classified by means of GIS programming (ArcView 3.2) based on satellite imagery. Thus, the areas of interest (Cpt. 2.2.1) were divided into classes of different altitudes with intervals of 50 m: 800 to 950 m asl in area one and 850 to 1000 m asl in area two, resulting in three and four strata, respectively. Within each altitudinal stratum four sample plots were randomly positioned using a dot grid of 100 x 100 m and subsequently established and measured in the field. Plot positions *in situ* were located by using a hand held GPS navigation device.

In total, 36 sample plots were established and measured. 11 plots were randomly distributed within three strata in area one (Fig. 4). In area two, a total of 17 plots were randomly distributed in four strata.
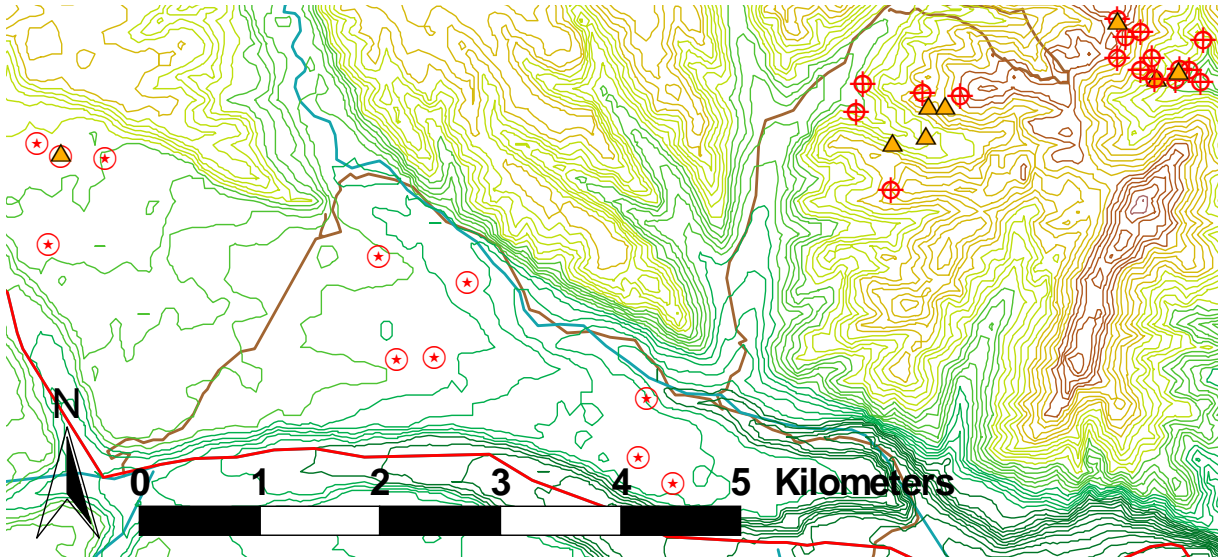
Figure 4: Distribution of sample plots in two areas in Finca Pintascayo(Δ indicate position of sample trees)

2.2.3 Sample plot design

The applied sample design was adopted and modified according to existing studies within the area. Pinazo et al. (2005) sampled structural changes on species composition after selective harvesting in the *Yungas* by means of concentric sample plots with two nested sub sample areas. With regard to the comparative nature of the on hand study, a similar sample design was implemented with increased sample area of 1000 m^2 to ensure that sufficient individuals of larger diameter classes are included (Kleinn, 2005; Gasparri, personal recommendation).

The plots were either distributed randomly within *a priori* selected strata, which were classified according to altitude or allocated to individuals of *Cedrela spp.* selected for destructive analysis (Cpt. 2.2.10). In these cases, the bole center at the foot of the trunk served as central point for the establishment of the sample plots, whose design resembled the former.

Around the reference tree or assigned plot center, concentric sample plots which incorporated two nested sub plots were established, resulting in two distinctive plots: A and B, respectively (Fig. 5). The radius of the sample plot A was 17.84 m, thus covering a total sample area of 1000 m^2. Further, sample plot B was set up within the former, which consisted of a smaller circle with a radius of 12.62 m (500 m^2).
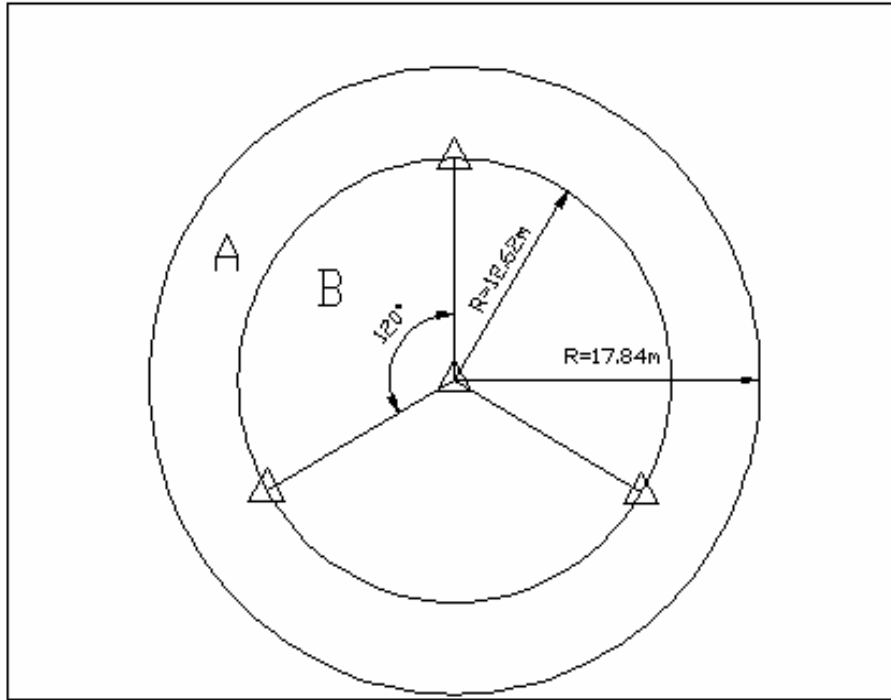
Figure 5. Design of sample plot with position form where canopy pictures were obtained (Δ: canopy picture).

Inside sample plot A all trees were measured with $D_i \geq 30$ cm, while in sample plot B all trees were recorded that displayed $D_i \geq 10$ cm.

2.2.4 Tree parameter assessment

Total tree height (H_t) and crown height (H_c) of all trees was measured and attributes such as species, stem quality, vitality and crown diameter were recorded. Species were identified with the aid of local experts and the field crew (Brown and Malizia, 2007). In the following, assessment of tree parameters is described in detail.

2.2.4.1 Measurements of diameter, total and crown height

Diameter at 1.3 m above ground (D_i) was measured by cross-wise caliper readings, which were averaged and rounded to the nearest cm. H_t and H_c were measured by using a BLUME-LEISS measuring device whenever given that vegetation allowed for direct readings. In cases where dense canopy cover made direct measurements impossible, H_t and H_c were estimated by visual inspection, with reference to a known height, which was previously measured.

2.2.4.2 Measurement of crown diameter

Crown dimensions were assessed by measuring crown diameter (D_c), represented by the precise projections of the crowns extensions on the ground. This was done for the longest and its perpendicular extension in order to average the projected crown area.

2.2.4.3 Evaluation of stem quality

Characterization of stem quality was adopted according to the classification scheme applied in *Bundeswaldinventur II in Baden-Württemberg* (Mahler et al., 2001) which considers key features of the commercial part of the trunk (Tab. 3) to assign the numbers 1 (excellent) through 6 (not utilizable). Overall appearance of the stem up to crown base was considered as key element for classification (Mahler et al., 2001).

Table 3: Characterization of bole quality.

Class:	1	2	3	4	5	6
Bole form:	straight	more or less straight	slightly warped	warped	strongly warped	strongly deformed
Branches:	free of small branches	more or less free of branches	several branches	several to many branches	many branches	numerous branches
Shape of bark:	homogenous and flat	few irregularities	irregular	heterogeneous	very heterogeneous	damaged, fallen off
Suitability for utilization	excellent	good	average	below average	hardly utilizable	none

2.2.4.4 Evaluation of tree vitality

Further, overall vitality of each tree was evaluated and allocated to one of three classes: Class 1 (healthy), 2 (partly damaged) and class 3 (damaged). Mechanical, as well as biotic damages were considered and equally valued.

2.2.4.5 Evaluation of social position

Social position was assessed by assigning classes 1-5 to each tree according to position within the vertical stand structure (Kraft, cited in Kramer and Akça, 2002). Thus, emergent trees were labeled as 'open growth' (class 1), whereas tress of the upper stand strata that are most likely to reach the canopy after gap openings following the collapse of the former were referred to as 'dominant' and 'co-dominant' (classes 2 and 3, respectively). Trees of the lower stand strata were regarded as 'intermediate' (class 4) or 'overtopped' (class 5) in cases where trees were obviously suffering from lack of light availability and changes seemed minimal that these would reach the upper stand strata, even if gap openings would occur.

2.2.4.6 Assessment of natural regeneration

Additionally, natural regeneration was recorded on all plots in area one. Five circular cluster plots were incorporated in the sample design to assess natural regeneration. Corresponding

sample plots consisted of circles with a radius of 1.13 m (A = 4 m^2), resulting in a total sample area of 20 m^2 per plot. The five cluster plots were distributed at 0°, 72°, 144°, 216° and 288°, respectively and positioned 20 m away from the plot center to ensure that the plants were not destroyed during the sampling procedure. Distribution and set up of satellite plots for regeneration sampling is displayed in the following figure (Fig. 6):
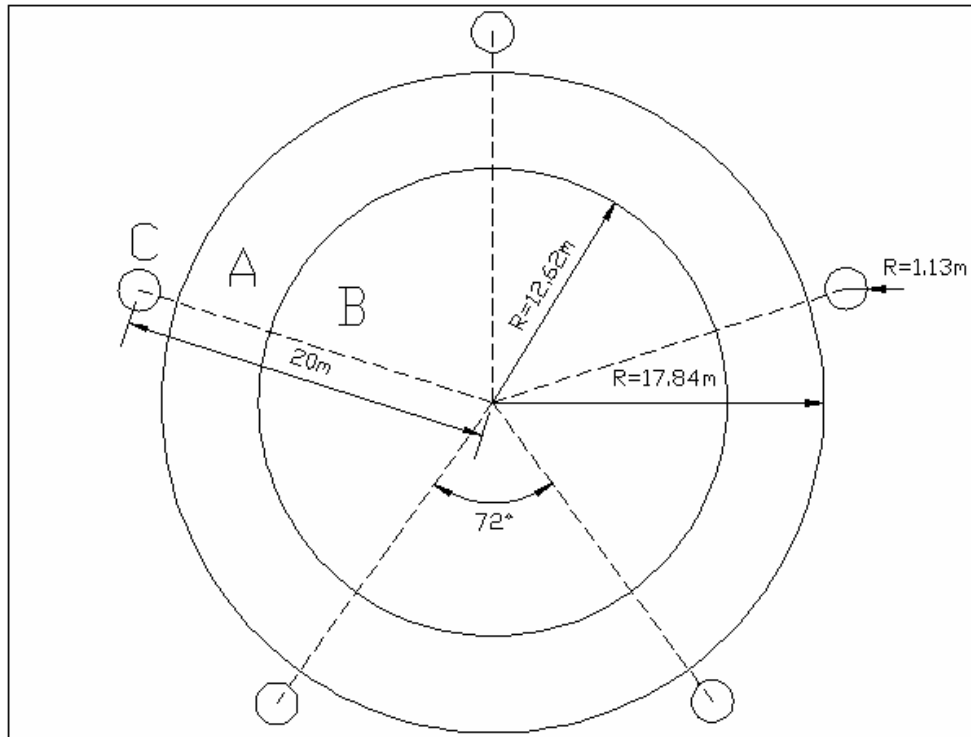
Figure 6: Sample plot design with satellite plots to assess natural regeneration.

In the five satellite plots depicted above, all saplings with $H_t \leq 1.3$ m were identified and the respective H_t and vitality was recorded.

2.2.5 Stand parameter assessment

The exact coordinates of the sample plot center were recorded by means of a hand-held GPS device, which also provided data according to elevation (m asl).

Further, as inclination influences growing conditions for trees and might also account for specific species composition with varying degrees of sloping (Gadow, 2004), slope gradient (%), position on slope and prevailing topography of a site were recorded and evaluated.

Percentage of slope was measured using a SUUNTO inclinometer and recorded along with position on slope. If necessary, plot dimensions were corrected according to existing slope. The following formula was applied (Kramer and Akça, 2002):

$$r_{slope} = \frac{r}{\sqrt{\cos \alpha}}$$
[1]

2.2.5.1 Topography and Exposition

Pertaining to the extremely furrowed topography found in *FPC*, the exact position at which each sample plot was located was recorded with regard to slope. The classification of position on slope incorporated six classes, ranging from the lowest part of the slope (toe) to the highest point of the respective continuous slope (top). Thus, assigned categories included the following positions: toe, foot, middle, shoulder and top.

Exposition of each plot was recorded with regard to the predominant cardinal direction of slope and classified according to four major orientations, North, West, South, East, respectively. Consequently, included angles for each orientation equaled 45° per cardinal direction.

2.2.5.2 Humidity

Additionally, sites were classified according to humidity. As most stands presented distinct physical appearances attributed to different degrees of stand moisture, such as the presence of thermophile species (i.e. cacti), abundance of bryophytes or moisture of humus layer, stand humidity could be categorized according to these stand components.

2.2.6 *Leaf area index and crown cover*

Canopy parameters of forest stands bear valuable information on the growing conditions realized by the occupying trees. (Arias et al., 2007; Weiss et al., 2003). To evaluate the influence of canopy conditions present in different stands, estimates of leaf area index (LAI) and crown cover were derived from canopy pictures taken at four pre-designed positions within plot B. With regard to practicability of the applied measures, data was obtained using a standard digital camera (SONY© Cybershot DSCS40 41MP, with a Carl Zeiss Vario-Tessar lens and a focal length of 5.1 to 15.3 mm). According to Macfarlane et al. (2006), using consumer-grade digital cameras is an inexpensive, rapid and simple approach to estimate LAI and crown cover.

Hence, four photographs of the canopy were taken at each plot at a 0° angle at a predestined height of 1.5 m above ground (Fig. 5). One picture was taken at the plot center and additional three at a distance of 12.82 m around the center at 0° north, 120° southeast and 240° southwest, respectively. As in the eight directed plots established around sample trees of *Cedrela spp.*, the plot center was composed of the target tree itself, two pictures where taken prior to cutting, one picture north and a second south of the base of the trunk.

The exact position to obtain each picture was determined by using a compass and metric tape. The camera was positioned on a rod of 1.5 m length and horizontally leveled using a hand held water-level device. All pictures were obtained at the same angle, as so the picture diagonal corresponded to a bearing of the plot center at 0°, 120° and 240°, respectively.

2.2.7 Analysis of tree parameters

Following the editing and processing of the obtained tree data, several additional variables were computed. In the following chapters the methodology used to obtain these variables is briefly explained.

2.2.7.1 Basal area

Basal area (G_i) at 1.3 m height was calculated for each tree according to the following formula (Kramer and Akça, 2002):

$$G_i \ = \ \frac{\pi}{4} D_i^{\ 2} \cdot 0.001 \qquad\qquad [2]$$

Equation 2: Basal area (m^2) estimation from measurements of D_i (cm).

2.2.7.2 Crown length, crown surface area tree slenderness

Length of crown (m) was obtained by subtracting H_c from H_t. In addition, tree slenderness was quantified as percentage of H_t divided by D_i (H_t/D_i).

As individual crown diameter per tree was obtained (Cpt. 2.2.4.2), crown surface area (m^2) was subsequently calculated by applying the formula above (Eq. 2). In this case however, D_i is substituted by D_c and the conversion factor of 0.001 is ignored, as crown surface area is given in m^2 and hence, the conversion of units is unnecessary.

2.2.7.3 Commercial volume

Commercial tree volume (V_c), defined as stem volume up to the lowest branch of the crown was calculated by using specific equations according to species (Tab. 4) as commonly applied in northwestern Argentina (GMF, 2005), with input parameters being D_i and H_c, respectively.

Table 4: Equations for stem volume estimation (m^3, inside bark) according to species.

Species	Formula	
Anadenanthera colubrina	$V_c = e^{\left(-3.025 + 1.01618 \left(Ln\left(D_i^2\right)H_c\right) - 0.00003 \left(H_c^2\right)D_i\right)} 0.001$	[3]
Chrysophyllum gonocarpus	$V_c = e^{\left(-2.66494 - 0.04695 \, Ln\left(H_c^2\right) + 0.99796 \, Ln\left(D_i^2\right)H_c\right)} 0.001$	[4]
Myroxylon peruiferum	$V_c = e^{\left(-3.27947 - 0.07343 \, Ln\left(H_c^2\right) + 1.05804 \, Ln\left(D_i^2 H_c\right)\right)} 0.001$	[5]
Cedrela spp. and others	$V_c = e^{\left(-2.43851 + 0.95605 \, Ln\left(\left(D_i^2\right)H_c\right) - .8035 \left(H_i/D_i\right)\right)} 0.001$	[6]

As the main objective of this study focuses on distribution and performance of commercial tree species in *FPC*, mean vitality and mean stem quality of commercial species were separately calculated per plot. Further, commercial tree species were classified according to timber value for industrial utilization, as defined by GMF (Cpt. 2.1.3.7). Thus, commercial quality classes ranged from 1 to 3 indicating increasing value of produced timber.

2.2.8 Analysis of stand parameters

In order to evaluate site quality, tree variables were converted to per hectare values or averaged to obtained attributes corresponding to each specific site. In the following chapters, methods of conversion of tree parameters are explained shortly. Subsequently, distributions of stand values were compared according to different site factors. Applied methodologies are given in chapter 2.3.

2.2.8.1 Conversion of tree variables to per hectare values

As sample plot B encompassed a total sampling area of 500 m^2, included tree parameters were converted to per hectare values by multiplication with an extension factor of 20. In contrast, parameters of trees with $D_i \geq 30$ cm, as sampled in plot A (A = 1000 m^2, Cpt. 2.2.3) were summed up and subsequently averaged with values obtained for trees of the same diameter classes in plot B (Cellini, personal communication). Respective means were converted to per hectare values by multiplication with an extension factor of 10.

Accordingly, G_i and V_c were calculated as described above, summed up per plot and converted to per hectare values. Further, mean crown surface area was multiplied by number of stems per hectare to estimate crown coverage (ha ha^{-1}) for each sample plot.

Stand top height (H_{top}) was calculated by averaging H_t of 20% of the strongest trees (Weise, cited in Kramer and Akca, 2002).

2.2.8.2 Comparison of stand variables in two areas of *FPC*

In order to scrutinize stand variable distribution within the area of *FPC*, means of stand values were analytically compared. Hence, an analysis of variance (ANOVA) was carried out to identify statistically significant differences between means of stand values according to different site categories with the aim to assess and determine certain trends of tree parameter distributions within each area.

With regard to statistical soundness, analyses of stratified samples and directed sample plots (eight plots around sample trees; Cpt. 2.2.3) were carried out separately. Further, as area one and two not only decisively differ with regard to past management history, but also in terms of predominant topography (relief, degree of sloping, elevation, etc.) both areas were evaluated separately and subsequently compared.

Subsequently, analyses of variances (ANOVA) were computed to identify certain trends of stand characteristics in both areas. Prior to the analyses, the data was tested to fulfill the default prerequisites (*Gaussian* distribution of data within each group and homogeneity of variances) by the corresponding statistical tests (*Levene* test and *Kolmogorov – Smirnov* test). Thus, the data was checked for differences between means of tree parameter distributions within different site groups. If the computed p value of an ANOVA equaled or fell below 0.05, the null hypothesis (assumption of equality of group means) was rejected and a post hoc test (*Tukey HSD for unequal* N) was run to identity significant between group differences in particular.

2.2.9 Stem analysis

According to Kramer and Akça (2002), the most accurate results concerning individual tree growth are derived from stem analyses. They allow for precise estimations of age, height and diameter growth, total volume, volume growth, form factors or form quotients.

For the analysis of growth performance, eight individuals of *Cedrela spp.* were selected for destructive analysis. Only trees were felled, segmented and subsequently analyzed, that showed the following characteristics:

   - individuals of social class 1 or 2, according to Kraft (Cpt. 2.2.4.5)

- excellent to good stem quality (classes 1 and 2; Cpt. 2.2.4.3)

- well developed, emergent crown

- free from visible damage (vitality class 1; Cpt. 2.2.4.4)

At each slice, cross-wise diameter measurements were taken subsequently to cutting. Tree age and diameter growth was estimated based on counts and subsequent measurements of all growth rings acquired from the slice at 1.3 m of each tree.

Subsequently, various parameter estimates were obtained using digital picture analysis at the University of Göttingen. Basal area was estimated by assigning polygons to the wooden surface as displayed in the digital pictures and subsequent calculation of the corresponding area.

Prior to cutting, sample plots were established around these trees to assess stand characteristics and individual growing conditions. Distances between the reference tree at plot center and competing trees within plot B were also measured to assess competition. Since all reference trees were selected only if $D_i \geq 30$ cm, nearby trees were likewise considered as competitors only if $D_j \geq 30$ cm.

Since proper equipment for annual ring analysis was not available in Argentina, the samples were photographed with a digital camera and analyzed with adequate software at the University of Göttingen, Germany. The software ImageJ[©] (Image processing in Java) was applied, an image processing program which is available online.

To assure proper subsequent year ring analysis in the laboratory all trees were marked in the field with orientation to magnetic north prior to cutting and segmentation. Segmentation started from 1.3m, and continued at intervals of 2 m thereafter (3.3 m, 5.3 m, 7.3 m, etc), extracting slices with a length between 5 and 10 cm. Further, all stems were cut at 0.3 m height. All samples were composed in each case by the lower part of the consequent bole.

Due to physical and time constraints, only five trees could be segmented up to the upper end of the apical stem. The remaining three trees were cut and merely the commercial part of the stem was segmented, until reaching the first lower branches of the crown.

2.2.10 Assessment of stem dimension, age and diameter growth

On all stem samples, diameters in north-south and east-western direction were cross-wisely taken, bark thickness was recorded and all samples were photographed for subsequent computer-based analysis. The number of tree rings on all sample slices was counted along the four radii according to initial orientation in the field, north, west, south and east, respectively.

On the slices extracted at 1.3 m height a total of eight radii were measured, as age determination was derived from these samples and thus higher precision was required.

To ensure exact analysis of age and slice dimensions, samples have to be sanded. Due to a lack of proper equipment and prevailing time constraints, sanding was carried out using an angle grinder with sand paper of grain classes 40 to 60. As a result, the wood at the samples' surface was burned in some cases due to the high rotation frequency of the device. However, unambiguous diameter readings were still obtained in most cases. It is highly recommended to refrain from future uses of such a device for sanding operations of tree samples as the burned surface exacerbate clear identification of annual growth rings and annual ring differentiation becomes blurred.

2.2.10.1 Radial eccentricity, taper and form quotients

Radial eccentricity defines the deviation between the actual lateral cut and a theoretically presumed circular form of the stem (Kramer and Akça, 2002). It was estimated by dividing measurements of the largest distance between mark pith and outer perimeter of the wooden solid and the respective smallest distance, as obtained from all sample slices at several heights along the bole (H_i). Radial eccentricity reflects to a certain degree the growing conditions under which a tree developed. If for instance, a high degree of sloping is present, the largest extensions of diameter will be found parallel to the slope (Kramer and Akca, 2002; Husch et al., 1993).

Taper curves are derived to determine product yields, biomass calculations or estimate merchantable volumes to any merchantability limit as they precisely model the overall stem profile (Laar and Akça, 1997; Riemer et al., 1995; Brink and Gadow, 1983). Consequently, taper equations are usually developed to predict the diameter at any point on the stem.

Thus, mean diameter at different heights along the bole (D_h) of all sample trees was plotted against the respective H_i with the aim to subsequently fit a simple regression which describes the average bole form of the eight sample trees of *Cedrela spp.*

Another approach to model stem or bole form of trees frequently applied in forest mensuration is the use of form quotients. Form quotients are derived by calculating the proportion between D_i and various D_h along the bole and are usually given in % (Kramer and Akça, 2002; Laar and Akça, 1997; Husch et al., 1993). Distinct form quotients are known and differentiated according to absolute or relative position of the reference diameter. Whereas *false* form quotients relate D_i to diameters at fixed heights along the stem, *true* form quotients calculate the proportion of D_i and D_h at relative heights of the bole (Kramer and Akça, 2002).

As this stem analysis is based on segmented stem samples obtained at predestined heights, *false* form quotients were calculated separately for each D_h (Eq. 7).

$$q_i \, (\%) \quad = \quad \frac{D_h}{D_i} \cdot 100 \qquad\qquad [7]$$

Equation 7: False form quotients, according to Kramer and Akça, 2002.

The obtained proportions were plotted against the corresponding H_i to subsequently derive an overall taper curve for all sample trees. Subsequent fitting of an equation allows for a general description of bole form for *Cedrela spp.* in *FPC*.

2.2.10.2 Bark thickness

Mean bark thickness per sample slice was obtained by repetitive readings of bark dimensions from the outer perimeter of the wooden solid to the outward cork at four cardinal orientations. On all slices, maximum and minimum bark thickness was measured in mm. Values for mean bark thickness were subsequently averaged from these repetitive measurements for all sample slices.

2.2.10.3 Diameter growth

The course of eight radii, according to major orientations (N, NW, W, SW, S, etc.) was recorded in detail by means of digital photography at all sample slices at 1.3 m height. Thus, tree age was determined by counting all annual rings along these radii. Since the total number of annual rings counted varied in some cases, the maximum number of rings per radius and slice was chosen to determine tree age to ensure conservative estimates. Mean diameter growth was estimated by averaging repetitive measurements of five consecutive growth rings along all eight directions (Kramer and Akça, 2002). Thus, distances between each consecutive growth ring were measured to the nearest

Figure 7: Alignment of eight radii for diameter growth estimation.

millimeter and the sum was compared to radial measurements taken in the field to ensure accuracy.

2.2.10.4 Competition

To evaluate the individual situation of competition for each sample tree, the specific Hegyi-competition index (according to Hegyi (1974), cited in Gadow (2004)) was calculated for each tree. This index (Eq. 8) sums up the relations between breast height diameters of the reference tree and its competitors (D_i and D_j, respectively) weighted by the corresponding distance ($dist_{ij}$) (Gadow, 2004).

$$HgCI = \sum_{j=1}^{n} \frac{D_j}{D_i} \frac{1}{dist_{ij}} \quad\quad\quad [8]$$

Equation 8: Hegyi-competition index.

With regard to practical feasibility, only adjoining trees with $D_i \geq 30$ cm were considered as potential competitors. However, as tree competition occurs on various levels, i.e. light availability, nutrient assimilation, rooting space, etc (Gadow, 2004; Otto, 1994) trees in both plots (Cpt. 2.2.3) were included.

2.2.10.5 Height growth

According to Vanclay (1992) tree height at the cessation of height growth can be a good indicator for site productivity, if the investigated trees are sufficiently developed to reflect the maximum height that is potentially attained on a site. As height growth can be precisely modeled from stem analyses (Kramer and Akça, 2002, Husch, 1993), height development of all sample trees was scrutinized with the aim to give sound estimations of mean height growth per site and to identify age of culmination of height growth for *Cedrela spp.* in *FPC*.

The initial step was to define the exact age of all 77 slices at different heights (H_i) by accurate counts of annual rings at that certain height. Differences in height were divided by differences of age to acquire individual growth rates in m a^{-1}. Subsequently, all obtained height–age relationships were averaged for different age intervals of all sample trees of *Cedrela spp.*

2.2.10.6 Volume

Additionally, commercial and total volume was estimated by section-wise volume calculation. Accordingly, volumes per segment were estimated by applying Smalian volume equation (Smalian, 1837, cited in Kramer and Akça, 2002) for segmented tree samples and subsequent summing up of the estimates. Volume per segment is thus calculated by multiplying the mean of the basal areas of the lower part of the segment (g_u, cm^2) and the upper part (g_o, cm^2) with the corresponding length (l_q) of the segment (Kramer and Akça, 2002). The obtained values are summed up to obtain total tree volume and given in m^3 (Eq. 9):

$$V_q \quad = \quad \sum_{j=h_{0,3}}^{h_c} \frac{g_u + g_o}{2} l_q \qquad\qquad [9]$$

Equation 9: Volume estimation of stem segments according to Smalian.

The relation between actual tree volume and a geometrical solid cylinder of identical dimensions, both calculated with the same parameters (D_i, H_c) is called form factor. (Kleinn, 2005; Kramer and Akça, 2002; Husch, 1993). Analogous to form quotients (Cpt. 2.2.10.1), distinct form factors are known and vary according to the reference diameter (Kramer and Akça, 2002). If volume is estimated based on D_i as reference point, the proportion of tree volume and volume of a solid cylinder is referred to as absolute or breast height form factor (Kleinn, 2005; Laar and Akça, 1997) (Eq. 10).

$$FF_{1.3} \quad = \quad \frac{V_c}{V_{cylinder}} \qquad\qquad [10]$$

Equation 10: Breast height form factor, according to Laar and Akça, 1997.

According to equation 10, *breast height form factors* were calculated for each sample tree separately. With regard to the elevated number of sample trees that were segmented up to H_c only, form factors were derived to estimate stem volume as this part further bears the most valuable portion for timber production (Eq. 11).

$$V_c \quad = \quad D_i H_t FF_{1.3} \qquad\qquad [11]$$

Equation 11: Commercial volume estimation using breast height form factors:

To predict average volume growth of *Cedrela spp.* at different age intervals tree height at a specific age was modeled according to D_i at that age. As D_i at a certain age was easily measured from sample slice at 1.3 m, the corresponding height of the tree was modeled using a specific diameter–height relationship for each tree individually, provided that enough observations allowed for a sufficient fit of the model.

2.2.10.7 Modeling growth of *Cedrela spp*.

Following the investigation of diameter-, height- and volume growth of eight individuals of *Cedrela spp.* and subsequent evaluation of influencing site parameters (Cpt. 2.2.5), the identified relationships were used to generate a model to describe growth performance of the target species under different site conditions. As implementation of such a predictive model is decisively determined by its easy appliance in the field, parameters were considered that a) were identified as possible predictor variables of growth and b) are rather easily obtained in the field.

Prior to adjustment, the best combination of possible predictor variables was determined by stepwise-linear regression (Muhairwe, 1993; 1999) of the SAS/STAT$^{\circledR}$ NLIN procedure (SAS Institute Inc., 2000). The adjusted functions proved to be non-linear regression models and thus were fitted to the data set using the algorithm proposed by Marquardt (1963) in order to estimate the parameter values (Cellini et al., 2002).

The comparison of the estimates for the different models that were fitted was based on numerical and graphical analyses. Three statistical criteria obtained from the residuals were examined: mean absolute error (*MAE*), which evaluates the absolute deviation of the model from the observations; mean square error (*MSE*), which analyses the accuracy of the estimates; and the adjusted co-efficient of determination (R^2_{adj}), which shows the proportion of total variance of the dependent variable as explained by the model, adjusted to the number of model parameters and observations (Eq. 8-10).

$$MAE = \frac{\sum_{i=1}^{n} |y_i - \hat{y}_i|}{n} \qquad [12]$$

$$MSE = \sqrt{\frac{\sum_{i=1}^{n} (y_i - \hat{y}_i)^2}{n - p}} \qquad [13]$$

$$R^2_{adj} = 1 - \frac{(n-1)\sum_{i=1}^{n} (y_i - \hat{y}_i)^2}{(n-p)\sum_{i=1}^{n} (y_i - \bar{y})^2} \qquad [14]$$

where y_i, $\hat{y}_i$ and $\bar{y}$ are the observed, predicted and real value of the dependent variable, respectively; *n* is the total number of observations used to fit the model and *p* is the number of model parameters.

2.2.11 Soil assessment

Geological and pedogenic conditions of soils at nine sites in two distinct areas of *FPC* were evaluated. Physical and chemical properties were assessed by means of creating and describing soil profiles and subsequent laboratory analyses of topsoil samples, which were obtained at all sites.
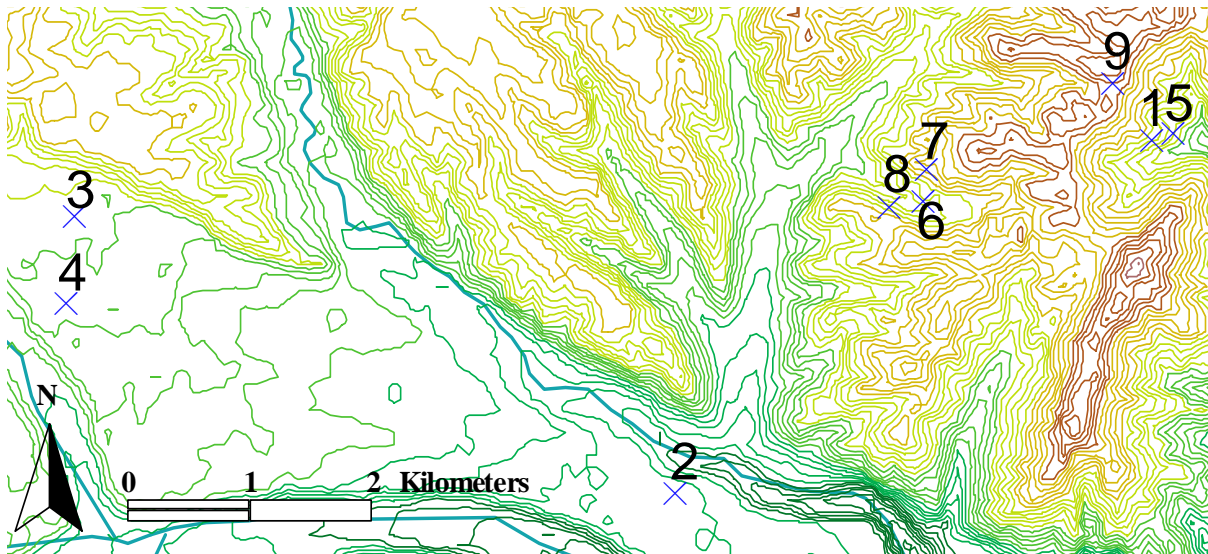

Figure 8: Location of soil profiles in area one and two of Finca Pintascayo.

As topography in area two of *FPC* is characterized by high degrees of sloping (Cpt. 2.1.3.1), six sites for investigation were assigned to cover the entire range of slopes, from shoulder down to the toe of the slope (shoulder, middle, foot and toe, respectively). Whereas in the predominantly leveled area one, three additional soil profiles were investigated in all altitudinal classes present.

Furthermore, as individual growing conditions of each sample tree are to be scrutinized to ensure comparability of the growth estimates, the profiles were excavated at close proximity of the target trees, whenever possible. Target depth of the profiles was 130 cm. In most cases however, digging was given up prior to reaching the assigned depth, either upon contact with the water table or parent material, resulting in increased hardship of manual work.

Predominant conditions found on the sites were recorded according to relief and topography, by means of descriptive parameters i.e. position on slope and degree of sloping (Schoeneberger et al., 1998). Further, altitude and exposition were recorded.

After having established the profiles using a hand operated spade, different horizons were marked, measured and digitally photographed. Physical properties in distinct soil layers

were identified and specific characteristics recorded. Subsequently, topsoil samples (upper 30 cm) were collected from ten randomly distributed sites within a radius of 17.84 m (corresponding to plot A; Cpt. 2.2.3) around the profile. Samples were mixed and transported for laboratory analyses to the central branch of INTA in Cerrillos, Salta.

Laboratory analyses included assessment of physical and chemical properties of primary constituents and chemical elements. Major soil texture was ascertained according to the method by Bouyoucos. Amount of organic material was assessed using the method of Walkley-Black, whereas total nitrogen content was estimated by means of the Kjeldahl method. Sulfur concentrations were determined according to Bray-Kurtz N° 1 (INTA, 2007).

Unfortunately, as time became a limiting factor towards the end of the study, it was not possible to establish soil profiles near all of the sampled trees.

In total nine soil profiles, along with the corresponding top soil sample analysis were evaluated and subsequently classified according to FAO standards (FAO, 2006). Two samples were obtained in the upper (height class 850 and 900 m asl, respectively) and lower part (height class 800 m asl) of area one and seven more in close proximity of sample trees in area two.

To evaluate pedogenic influences on plant growth, relationships between soil variables and stand parameters were investigated. Therefore, various soil attributes were related to site characteristics to identify major relationships that could facilitate the evaluation of site quality in the field.

Obtained soil properties were evaluated and examined for possible influences on growth performance of sample trees and distribution of stand attributes on different sites. In doing so, special emphasis was put on soil attributes that are easily quantified in the field.

2.3   *Data analysis*

The obtained data was processed and managed with Microsoft Excel 2002 (Microsoft Corporation, Redmond, Washington, USA). Graphical illustrations were also created with Microsoft Excel 2002 or Sigma Plot 2000 (Systat Software Inc., San Jose, California, USA). Statistical analyses were carried out using StatSoft Statistica 7 (Stat Soft, Tulsa, Oklahoma, USA), whilst model derivation was computed by means of the statistical analysis software SAS/STAT® (SAS Institute Inc., 2000).

Digital analysis of canopy pictures was computed by the program Can_Eye© 3.6 (INRA, Avignon, France; Weiss et al., 2002), which was designed to estimate the leaf area index (LAI) (Jonckheere et al., 2005). The digital picture analysis program ImageJ (Wright Cell

Imaging Facility, Toronto, Ontario, Canada), was used for stem picture measurements and subsequent analysis. Graphics were created with AutoCAD® 2007, (Autodesk, San Rafael, California, USA).

3   Results and Discussion

In the following chapters, the obtained results are displayed in tables or graphical form and subsequently discussed. Respective standard errors for each calculated mean value are given in parentheses, if not indicated otherwise. As mean values of stand parameters were compared between different site categories, analyses of variance (ANOVA) were computed (including natural regeneration in area one). All significantly different group means are marked by unequal letter assignment. Thus, mean values that share the same letter are not significantly different for $p \leq 0.05$. Distributions of means are only displayed if results allowed for an identification of certain trends or the respective variables were of elevated importance.

3.1   Soil and topography

3.1.1   Classification of major soil groups in Finca Pintascayo

In total, three soil groups were identified in the entire territory of *FPC*. Soil formations occurring in area one are dominated by one soil group only, whereas two soil groups were identified in area two (Tab. 5).

Table 5: Major soil group classification of nine soils described in Finca Pintascayo.

FAO soil group classification	Fluvisols	Cambisols	Leptosols
Parent material:	fluvial sediments	sedimentary rock	sedimentary rock
Altitudinal range:	800 – 900 m asl	750 – 1000 m asl	1050 m asl
Major land form:	predominantly flat,	linear, convex or concave	linear, convex or concave
Drainage class:	well drained	well to somewhat excessively drained	well drained
Moisture conditions:	humid/wet	dry/humid	humid
Estimated depth of ground water table:	between 1 and 2 m	> 1.3 m	> 75 cm
Rooting depth	65 – 130 cm	90- 130 cm	60 cm
Evidence of erosion:	none	common	frequent

In area one, mean thickness of humus layer is generally lower, with 3 cm on average, indicating a higher biological activity (Schachtschabel and Scheffer, 2002). On average, texture of topsoil includes approximately 63% sand, 30% silt and 7% clay. The lowered mean clay content if compared to other soil groups can be attributed to clay translocation down the profile (Schachtschabel and Scheffer, 2002). All profiles show deep rootability, if not inhibited by high ground water table. Rootability decreases with altitude of site, ranging from 100 cm (at 900 m asl) to 65 cm (at 800 m asl). Water retention capacity is 40% on average and only slightly lowered (26%) at 800 m asl. Mean pH-value of area one equaled 4.9.

In area two, mean thickness of humus layer is around 4 cm and exceeds the extension of humus in area one. Observed soil profiles present texture classes of the upper 30 cm of topsoil are on average composed of 60% of sand, 30% lime and 10% clay, respectively. Rootability is around 100 cm on average and mean water retention capacity is 38%.

On the top of slopes in area two, shallow leptosols are represented by one soil profile only, which showed a humus layer of 4 cm thickness over a shallow A-horizon consisting of 54% sand, 37% lime and 9% clay, respectively. Rootability did not exceed 60 cm. Water retention capacity was around 40%. Mean pH–value of 30 cm of topsoil equaled 4.5 (±0.14) for all nine soil profiles in the entire area of *FPC*, indicating rather basic chemical soil conditions. Hence, average pH-value in area one exceeded the average calculated for the entire area.

The three identified soil groups are clearly attributed to different topographic locations in *FPC*. Fluvisols dominate the alluvial plain which constitutes area one. Probably evolved from alluvial deposits, the observed soils show similar characteristics in alignment of horizons and chemical composition. Fluvisols are usually young soils that evolve from fluvial deposits. They are frequently found along rivers on alluvial plains, characterized by weak horizon differentiation and usually present good natural fertility (FAO, 2006; Schachtschabel and Scheffer, 2002).

The predominant soil group commonly found on higher elevations in area two of *FPC* was classified as cambisol which was basically present on all lower parts of slopes. These soils represent an advanced stage of soil formation and are often characterized by brownish coloration (FAO, 2006; Schachtschabel and Scheffer, 2002). Suitability for plant growth of cambisols is largely determined by the chemical composition of the present parent material and predominant soil texture (FAO, 2006).

The third classified soil group consisted of leptosols which was found on the top of the slopes in area two. This soil group was represented by poorly developed profiles that were

usually very shallow. Again, chemical properties are strongly determined by parent material, but root penetration is often limited due to shallowness of A and B horizons (FAO, 2006). This soil group is rarely used for agricultural purposes, but considered to compose suitable sites for forestry (FAO, 2006; Schachtschabel and Scheffer, 2002).

In general, it can be stated that all identified soil groups represent relatively fertile soils with a rather alkine chemical soil regime, that should serve well for forestry related land uses. The underlying parent material strongly determines the chemical properties of all soils, as it provides the necessary supply of nutrients (FAO, 2006). Contradictory to finding by Nadir and Chafatinos (1990) chernozems (*Suelo de Candado*, US taxonomy: mollisols, black soils rich in organic matter, FAO, 2006) were not identified in the investigated areas of *FPC*.

Nonetheless, as only a very small portion of *FPC* was sampled, their presence in other parts cannot be precluded, but is probably restricted to areas at lower altitudes. Further, in the course of pedogenesis the formation of mollisols by accumulation of organic matter from the described cambisols seems probable, although time frames of soil formation must be considered as very long.

The second major soil group identified by the authors, namely regosols (*Suelo Alisar*) corresponds to the observed group of leptosols found in higher elevated areas of *FPC*. Both soil groups have similar characteristics and histories of origin. These are very young soils that possibly develop from erosion and merely differ in terms of depth, whereas leptosols are usually shallower. Being very susceptible to erosion both soil groups are best left under forest cover and require sensitive proper management (FAO, 2006).

3.1.2 Geocentric approach to site evaluation based on soil properties

The geocentric approach to site evaluation is based on the correlation between a soils nutrient status and site productivity (e.g. Carmean, 1973, cited in Vanclay, 1994). Accordingly, soil profiles were compared to corresponding growth data of sample trees and specific stand parameters. To facilitate assessment of soil properties in the field, relationships between easily measured variables and soil suitability for plant growth were identified.
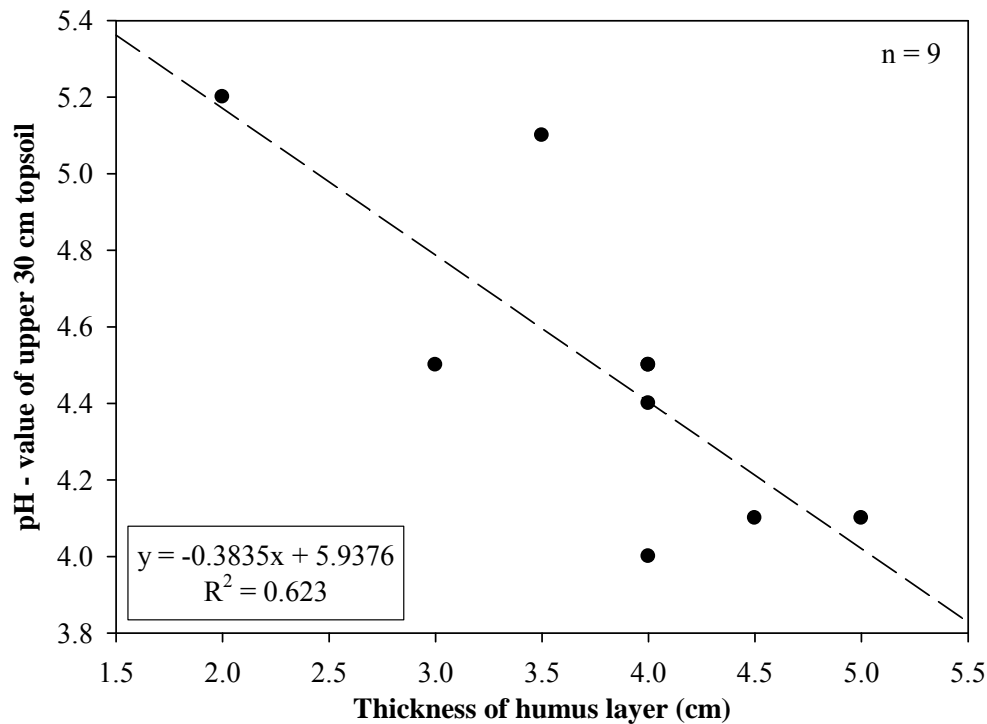
*Figure 9: Thickness of humus layer versus pH–value of upper 30 cm top soil, all soil
samples.*

As depicted in figure 9, pH-value of 30 cm topsoil was plotted against thickness of humus
layer and a negative linear relationship between the variables was identified.

Further, the relation between thickness of humus layer and organic carbon content of the
upper 30 cm topsoil was examined (Fig. 10).

*Figure 10: Thickness of humus layer (cm) versus organic carbon content (%) of upper 30
cm topsoil, all soil samples.*

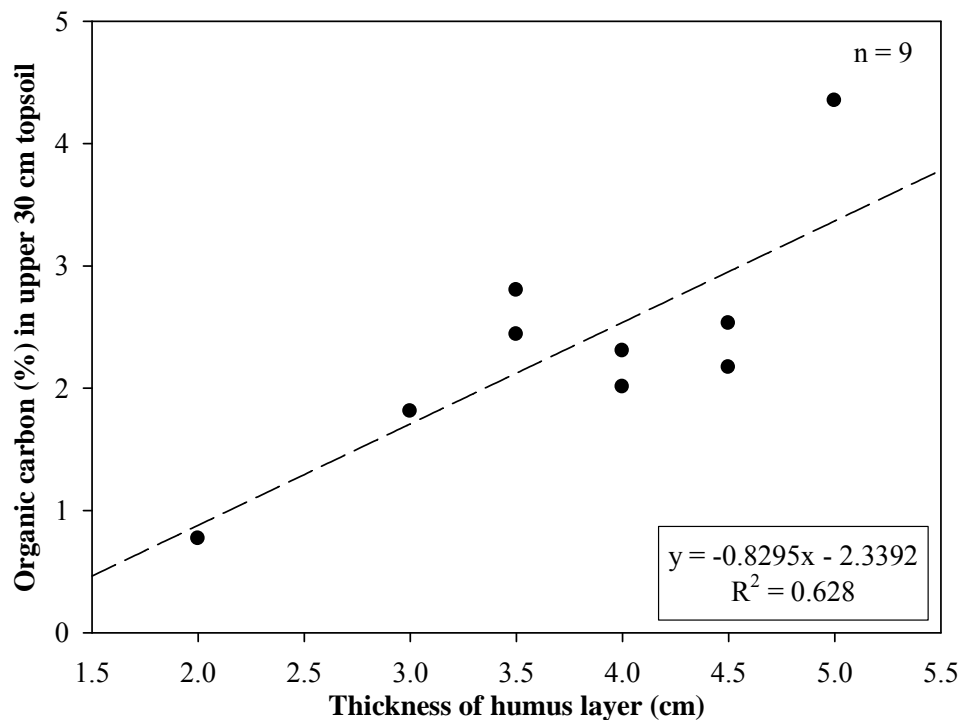As thickness of humus layer presents a prominent factor of soil that is easily evaluated, its indicative valor was scrutinized. The pH-value of topsoil is usually only rather intricately assessed as it requires laboratory analysis. The analyzed relationship with size of humus layer produced a satisfactory value of the coefficient of determination (Fig. 9). The same holds true if amount of organic carbon in the upper 30 cm of topsoil is considered (Fig. 10). As both soil parameters are related to biological activity present in the soil (Schachtschabel and Scheffer, 2002; Schoeneberger, 1998), which in turn might be indicative for site productivity.

Further, thickness of humus was also positively correlated to total Nitrogen present in the upper 30 cm of topsoil ($R^2 = 0.820$). Surprisingly however, the relationship between extent of humus layer and C/N ratio was lacking a proper fit.

Consequently, distributions of mean pH–values in topsoil were analyzed according to site class (Cpt. 3.2.5). Although the applied ANOVA did not indicate significant differences between means ($p = 0.167$), visual inspection allows for identification of a related trend between mean pH–values of topsoil and site class (Fig. 11).
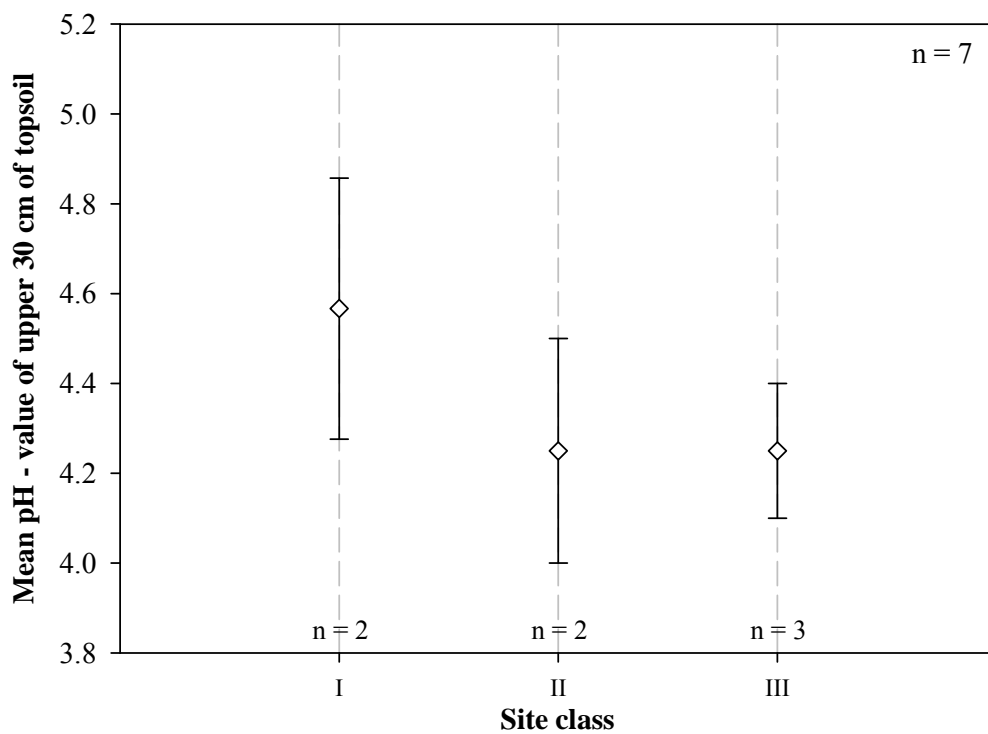
Figure 11: Mean pH–value of upper 30 cm topsoil versus site class for Cedrela spp. in FPC, with respective standard error.

For site class I a mean pH of 4.8 (±0.3) was observed, mean pH–values of the remaining two site classes II and III are clearly lowered, with 4.3 (±0.2) and 4.2 (±0.12), respectively. With regard to the few findings related to soil factors determining tree growth, the identified relationship might indeed be of practical value. The rather poor outcome of soil assessment

with regard to site quality most likely results from poor data quality and an insufficiently large sample size.

However, with regard to soil factor distribution according to topography, especially pH–value of the upper 30 cm topsoil, a clear trend was identified along different positions on slope. The obtained p-value equaled 0.029 and a statistically significant negative relationship between mean pH–value and position of slope was identified for $p \leq 0.05$. Hence, sites tend to exhibit lower pH–values, the further upslope they are situated. PH-values ranged from 4.9 (±0.22) and 4.5 (±0.25) to 4.2 (±0.11), at the toe, middle and shoulder of slope, respectively. Significant differences were detected between toe and shoulder of slope ($p = 0.032$).

These findings might be interesting with regard to evaluation of site quality based on a geocentric approach according to soil properties, although direct relationships with tree growth could not be identified.

Contradictory to the initial idea to compare soil chemical properties and the respective suitability for tree growth, detailed information about soil nutrient status could not be derived (i.e. exchangeable cations (CEC), anion exchange capacity (AEC)), due to lack of data concerning aluminum and iron concentrations in 30 cm of topsoil. If information on soil nutrient status for *FPC* is required in detail, these variables need to be available from laboratory analysis.

As stated earlier, these findings are based on rather modest data quality (very small sampling intensity, lack of information on chemical soil components) and thus should be regarded as merely indicative rather then absolute.

3.2 Stem analysis

In total, 77 stem samples obtained from segments at equal height of eight different sample trees were measured and subsequently analyzed (Tab. 6).

Table 6: Data for growth analysis of sample trees.

Tree No.	1	2	3	4	5	6	7	8
D_i (cm)	68.5	35	58.5	39	41	30	49.5	40
H_t (m)	21.5	21	28.3	21	19.1	21.2	20.6	21
H_c (m)	6.5	11.3	10.6	12.9	10.1	11.8	10.6	10.4
No. of samples	11	11	14	12	6	7	6	10
Age	63	65	59	63	108	66	80	75
V_c (m^3)	1.402	0.690	2.062	0.925	0.849	0.507	0.943	0.774

The eight selected sample trees for stem analysis presented the largest trees of all measured individuals of *Cedrela spp.* According to Vanclay (1994) potential sample trees for site

quality evaluation should be large enough to reflect the maximum potential height that the nominated tree species is likely to attain on the specific site.

Since diameters of all sample slices were also measured in the field, two distinct estimations of G_i were available. As possible errors due to distortion in picture resolution are unknown, performance of both estimators was compared (see Appendices). G_i estimates obtained by digital analysis usually yielded lower values. Considering the often noncircular bole form of *Cedrela spp.*, especially in the lower part of the stem, where buttresses are common, basal area estimations are prone to overestimation if based on means of cross-wise diameter readings only. Digital picture analysis allowed for measurements of increased precision regarding actual basal area by exactly fitting polygons to the area occupied by wood. Subsequent calculations were entirely based on estimates resulting from digital analysis to ensure the outcome of conservative reference values.

3.2.1 *Radial eccentricity, taper and form quotients*

Radial eccentricity was plotted against relative height (%) of all stem samples (Fig. 12).

The chart contains the equation:

$$y = -2E\text{-}05x^3 + 0.0036x^2 - 0.189x + 4.7038$$
$$R^2 = 0.626$$

with n = 77, axes labelled "Radial eccentricity" (y-axis) and "H (%)" (x-axis).
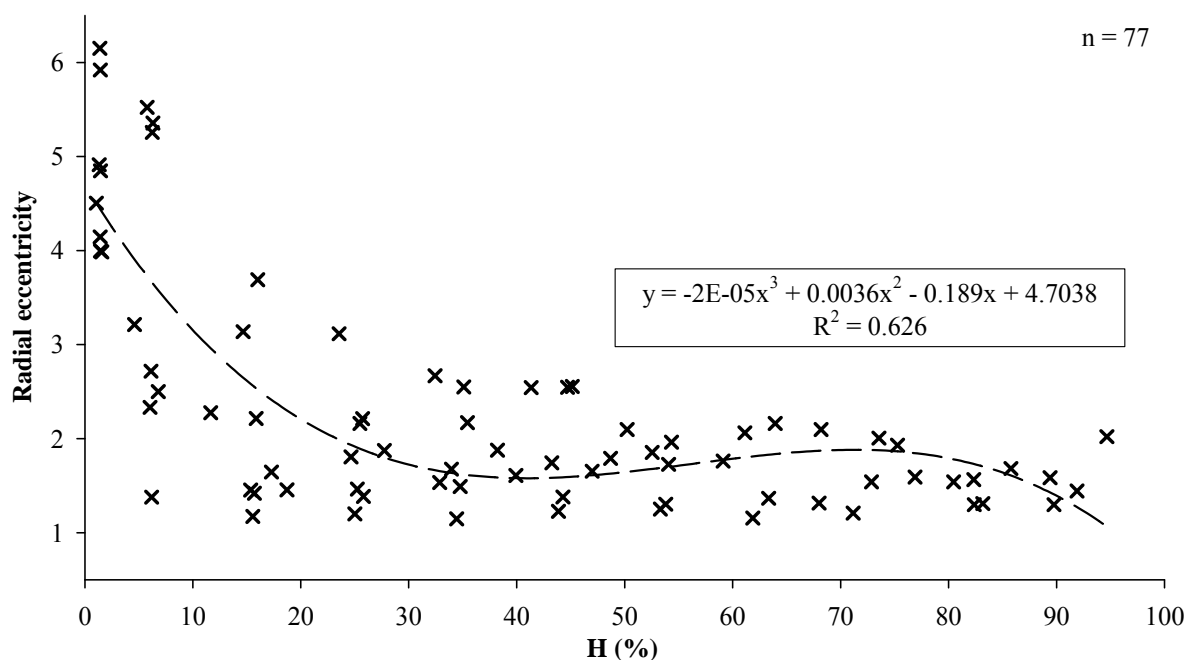
Figure 12: Radial eccentricity at relative tree height (%) of all sample trees

A cubic polynomial regression was fitted best to describe diminution of radial eccentricity with increasing relative height of all sample trees.

Radial eccentricity was partially explained by regression analysis between slope gradient and mean radial eccentricity of slices obtained at $H_{0.3}$ and $H_{1.3}$. The relationship was best reproduced by a linear trend line with a respective $R^2 = 0.570$.
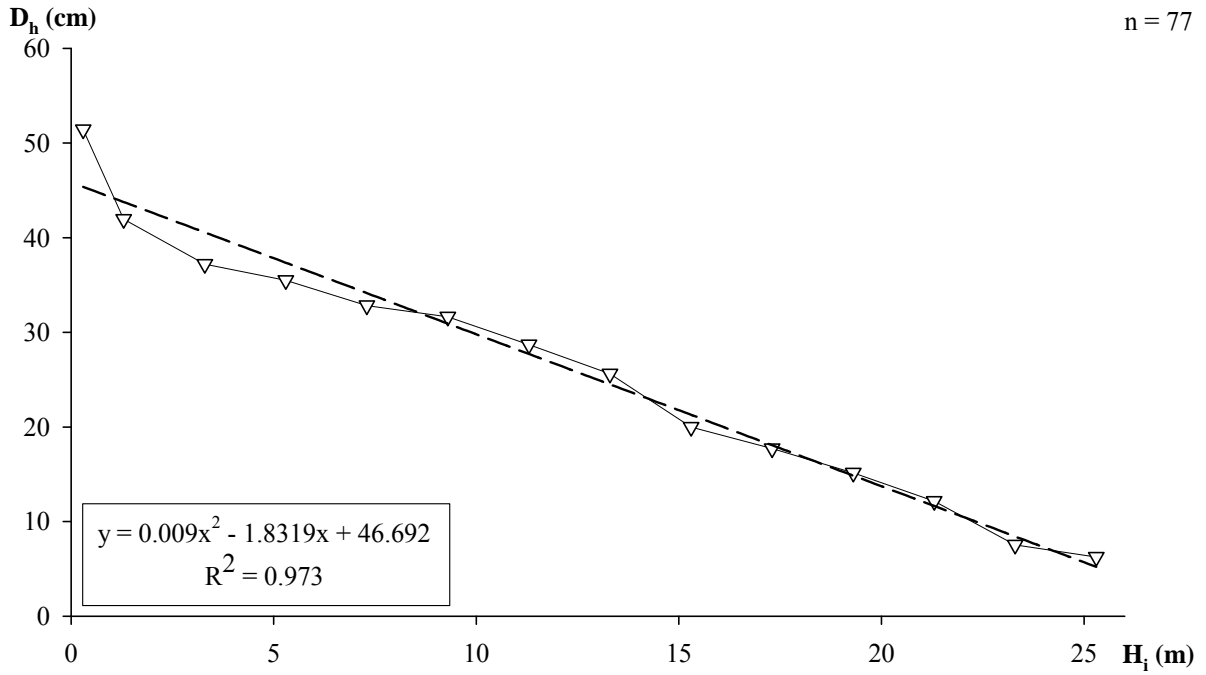
Figure 13: Taper curve for Cedrela spp. derived from average D_h (cm) at respective H_i (m).

With regard to average stem form of *Cedrela spp.,* a quadratic polynomial regression was fitted to quantify mean D_h at any H_i along the stem of all eight sample trees (Fig. 13). As a result, a generalized taper function for *Cedrela spp.* in *FPC* was computed. The overall fit yielded a very high coefficient of determination. However, the increase in D_h at the corresponding $H_{7.3}$ might lead to somewhat skewed results. This irregularity in the otherwise rather linearly declining taper curve might be attributed to the extremely low crown height of tree number one at 6.5 m above ground. The impact of such inconsistencies can be diminished by increased sample sizes (Husch et al., 1993).

Additionally, form quotients were derived for all sample trees (Cpt. 2.2.10.1). The obtained q_i (%) for all eight sample trees were plotted against H_i (Fig. 14):
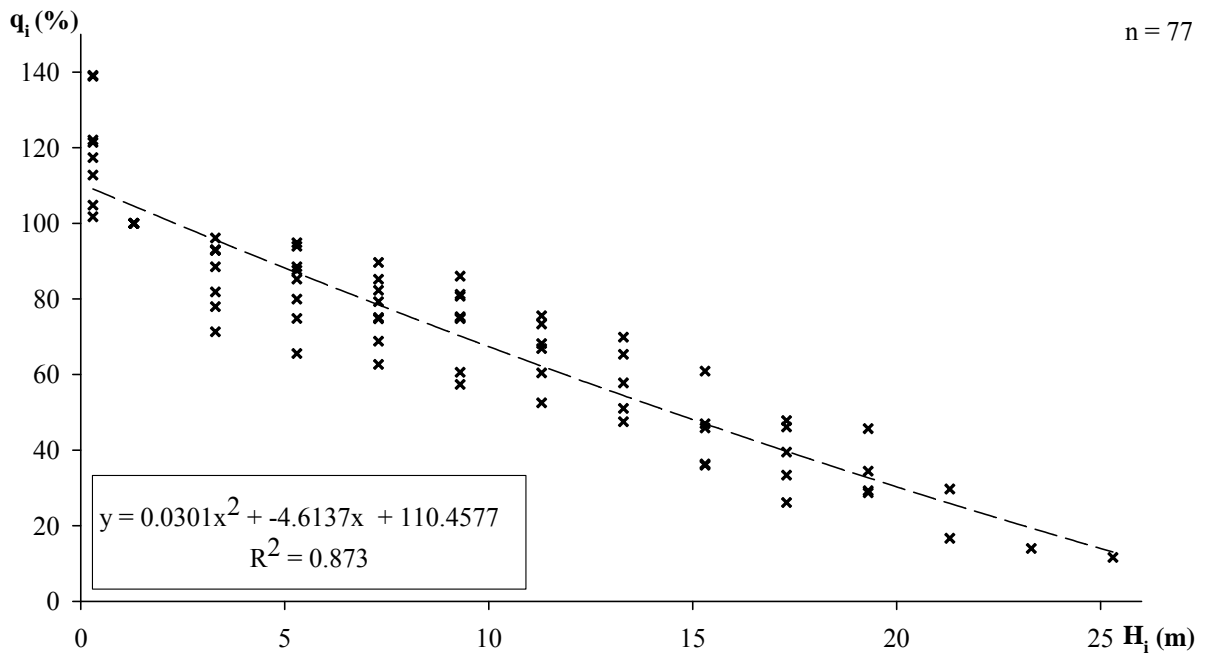
Figure 14: Form quotient versus height of all sample trees.

Although in general, the fitted curve performs well, observations are increasingly scattered in the range of the commercial part of the stem (between 1.3 m and 9.3 m; Fig. 14). Consequently, prevailing bole forms of all eight sample trees were identified and subsequently classified (Fig. 15).
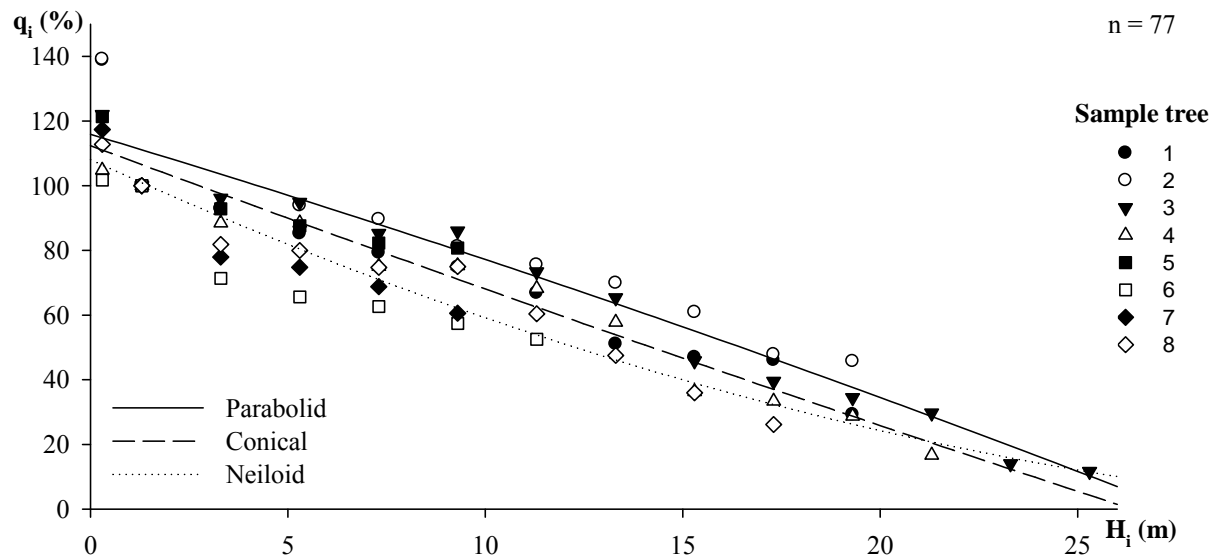
Figure 15: Classification of bole form according to form quotients for all sample trees.

The fitted quadratic polynomial curves yielded elevated coefficients of determination and resemble basic geometrical solids such as parabolid ($R^2 = 0.942$), conical ($R^2 = 0.932$) and neiloid ($R^2 = 0.857$), respectively.

In general, the findings related to stem form may provide useful insights on further attempts to model stem form of *Cedrela spp.* in northwestern Argentina.

3.2.2 Bark thickness

Further, mean, maximum and minimum bark thickness at different heights above ground along the stem were averaged (Fig. 16).

Figure 16: Maximum, mean and minimum bark thickness of all trees.

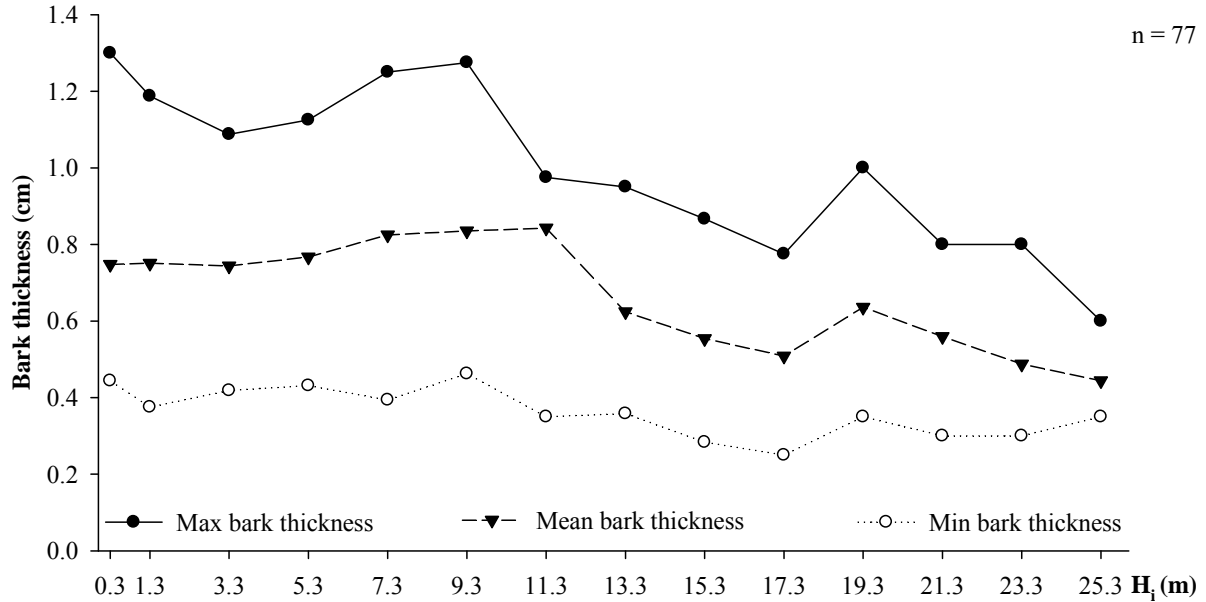As bark volume accounts for 10% to 20% of unpeeled tree volume for most species (Husch et al., 1993), information on bark thickness development along the stem of *Cedrela spp.* might provide valuable information, concerning volume estimations. According to the findings (Fig. 16) mean bark thickness at the base of stem $H_{0.3}$ equaled 0.75 cm (±0.06), whereas mean bark thickness at $H_{25.5}$ was 0.44 cm. The high variation between minimum, mean and maximum values at lower heights seems logical if the frequently observed buttresses are considered. This variation declines with increasing H_i along the bole. The observed reduction of bark thickness with increasing H_i proceeds irregularly. Two major incisions occur between 5.3 m and 7.3 m, and 9.3 and 11.3 m, respectively. These gaps in the otherwise rather linearly declining gradient, can be attributed to the occurrence of limbs at that specific height.

3.2.3 Diameter growth

The arithmetic means and medians of estimates of diameter growth at intervals of 5 consecutive growth rings were generated and plotted for each tree individually (Fig. 17). The overall average annual diameter growth for all eight sample trees in *FPC* was estimated to be 0.46 cm a^{-1} (±0.04). Individual values ranged from 0.25 to 0.73 cm a^{-1}.
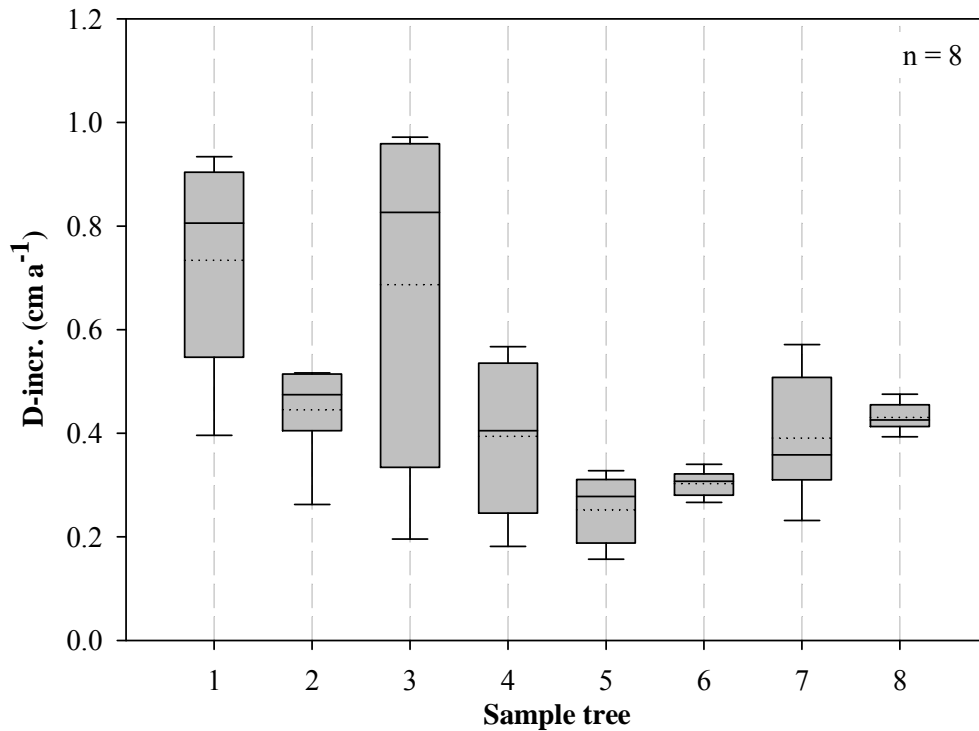
Figure 17: Mean (dotted) and median (solid) diameter growth of sample slice at 1.3 m.

The highest mean annual diameter growth was detected for sample tree number one and three, with 0.73 cm a^{-1} (±0.02) and 0.69 cm a^{-1} (±0.03), respectively. However, estimates of both samples also yielded a comparably high variance. The lowest growth rate was detected for tree no. five with 0.25 cm a^{-1} (±0.01). This tree exceeds all others in terms of age with 108 years versus a mean 67 for the seven remaining sample trees.

Gasparri and Goya (2005) analyzed diameter growth of 59 individuals of *C. lilloi* in north western Argentina and assessed mean growth rates for different diameter classes. According to their findings, diameter growth was positively correlated to crown illumination, D_i and crown surface. The highest diameter increments were realized in DBH–classes 30 to 40. Observed mean diameter growth in DBH-classes 30 to 70, ranged from approximately 0.3 cm a^{-1} to about 0.9 cm a^{-1}, depending on crown illumination. However, the authors considered diameter increments of up to 2 cm a^{-1} under optimal growing conditions to be possible. As crown illumination of all eight sample trees in the study at hand displayed values of crown illumination between 4 and 5, influence of this factor could not be incorporated in the growth model (Cpt. 2.2.10.7).

According to Castillo et al. (2005), juveniles of four different species of the genera *Cedrela* showed mean diameter increments of 1.6 cm a^{-1} in plantations under open canopy in the province of Salta, Argentina. The elevated rates of increment result from the very young age of the recently established trees.

Dauber et al. (2003) investigated diameter increments of various species in pre-Andean zones of Bolivia, which also encompass the ecological entity of the *Yungas*. According to their findings, *Cedrela odorata* yields mean annual increments of 0.45 cm a^{-1} in the area.

Considering the few studies that have scrutinized the growth performance of the genera *Cedrela* in northwestern Argentina, the presented findings result in values well within range of previously reported observations.

Individual diameter growth of all sample slices at 1.3 m was further plotted against age with the aim to synchronize growth patterns and possibly identify major climatic impacts during the growth sequence. With regard to facility of inspection, only the last 20 years are displayed in figure 18.
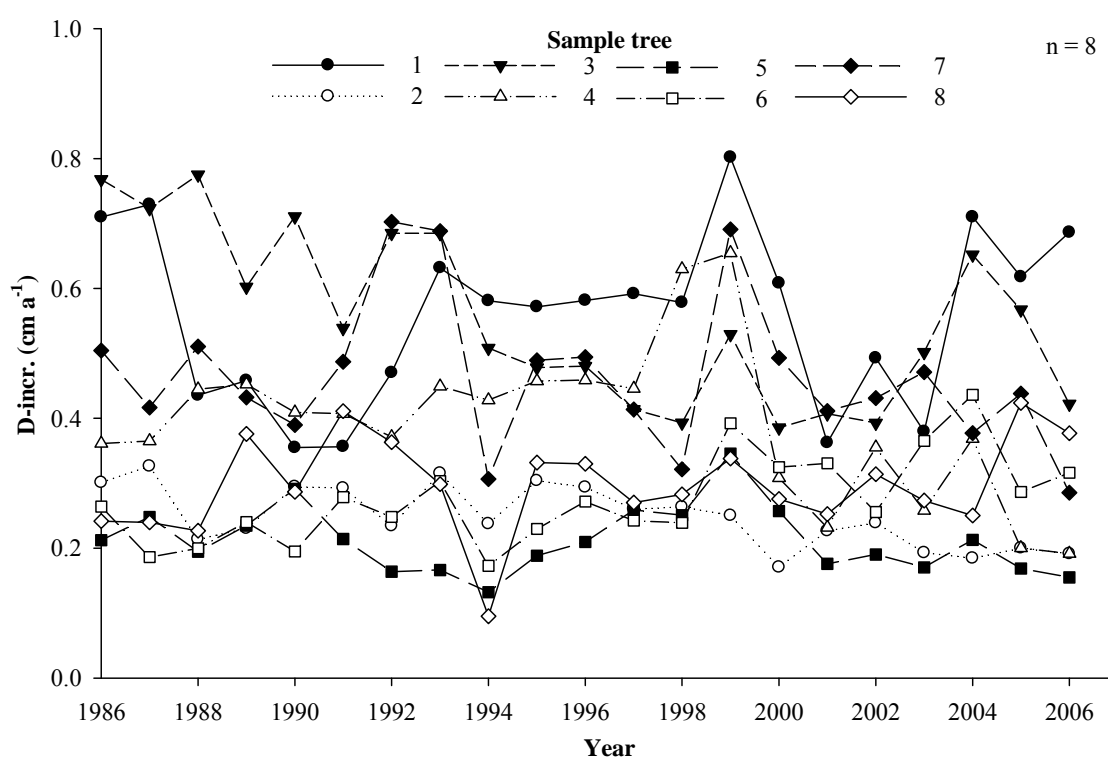
Figure 18: Diameter increments of all sample slices at 1.3 m of the last 20 years.

With regard to comparison of observed growth patterns of the eight sample trees overall tendencies are rather blurred, especially during the first years of this millennium (Fig. 18). However, observed diameter growth patterns show a certain degree of synchronization regarding the time span from 1994 till 1999, which is marked by two strikingly severe changes in growth pattern. These might be attributed to climatic extremes during the growing cycle, e.g. extremely dry years (Grau and Veblen, 2000; Villalba, et al., 1998), but could not be verified due to lack of climatic data available. Further, growing patterns can to some extent be grouped according to sample tree, as trees number one and five, display somewhat similar

growing patterns from 1994 onwards. The same holds true for trees number three and eight, although less pronounced and with a certain delay of the latter.

Further, variations in annual diameter increments can be distinguished (Fig. 18). Trees with higher mean annual increments, i.e. trees number one and three, show a higher variation between years on average, whereas trees with lowered annual diameter increments, such as trees number five and two, maintained comparably low increments throughout the last twenty years.

In figure 19, individual diameter development at breast height is plotted against age for each sample tree.
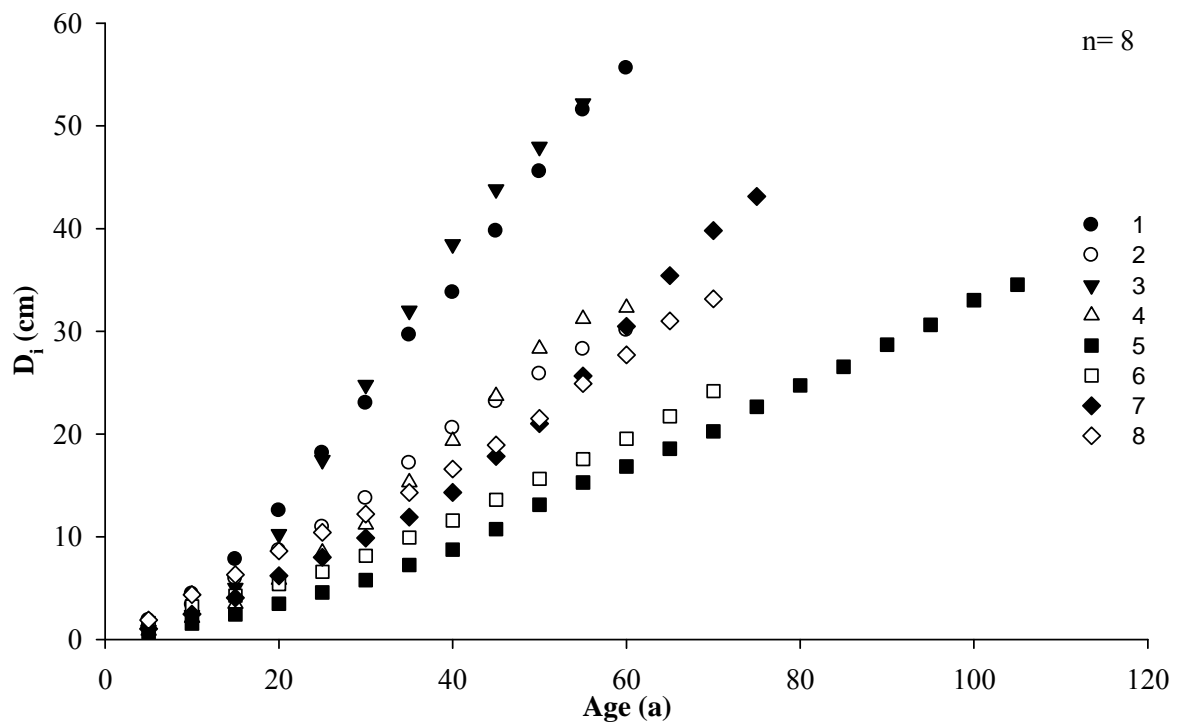
Figure 19: Diameter development of all sample slices at 1.3 m

If the reconstructed D_i at a specific age for each sample tree is observed, the eight sample trees arrange well in three distinct classes. Trees one and three describe the steepest increment curve over age, whereas diameters of trees five and six accumulate comparably slowly. At the age interval between 50 and 70 years most increments curves reach the point of inflection. Subsequently, increment curves change from progressive to regressive augment, with per year increment rates declining thereafter (Fig. 19).

3.2.4 Competition

In figure 20 the corresponding Hegyi index was plotted against D_i of each sample tree.
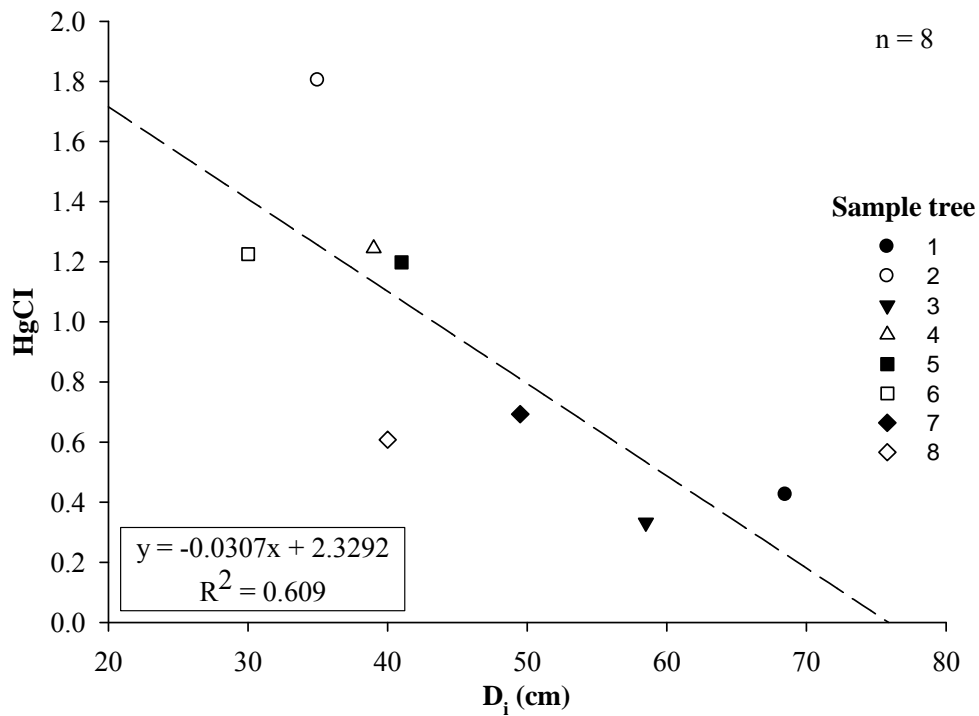
Figure 20: D_i (cm) versus Hegyi-index, all sample trees.

The established relationship is linear and yields a sufficiently high coefficient of determination ($R^2 = 0.609$) to be considered as indicative, although goodness of fit is most likely slightly lowered by outlier tree number two.

Hence, a tree's diameter growth is strongly influenced by specific growing conditions *in situ*, especially by competition with neighboring trees (Gadow, 2004; Laar and Akça, 1997). Thus, competition was quantified for all sample trees (Cpt. 2.2.10.4) to assess the corresponding influence on tree growth.

Sample trees with larger D_i are most likely to present a smaller HgCI (Fig. 20), because larger D_i tend to attenuate the value of calculated competition for corresponding D_j. Therefore, as the denominator (D_i) increases, D_j, as numerator, needs to be much higher to decisively impact the competition index, not regarding distance.

Subsequently, diameter growth of the last 20 years was compared with the specific HgCI of each sample tree (Fig. 21). It was presumed that 20 years present an extent to which site conditions can be expected to have remained more or less constant.
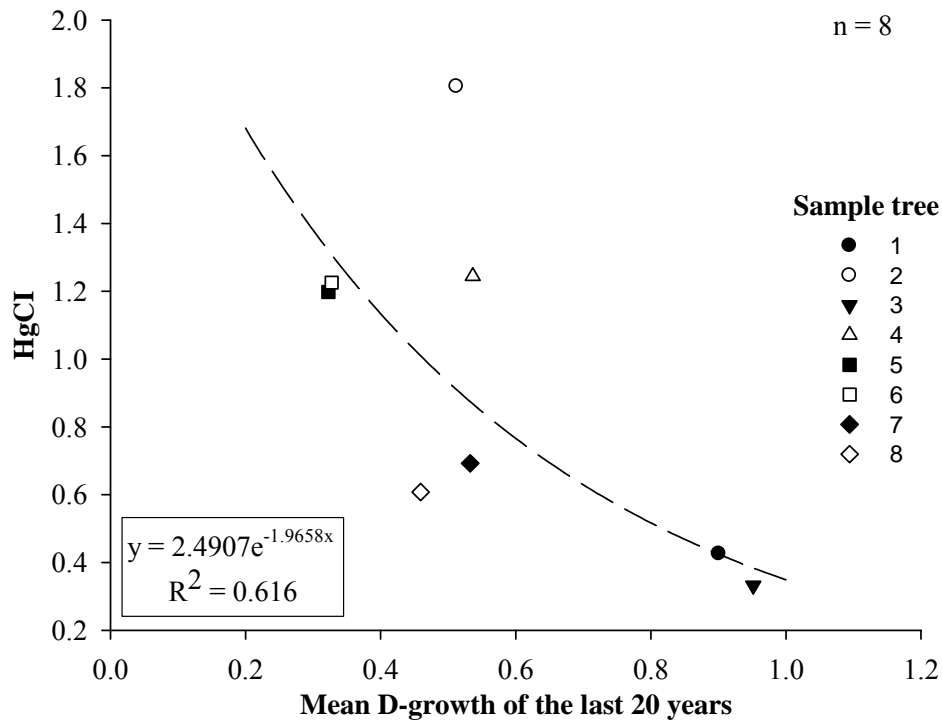
Figure 21: Relationship between mean diameter growth of the last 20 years and Hegyi index.

Consequently, an exponential regression was fitted which explains approximately 60% of the realtionship between mean diameter growth of the last 20 years of each tree and its respective HgCI.

Regarding this observation, it can be presumed that the impact of competition on diameter growth increases over-proportionally with decreasing mean diameter growth of *Cedrela spp*. Thus, trees of the same species that already realize low diameter growth, most likely due to variability of site factors are apparently even more susceptible to competition by neighboring trees than trees of better vigor, as indicated by a comparably high diameter increment. However, the investigated sample size is rather low and generalization of these findings should be exercised with caution.

Nonetheless, it can be stated that diameter growth of *Cedrela spp.*, especially of trees with smaller D_i is influenced by D_j of nearby trees and the corresponding distance to the target tree (Gadow, 2004; Laar and Akça, 1997).

3.2.5 Height growth and site class

Furthermore, H_i was plotted against age and a polynomial regression was fitted (Fig. 22).
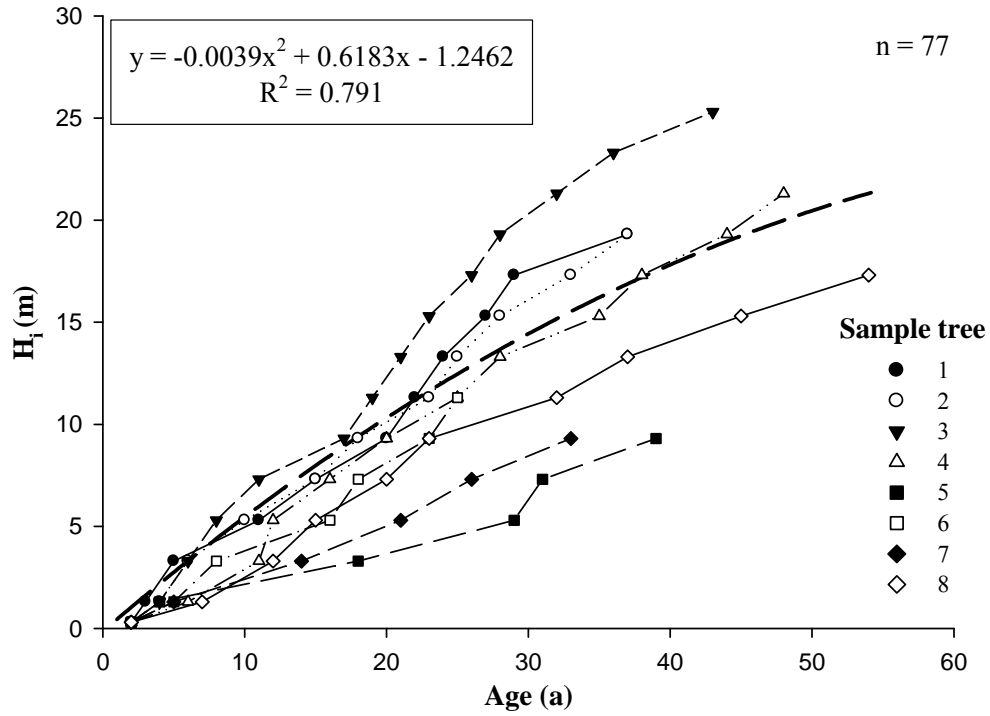
Figure 22: Height of segments versus age of all sample trees.

Subsequently, a quadratic polynomial curve was fitted to all H_i–age combinations.

As each sample slice at different heights displays a definite number of annual rings, height growth was estimated by dividing given heights (H_i) by the corresponding number of annual tree rings (Kramer and Akça, 2002) (Fig. 23).
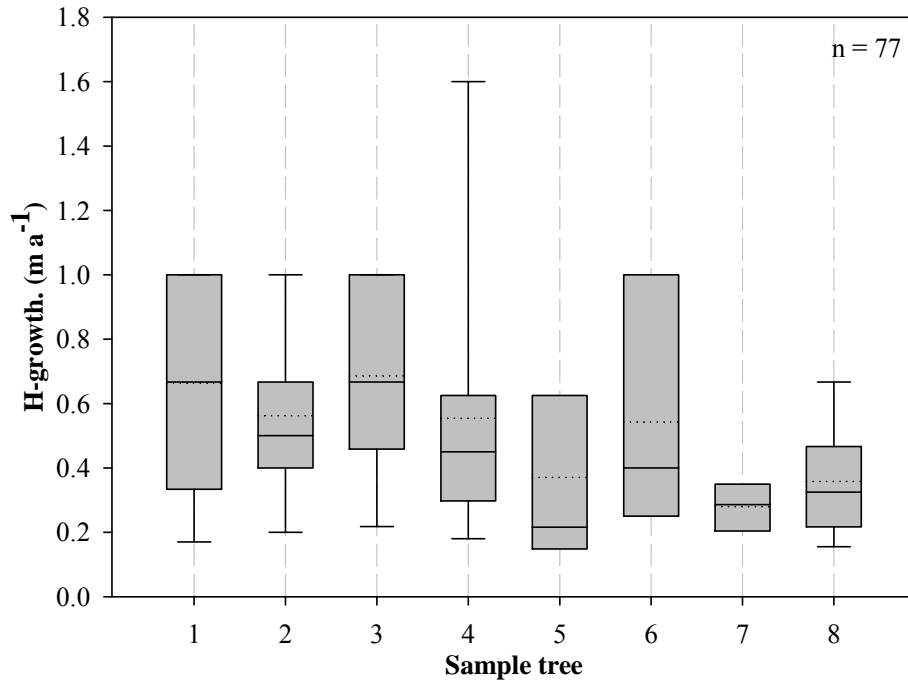
Figure 23: Mean (dotted) and median (solid) height growth of all sample trees.

On average, height increment of all sample trees was 0.5 m a^{-1} (± 0.05). The trees one and three show the highest mean increments of height (0.66 (± 0.10) and 0.69 m a^{-1} (± 0.08),

respectively). Missing confidence intervals for trees number five, six and seven result from the lack of sufficient samples slices.

Hence, the estimated mean height growth of the eight target species ranged from 0.28 to 0.69 m a^{-1}. Unfortunately, the obtained results could not be verified as few studies have focused on height growth of *Cedrela spp.* so far. However, as stem samples of three sample trees were only obtained up to crown height, height growth along the stem could be assessed based on an even smaller sample size only. This might account for the somewhat blurred results.

Del Castillo et al. (2005) reported mean height growth for very young trees of *C. balansae* in plantations of 0.49 – 1.06 m a^{-1}. Comparability of the two findings is only limited considering the very different ages of sample trees.

The obtained values were subsequently averaged and categorized in intervals of ten years.
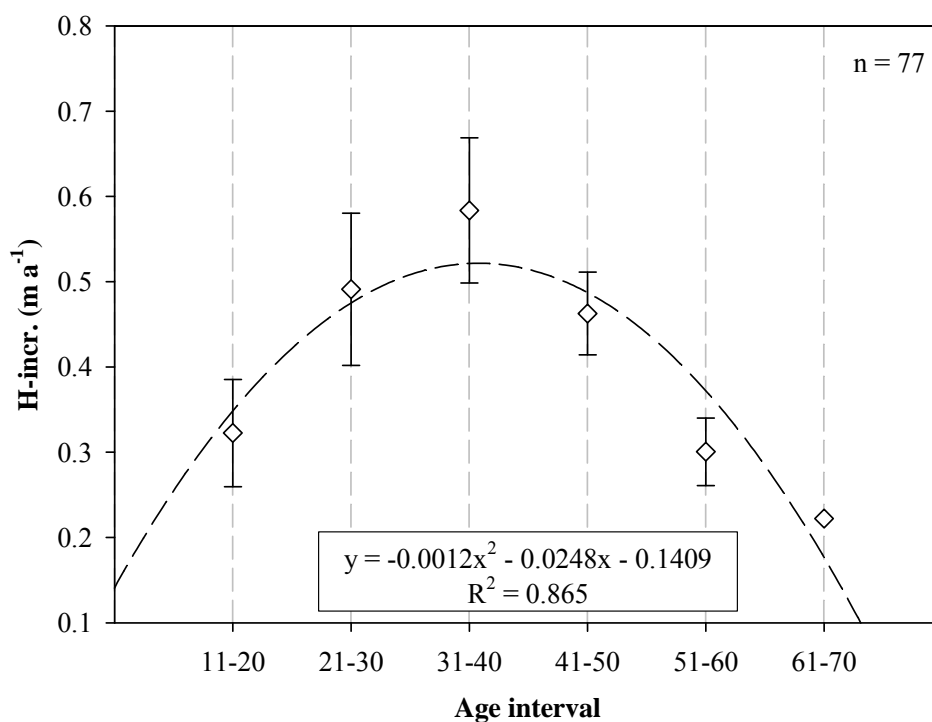
Figure 24: Mean height growth of all tree samples at different age intervals, with respective standard error.

The estimated height growth of *Cedrela spp.* in *FPC* culminates at an age of 31 to 40 years (Fig. 24). The findings are rather questionable, considering that this species was reported to reach considerable ages (Grau, 2000; Brown et al., 2001). Nonetheless, Grau (2000) considered *Cedrela lilloi* to be fast growing, whereas Easdale et al.(2007), contrasting the former statement, argued that wood density of a species may be an indicator for individual lifespan of a species.

If total height is plotted against age, visual inspection of individual height development over age allows for a broad classification of investigated sample trees. Thus, the eight sample trees were grouped according to obtained height at specific reference age. Subsequently, non linear regressions were fitted to three separate classes (Fig. 25), which yielded coefficients of determination ranging from 0.918 to 0.964. Each class included at least two observations (samples trees) of distinct H_i-age relationships.
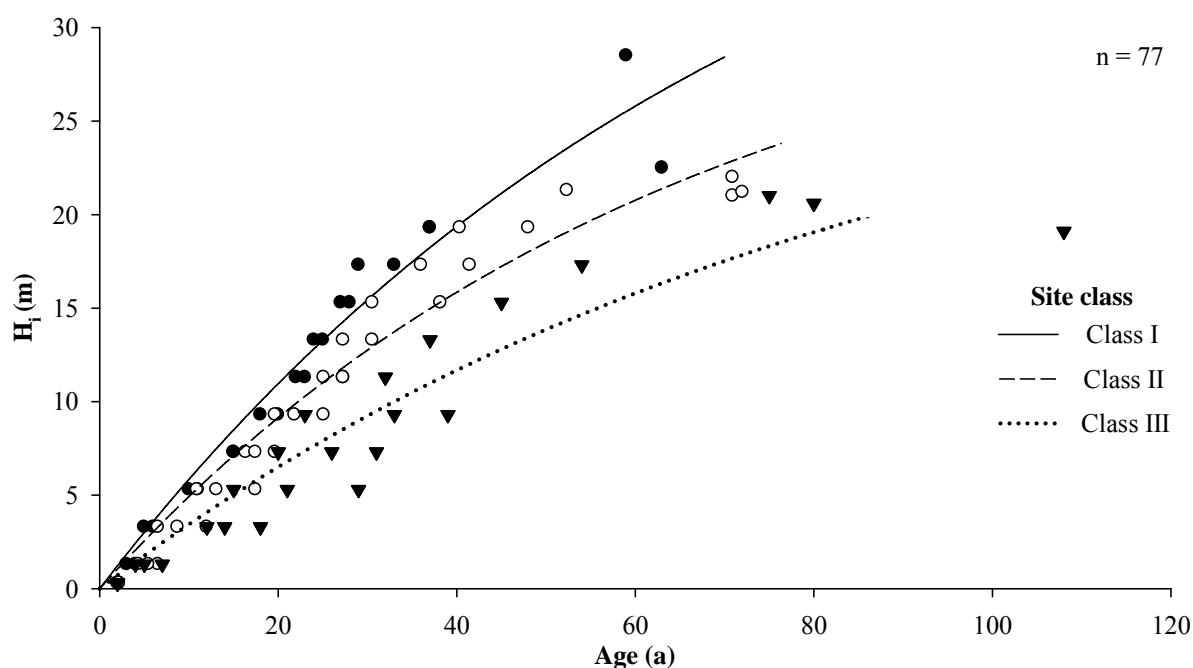
Figure 25: Classification of site according to height growth versus age of all sample trees.

3.2.6 Volume

Commercial volume and corresponding *breast height form factor* were calculated for all sample trees (Tab. 7).

Table 7: Data for growth analysis of sample trees.

Sample tree	1	2	3	4	5	6	7	8	Mean (std. error)
V_c	1.402	0.690	2.062	0.925	0.849	0.507	0.943	0.774	1.02 (±0.18)
FF_c	0.59	0.63	0.72	0.60	0.64	0.61	0.46	0.59	0.61 (±0.02)

Mean V_c of all eight sample trees in diameter classes between 35 and 70 cm was 1.02 m^3, and ranged from 0.51 to 2.1 m^3. The averaged form factor to estimate commercial volume by multiplication with G_i and H_c was 0.61 for all trees of *Cedrela spp.* in *FPC*. Minimum and maximum values of form factor ranged from 0.42 and 0.72, depending on geometrical bole form (Cpt. 3.2.1). Certain form factor classes correspond to specific geometrical shapes

(Husch et al., 1993). In this case, the lowest of the estimated form factors (0.46 for tree number seven) resembles a conoid, whereas the form factors ranging from 0.59 (tree number one and eight) to 0.72 (tree number three, including two, five and six) and the largest estimated form factor of 0.72 (tree number two) describe a quadratic parabolid and cubic parabolid, respectively.

The findings correspond to results obtained by classification of form quotients (Cpt 3.2.1) and may facilitate the selection of a specific taper function to accurately model stem taper of *Cedrela spp*.

Further, individual volume growth for all sample trees was examined (Fig. 26).
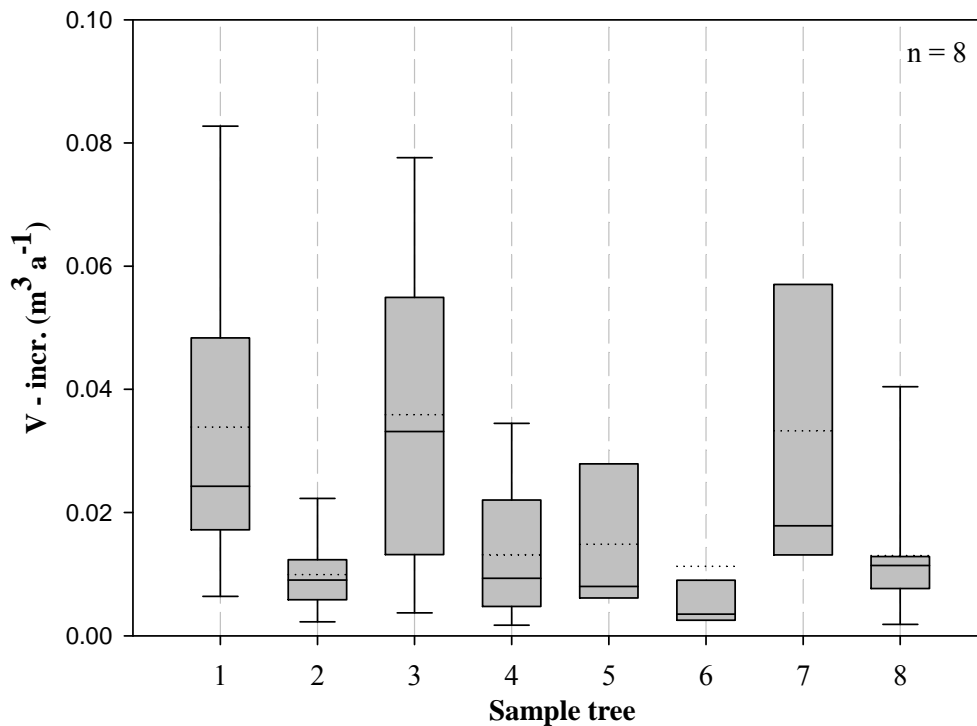
Figure 26: Mean (dotted) and median (solid) volume growth of each sample tree.

Mean volume growth per year averaged 0.021 m^3 a^{-1} and values ranging from 0.01 to 0.04 m^3 a^{-1} (for trees no. six and one, respectively) were observed. Note that confidence intervals for samples five, six and seven are missing due to missing sample slices above H$_c$ of these sample trees.

For sample trees five, six and seven, height modeling was based on average diameter - height observations of all sample trees. Consequently, volume growth at intervals of ten years was averaged and a quadratic polynomial regression was fitted (Fig. 27).
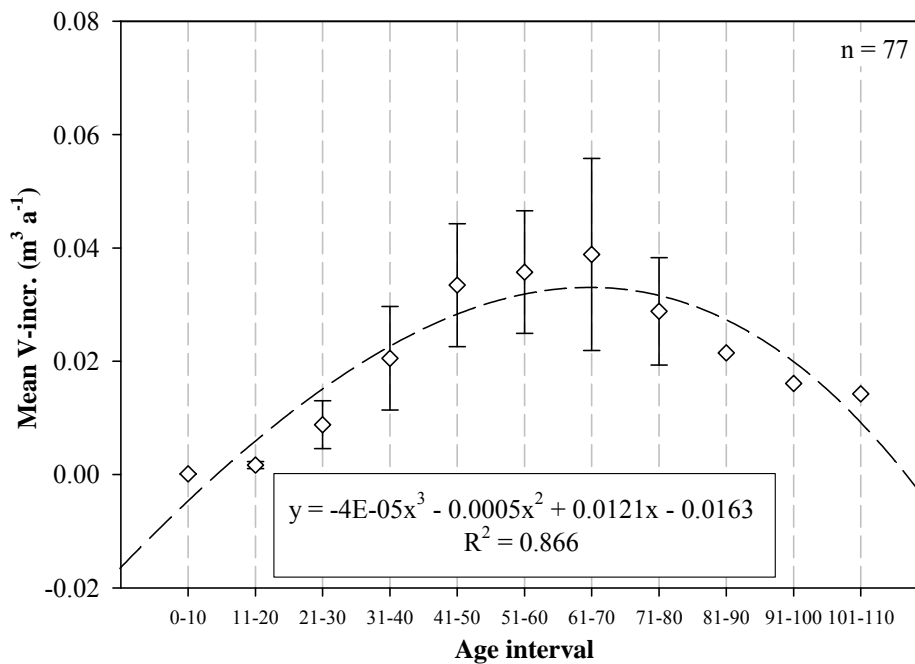
Figure 27: Mean volume growth at different age intervals of Cedrela spp. with respective confidence intervals.

Volume growth of *Cedrela spp.* culminates between 60 and 70 years with a maximum of mean diameter growth of 0.04 m^3 a^{-1} ($\pm$ 0.001) in *FPC* (Fig. 27). Confidence intervals begin to broaden at age interval 51 – 60, because the number of samples included in the subsequent age classes declines (Tab. 7). Only tree number five had reached the age class of 81 – 90 at time of sampling, thus confidence intervals could not be computed for the following age classes.

3.2.7 Modeling growth of Cedrela spp.

Some variables could be identified that were directly related to growth performance of *Cedrela spp.* For instance, a correlation was found between percentage of G constituted by individuals of *Cedrela spp.* and mean diameter growth, indicating that site quality with regard to diameter-growth is best, the higher the dominance of *Cedrela spp.* on that site (Appendices). The respective R^2 resulted in 0.779. However, as the predictive model should be of general applicability and extend beyond such apparent predictors, percentage of G made up by *Cedrela spp.* was not included in the analysis.

As possible predictive parameters, quantified site characteristics as well as ecological parameters were considered, i.e. altitude (m asl), exposition (1-5; Cpt. 2.2.5.1), pH-value of 30 cm topsoil, thickness of humus layer (cm) and total numbers of accompanying species (N ha^{-1}). Consequently, stepwise multiple non-linear regression analyses were computed, with

max V-growth (m^3 a^{-1}) and mean H-growth (m a^{-1}) as target and various site parameters as independent variables. Hence, non-significant parameters were discharged, if respective p-values yielded p ≥ 0.05.

Major parameters and precision statistics of the analyzed functions are displayed in the following table:

Table 8: Statistics of fit for growth model of Cedrela spp. in Finca Pintascayo.

Model no.	Dependent variable	Independent variables	MSE	MAE	R^2_{adj}
1	mean V-growth (m^3 a^{-1})	Altitude, *Pisonia ambigua, Anadentathera colubrina, Ocotea spp., Lonchocarpus lillio*	0.000016	0.001498	88.9
2	mean V-growth (m^3 a^{-1})	Altitude, *Anadentathera colubrina, Lonchocarpus lilloi*	0.000058	0.003388	58.7
3	mean V-growth (m^3 a^{-1})	Humus, *Anadentathera colunbrina, Lonchocarpus lilloi*	0.000037	0.003840	73.3
4	mean V-growth (m^3 a^{-1})	pH, *Anadentathera colunbrina, Lonchocarpus lilloi*	0.000033	0.003097	76.9
5	mean H – growth (m a^{-1})	pH, exposition	0.005744	0.048170	73.9

Eventually, a sufficient fit (Tab. 8) was obtained for the following predictive models:

$$\text{V-growth (m}^3\text{ a}^{-1}) = 0.0574708 \, ALT^{0.620725} \left(2.80426 + EXP\right)^{0.7316} \qquad [15]$$

$$\text{H-growth (m a}^{-1}) = 0.0303559 \left(EXP^{0.342838}\right)\left(pH^{1.65024}\right) \qquad [16]$$

Equations 15 and 16: Predictive models for mean V-growth (m^3 a^{-1}) and mean H-growth (m^3 a^{-1}) for Cedrela spp. in Finca Pintascayo.

In order to evaluate the performance of the model, predicted mean volume growth was plotted against observed growth rates. The adjusted linear regression yielded a satisfactory fit, with $R^2 = 0.748$ (Fig. 28 and Fig. 29).
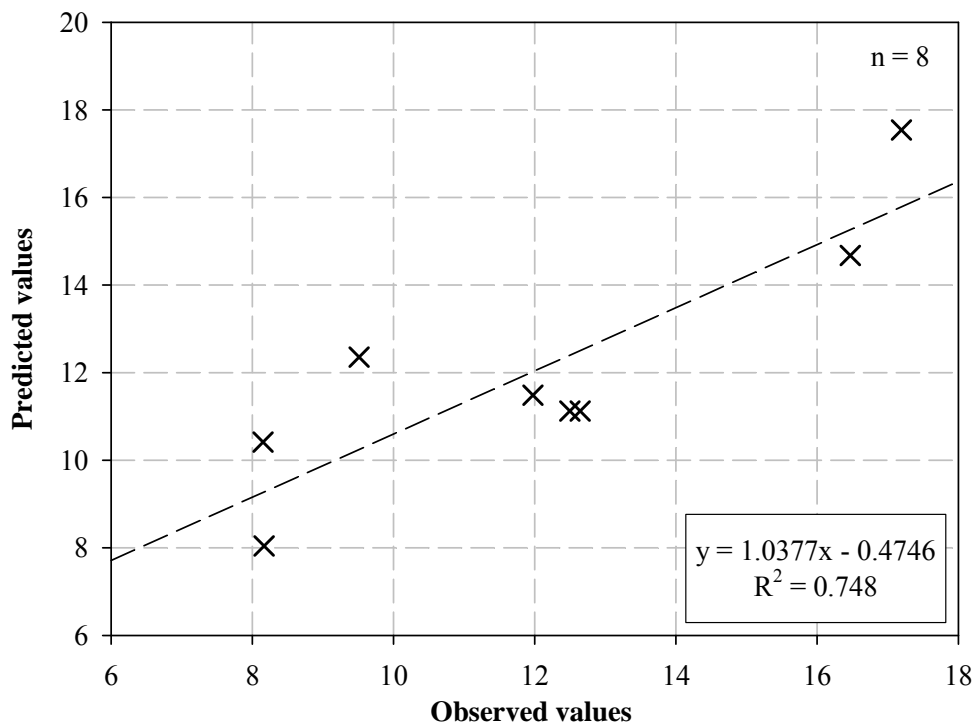
Figure 28: Observed versus predicted mean volume growth (m^3 a^{-1}) for Cedrela ssp. in Finca Pintascayo.
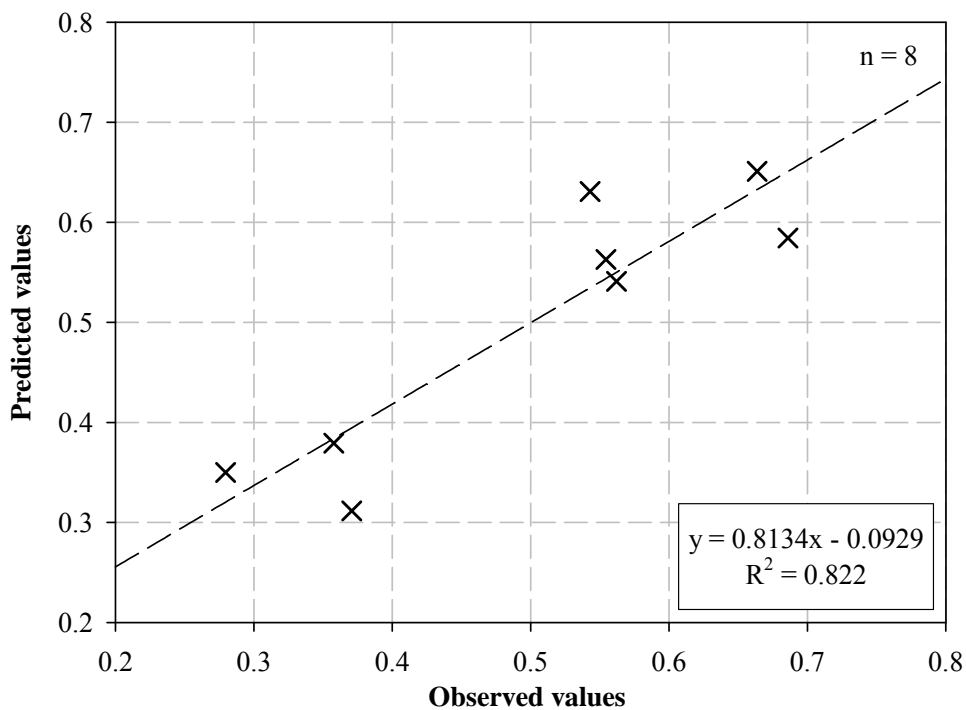
Figure 29: Observed versus predicted mean height growth (m a^{-1}) for Cedrela ssp. in Finca Pintascayo.

However, with regard to the very low number of observations (n = 8) and the considerably low number of significant predictor variables, these function can only serve as reference to a basic approach. Their applicability in the field will be rather restricted, but validation by means of larger data sets presents an interesting subject for further investigation.

3.3 Analysis of stands

In total, an area of 2.8 ha (area one: 1.1 ha; area two 1.7 ha) was sampled. Further, 8 additional plots were not randomly allocated and can therefore not be included in sampling intensity calculations. The remaining 28 plots result in a sampling intensity of $5.6 \times 10^{-3}\%$ if the entire area of *FPC* is considered. Regarding each area individually, sample intensities amount to 0.021% for area one and $4.3 \times 10^{-3}\%$ for area two, respectively.

All in all, sampled trees summed up to 1007 trees in 36 plots (Tab. 9):

Table 9: Descriptive statistics of tree data obtained at Finca Pintascayo.

	Total tree data set								
	(n = 1007)								
Statistics	D_i **(cm)**	H_t **(m)**	H_c **(m)**	G_i **(m²)**	V_c **(m³)**	**Stem quality**	D_c **(m)**	**Vitality**	**Social position**
Minimum	10	2.5	0.3	0.008	0.003	1	0.4	1	1
Maximum	87.5	25.3	14.6	0.601	3.587	6	19.5	3	5
Mean	23.1	10.9	5.4	0.057	0.235	3.3	5.6	2.1	2.8
Std. error	(±0.43)	(±0.14)	(±0.08)	(±0.002)	(±0.01)	(±0.04)	(±0.1)	(±0.02)	(±0.04)
Std. deviation	13.65	4.4	2.56	0.07	0.38	1.17	3.12	0.74	1.21

Site evaluation was based on comparison of major stand parameters obtained in all sampled areas and carried out separately for the two areas and the allocated plots surrounding target trees of *Cedrela spp.* (Tab. 10).

Table 10: Descriptive statistics of all sampled areas in Finca Pintascayo.

Area	**1** *(n = 11)*				**2** *(n = 17)*				*Cedrela spp.* *(n = 8)*			
Statistics	Mean	Min	Max	Std. dev.	Mean	Min	Max	Std. dev.	Mean	Min	Max	Std. dev.
N ha⁻¹	374	165	655	155.2	476	315	665	105.2	460	335	645	109.6
G (m² ha⁻¹)	11.9	8.4	17.3	3.26	15.0	11.3	20.4	2.59	18.0	12.6	26.4	5.85
H_{top} (m)	15.2	10.3	20.7	3.07	15.7	12.1	21.2	2.61	17.8	15.3	20.1	1.75
H_c (m)	4.7	3.1	5.7	0.71	5.0	3.7	6.5	0.82	4.6	3.0	5.1	0.74
commercial V_c (m³ ha⁻¹)	17.0	6.1	36.4	9.10	25.4	0	69.7	22.23	51.9	12.5	110.7	36.5
stem quality of commercial species (1 – 6)	3.3	2.3	4.4	0.56	2.2	1.7	3.5	0.94	2.9	2.2	3.6	0.49
vitality of commercial species (1 – 3)	1.7	1	2.2	0.43	1.5	1.0	2.0	0.61	1.8	1.6	2.0	0.20
crown coverage (ha ha⁻¹)	0.7	0.4	0.99	0.16	1.2	0.7	2.1	0.40	1.5	1.2	2.0	0.23

In area one, stands showing evidence of past logging activities summed up to 100%, whereas in the lesser accessible area two, signs of harvest were observed in only 24% of all sampled

plots. Mean number of occurring species per plot equaled 10.3 (±0.5) in area one and 9.4 (±0.84) in area two, respectively. Main stand characteristics of plots corresponding to the eight sample trees are discussed in chapter 3.3.4.

In 2005, GMF conducted a sampling of 2600 ha in the area of *FPC* to evaluate forest structure in stands that have been subject to harvest in previous years. The estimated number of mean stems per hectare in diameter classes ≥ 10 cm equaled 185 N ha^{-1}. Mean basal area per hectare in a southern part of *FPC* was estimated to be 13.6 m^2 ha^{-1} (GMF, 2005).

3.3.1 Structure and composition in area one and two

Both areas were compared with regard to mean stand characteristics and site parameters. Mean stems per hectare and diameter were calculated for each area (Fig. 30).
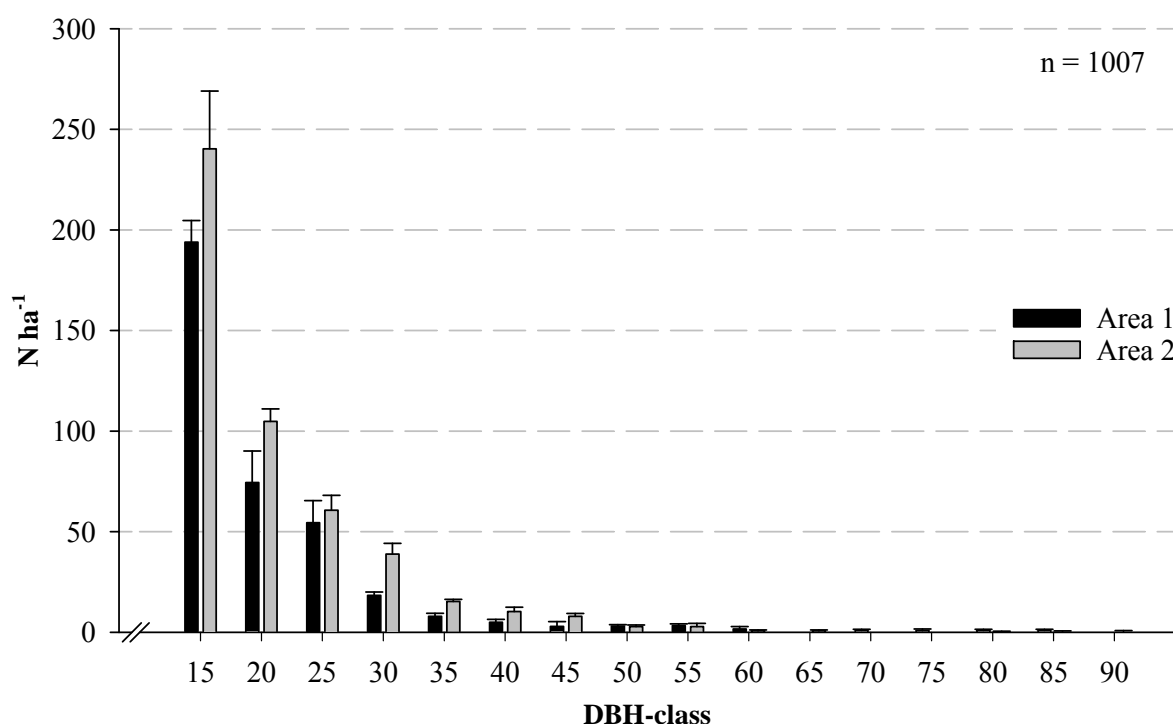
Figure 30: Mean diameter distribution in area one and area two.

Diameter distributions of both areas follow to a certain degree the expected distribution for natural forest (Husch et al., 1993). On average, N ha^{-1} in area two exceed values observed in area one. As mentioned earlier, area one has been subject to intense logging activities (Cpt. 2.2.1), whereas logging in area two has been restricted to sites of easy access. Thus, variances in mean number of trees per hectare can possibly be attributed to the distinct history of usage for both areas. Note that trees in diameter class 65 to 75 are missing, probably due to selective harvest of upper diameter classes. Trees with larger diameters ($D_i \geq 85$ cm) are entirely absent in area one.

Further, mean V_c was calculated for each tree and averaged per diameter class (Fig. 31).
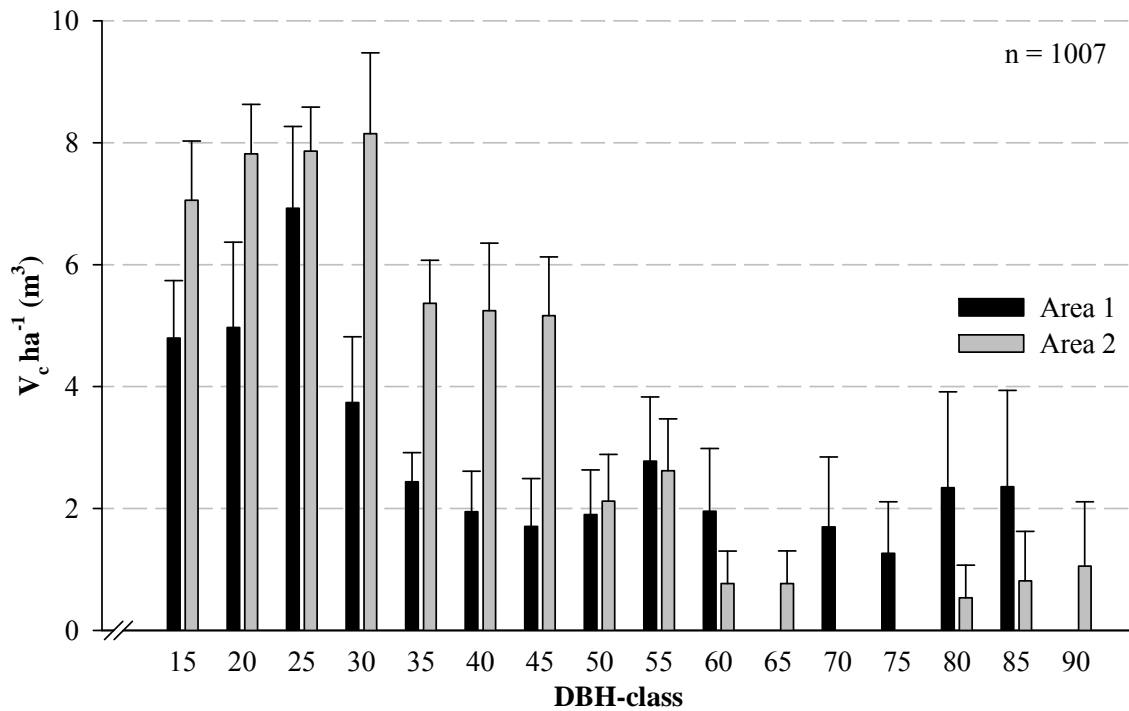
Figure 31: Mean V_c (m^3 ha^{-1}) per diameter class in area one and area two.

The impact of previous logging activities can clearly be distinguished when V_c–distributions per diameter class are investigated (Fig. 31). The expected distribution curve of tree volume per diameter class in natural forests resembles a normal distribution curve in the broadest sense (Husch et al., 1993). On the contrary, the bi-modal distribution of stem volume in both areas indicates former extraction of certain upper diameter classes, as stem volume in that range is entirely absent. On the other hand, stem volume is over proportionally present in lower diameter classes, most likely as a result from increased recruitment of saplings and pioneer species due to canopy openings that are caused by timber harvest operations.

Hence, approaches to site quality evaluation that are based on the assumption that the investigated sites are at a climax stage of succession cannot be applied offhand or at least might lead to inconsistent results, as the highest trees and therefore a portion of standing volume was most likely extracted from the majority of stands prior to sampling.

3.3.2 Stand parameter distribution in area one

Figure 32: Distribution of sample plots within three altitudinal strata in area one.

In area one, 252 trees were sampled in eleven plots (Tab. 11). Subsequently tree parameters were averaged and means of different site categories were compared.

Table 11: Descriptive statistics of tree data obtained in area one.

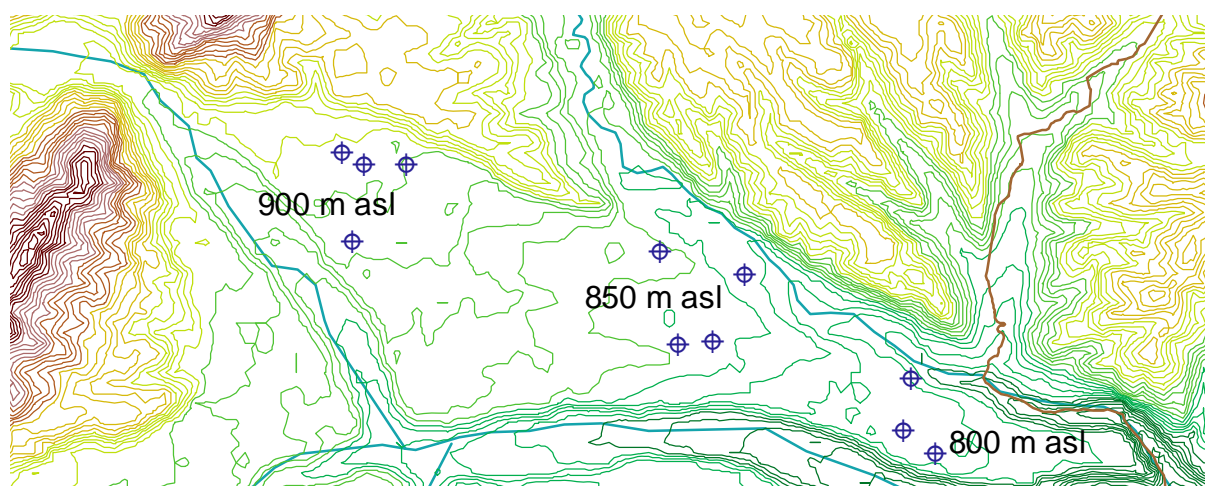| Statistics	D_i (cm)	H_t (m)	H_c (m)	G_i (m²)	V_c (m³)	Stem quality	D_c (m)	Vitality	Social position
Total tree data set, area one *(n = 252)*									
Minimum	10	3.0	0.8	0.008	0.005	1	0.5	1	1
Maximum	81	23.5	12	0.515	2.7	6	17	3	5
Mean	22.6	9.5	4.6	0.058	0.222	3.7	4.9	2.1	3.0
Std. error	±0.95	±0.25	±0.14	±0.006	±0.027	±0.07	±0.17	±0.05	±0.08
Std. deviation	0.95	0.25	0.14	0.006	0.027	0.07	0.17	0.05	0.08

As altitudinal strata in area one showed a comparably high degree of homogeneity in terms of topography and relief, descriptive site parameters were relatively few. Hence, category variables merely encompassed altitudinal classes and observed stand humidity. Statistical analysis of mean stand parameter distribution in three different altitudinal classes was computed and subsequently compared (Tab. 12):

Table 12: Mean stand parameters for three altitudinal strata in area one.

Altitudinal class	800 *(n=3)*		850 *(n=4)*		900 *(n=4)*	
Variable	**Mean**	**Std. error**	**Mean**	**Std. error**	**Mean**	**Std. error**
N ha^{-1}	315	(±70.5)	358.8	(±55.8)	432.5	(±111.3)
G (m² ha^{-1})	10.2	(±0.67)	12.9	(±1.55)	12.3	(±2.27)
G_{com} (m² ha^{-1})	4.1	(±1.32)	5.5	(±1.24)	3.2	(±0.59)
% commercial G	41.4	(±15.4)	42.6	(±6.7)	26.5	(±5.02)
V_c (m³ ha^{-1})	38.6	(±3.92)	43.5	(±8.32)	39.7	(±6.74)
commercial V_c (m³ ha^{-1})	18.6	(±5.59)	21.6	(±5.51)	11.2	(±2.04)
% commercial V_c	50.5	(±17.4)	48.5	(±6.12)	29.2	(±5.7)

The observed distribution of stand parameters within altitudinal classes in area one displays certain trends corresponding to elevation (Tab. 12). In the highest elevated stratum (900 m) stem number per hectare considerably surpassed those observed in the lower parts of area one. In contrast, mean V_c ha^{-1} was lower than in the intermediate stratum and only slightly exceeded mean values observed in the lowest stratum. The average percentage of commercial V_c ha^{-1} decreased with increasing altitude, possibly indicating intensified extraction of commercial timber in the upper area of *SNC*. As the area corresponding to altitudinal class 900 is also the most easily accessible, due to presence of a weak network of forest roads and skidding trails, the observed decline of commercial volume at that class might be attributed to increased accessibility.

3.3.2.1 Distribution of stand heights in area one

Means of three variables of tree height (H_{top}, H_t and H_c, respectively) were calculated per plot and subsequently compared between three altitudinal classes (Fig. 33).
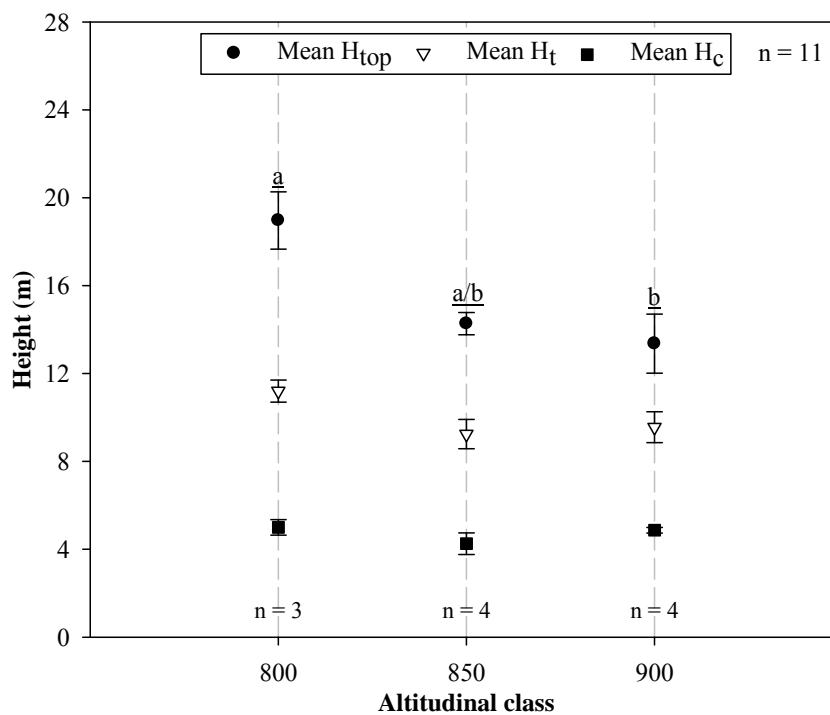
Figure 33: Mean values of tree height, according to altitude class, with respective standard error for area one. Mean values that share the same letter are not significantly different for p ≤0.05.

The computed ANOVA yielded an indicative p-value of 0.019 for variability between group means, resulting in the rejection of the null hypothesis. Further, the *post hoc* test identified group variability between altitudinal classes 800 and 950 to be statistically significant, resulting in a p–value of 0.027. Therefore, differences of means between the highest and lowest altitude class differ significantly, suggesting that mean top heights of stands decline

with increasing altitudinal class. Means per altitude class averaged 19 m (±1.31), 14.3 m (±0.51) and 13.7 m (±1.34) for altitudinal class 800, 850 and 900, respectively.

Differences between means of H_t and H_c did not significantly differ. In both cases the ANOVA produced p-values surpassing the significance quantile of $p \leq 0.05$. However, mean values of H_t ranged from 11.2 m (±0.5) and 9.2 m (±0.67) to 9.55 m (±0.7) for altitudinal class 800, 850 and 900, respectively, resulting in an overall average of 9.9 m (±0.43) for the entire area one. The arithmetic means for H_c ranged from 5.0 m (±0. 36) in altitudinal class 800 to 4.9 m (±0.13) in altitude class 900. The lowest mean value of crown height was observed in the intermediate altitudinal belt of 850 m, where mean H_c equaled 4.3 m (±0.49). On average, H_c was 4.7 m (±0.21) for the entire area one.

According to Vanclay (1994) stand height is a good indicator of site quality. Therefore, mean H_{top} of the three strata in area one was compared and statistically significant differences between means were identified (Fig. 32). Mean H_{top} was highest in altitudinal class 800 and decreased with increasing altitude. As the average total height of dominant trees after logging was previously used in dipterocarp forest in the Philippines to evaluate site productivity (Mendoza and Gumpal, 1987) it may yield practicable results here, in spite of altered stand structures due to former harvest activities.

3.3.2.2   Qualifying stand parameters in area one

In area one, few trends referring to distribution of stem quality according to altitudinal class could be observed (Tab. 13).

Table 13: Stem quality parameters for three altitudinal strata in area one.

Altitudinal class	800 (n=3)		850 (n=4)		900 (n=4)	
Variable	Mean	Std. error	Mean	Std. error	Mean	Std. error
stem quality (1 - 6)	1.8	(± 0.18)	2.0	(± 0.16)	2.1	(± 0.23)
stem quality of commercial species (1 – 6)	3.0	(±0.11)	3.3	(±0.17)	3.5	(±0.44)
vitality of commercial species (1 – 3)	1.51	(± 0.36)	1.79	(±0.18)	1.78	(± 0.21)

Overall mean of stem quality in area one equaled 3.4 (±0.20) and 3.3 (±0.17) for commercial species only. Vitality of commercial species averaged 1.7 (±0.13), whereas vitality of all trees resulted in 2.0 (±0.11). Note that vitality of all trees is not depicted in the table above, as variances between means were minimal and no major trend could be identified.

Thus, evaluation of stand parameters referring to stem quality resulted in better stem qualities and tree vitality on average in the lowest part of *SNC* (Tab. 13). Evaluation of an additional qualifying parameter, mean tree slenderness (H_t/D_i), led to identification of a similar trend (Fig. 34). With increasing altitude, tree morphology tends to become more compact.
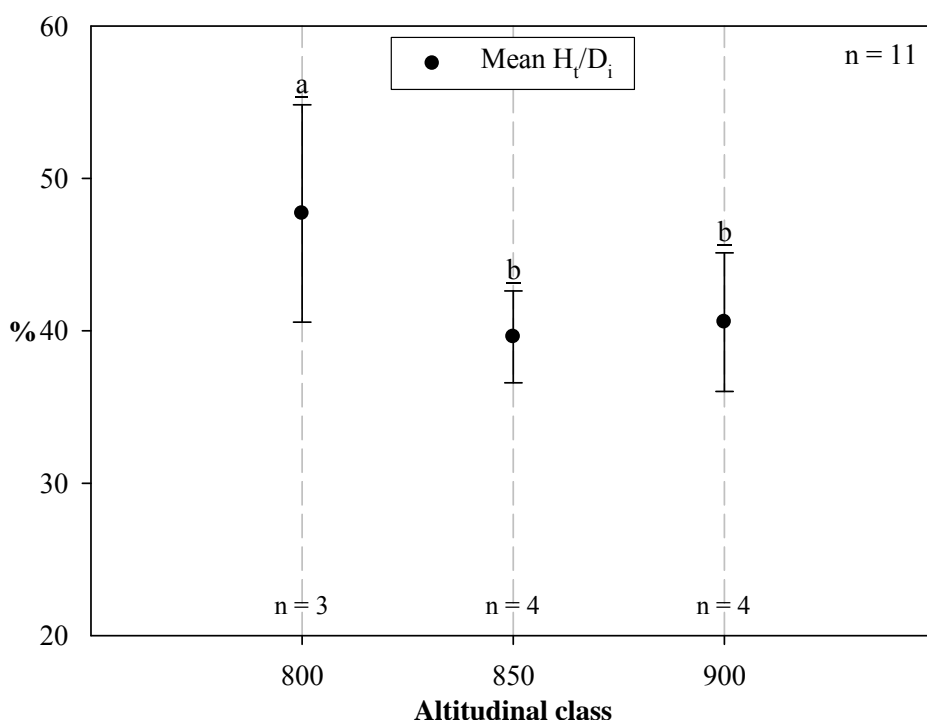
Figure 34: Mean values of tree slenderness, according to altitude class, with respective 95% confidence interval for area one. Mean values that share the same letter are not significantly different for p ≤ 0.05.

In area one, mean slenderness of trees differed with altitudinal class. In the lowest part (800), mean slenderness (H_t/D_i) equaled 47.7% (±1.66), whereas means of the intermediate and upper part were somewhat similar, with 39.6% (±0.95) and 40.6% (±1.43) in altitudinal class 850 and 900, respectively. In total, mean tree slenderness equaled 42.2% (±1.28).

According to the results obtained by the ANOVA, differences of mean slenderness in altitudinal classes were statistically significant for $p \leq 0.05$ ($p = 0.007$). Subsequently, the *post hoc* test indicated that average slenderness of trees found in the lowest part of area one do significantly differ from mean slenderness observed at sites at higher elevation.

Disregarding possible changes in stand composition as a consequence of anthropogenic activities, the evaluation of site quality produced well defined results, considering the above mentioned aspects for area one. Consequently, preferable growing conditions seem to be present in the lowest of the three altitudinal strata and a higher site quality could be attributed to that area.

If the discussed findings are related to the observed soil properties in area one (Cpt. 3.1.1), a relationship between topsoil attributes can be established as observed thickness of humus layer and pH–value of topsoil seem to be negatively correlate with mean tree heights in area one.

3.3.2.3 Canopy and crown parameters in area one

Canopy and tree crown parameter distributions were analyzed and subsequently classified according to altitudinal class (Tab. 14).

Table 14: Crown parameters of stands according to altitudinal class in area one.

Altitudinal class	800 (n = 3)		850 (n = 4)		900 (n = 4)	
Variable	Mean	Std. error	Mean	Std. error	Mean	Std. error
length of crown (m)	6.2 a	(±0.15)	5.0 a/b	(±0.21)	4.4 b	(±0.4)
mean D_c (m)	4.9	(±0.50)	4.5	(±0.26)	5.0	(±0.36)
crown coverage (ha ha^{-1})	0.74	(±.07)	0.68	(±0.04)	0.68	(±0.13)

Regarding average crown length per altitudinal class, the corresponding ANOVA indicated significant differences between means of altitudinal class 800 and 900 (p = 0.011). Crown length of all trees averaged 5.1 m (±0.27), whereas means D_c equaled 4.8 m (± 0.20). Average crown coverage of all stands resulted in 0.7 (ha ha^{-1}) (±0.05) for the entire area one.

If crown parameter distribution in area one is investigated, a negatively correlating trend with altitudinal gradient can be observed (Tab. 14). At the lowest elevations, the average crown length equaled 6.2 m (±0.15), and steadily declines with increasing altitudinal class thereafter, until crowns attain lengths of just 4.4m (±0.4) in altitudinal class 900. With regard to canopy analysis by means of canopy pictures, average crown cover (%) equaled 86.6% (±1.5) for all plots in area one, respective LAI_{True} resulted in 3.8 (±0.14).

3.3.3 Stand parameter distribution in area two
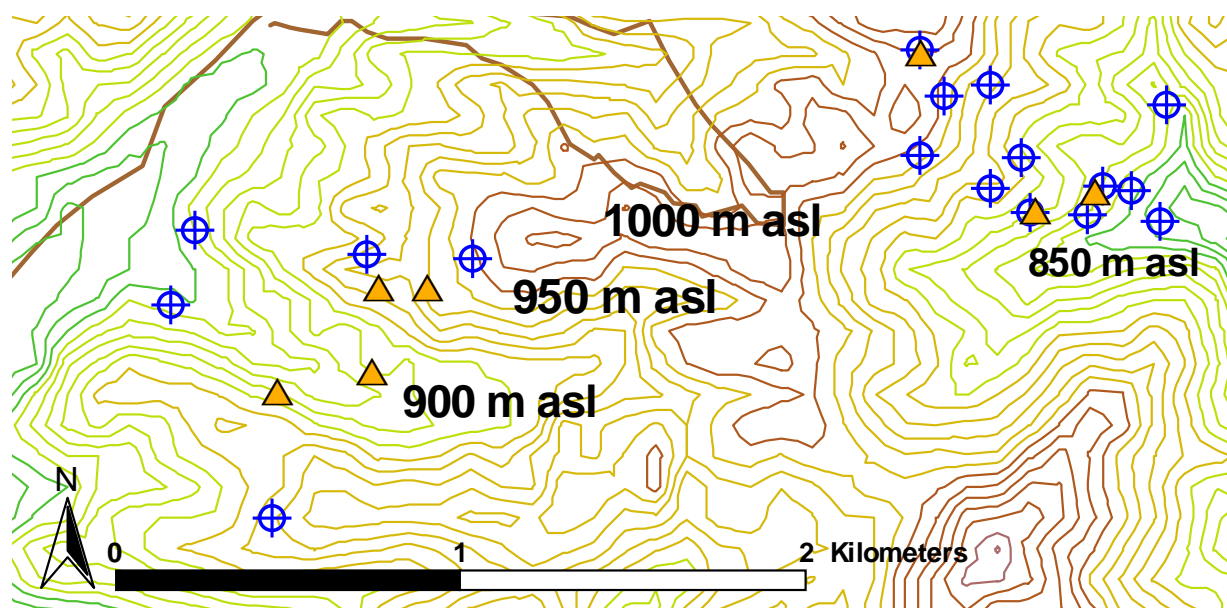
Figure 35: Distribution of sample plots in area two (Δ indicate position of sample trees).

In area two, a total of 509 trees were sampled in 17 plots (Tab. 15).

Table 15: Descriptive statistics of tree data obtained in area two.

Statistics	D_i (cm)	H_t (m)	H_c (m)	G_i (m²)	V_c (m³)	Stem quality	D_c (m)	Vitality	Social position
Minimum	10	3.3	0.3	0.008	0.003	1	0.4	1	1
Maximum	87.5	24	13	0.601	3.587	6	19.5	3	5
Mean	22.4	10.9	5.3	0.052	0.215	3.3	5.7	2.1	2.8
Std. error	(±0.55)	(±0.18)	(±0.11)	(±0.003)	(±0.015)	(±0.05)	(±0.14)	(±0.03)	(±0.05)
Std. deviation	12.46	4.14	2.53	0.06	0.34	1.18	3.06	0.76	1.20

Total tree data set, area two (n = 509)

Classification of stands in area two presented a more complex matter as site descriptive variables were multifold, due to the high heterogeneity of surface area in the higher elevated parts of *FPC*. Obtained stand parameters were averaged and analytically compared (ANOVA) between four altitudinal strata (Tab. 16).

Table 16: Mean stand parameters for four altitudinal strata in area two.

Altitudinal class	850 (n = 5)		900 (n = 4)		950 (n = 5)		1000 (n = 3)	
Variable	Mean	Std. error	Mean	Std. error	Mean	Std. error	Mean	Std. error
N ha^{-1}	451	($\pm$16.5)	499	($\pm$31.0)	431	($\pm$59.7)	563	($\pm$91.8)
G (m^2 ha^{-1})	14.5	($\pm$0.81)	14.9	($\pm$1.11)	14	($\pm$1.33)	18	($\pm$1.33)
G$_{com}$ (m^2 ha^{-1})	4.3	($\pm$1.74)	5.2	($\pm$1.49)	4.3	($\pm$2.1)	9.1	($\pm$4.22)
% commercial G	27.5	($\pm$9.97)	34.6	($\pm$8.54)	27.4	($\pm$10.7)	48	($\pm$21.5)
V$_c$ (m^3 ha^{-1})	47.9 a	($\pm$6.31)	52.3 a/b	($\pm$3.28)	52.3 a/b	($\pm$5.66)	77 b	($\pm$5.0)
commercial V$_c$ (m^3 ha^{-1})	21.4	($\pm$10.2)	24.2	($\pm$6.09)	19.2	($\pm$8.93)	43.9	($\pm$20.4)
% commercial V$_c$	39.2	($\pm$14.5)	47.5	($\pm$11.9)	33.8	($\pm$11.9)	54.4	($\pm$24.5)

The ANOVA did not identify statistical significant differences between mean values of stand parameters, with the exception of the distribution of total stem volume within different altitudinal strata which resulted in a p–value of 0.049. Thus, the null hypothesis was rejected and the continuative analysis indicated the differences of means between altitudinal class 850 and 1000 to be statistically significant for $p \leq 0.05$.

In contrast to area one, distribution of stand parameters according to altitudinal class did not show a consistent trend with regard to elevation (Tab. 16). Although stand parameter at the highest elevation exceeded those recorded at lower altitudinal classes on average, respective means were accompanied by comparably high standard errors. Possibly due to the small sample size by which this group was represented (n = 3), all observed trends should be judged with care as they are combined with a high within group variability, especially in altitudinal class 1000. However, considering mean V$_c$ ha^{-1}, being the one single parameter that displayed significant differences between means for $p \leq 0.05$, this is not the case. Therefore, it can be stated that V$_c$ ha^{-1} does increase with increasing altitude, although differences between altitudinal classes 900 and 950 are marginal.

3.3.3.1 Distribution of stand height in area two

Although significant differences between means for the remaining parameters could not be detected, some major trends can be observed regarding distribution of mean tree heights among different altitudinal classes (Fig. 36).
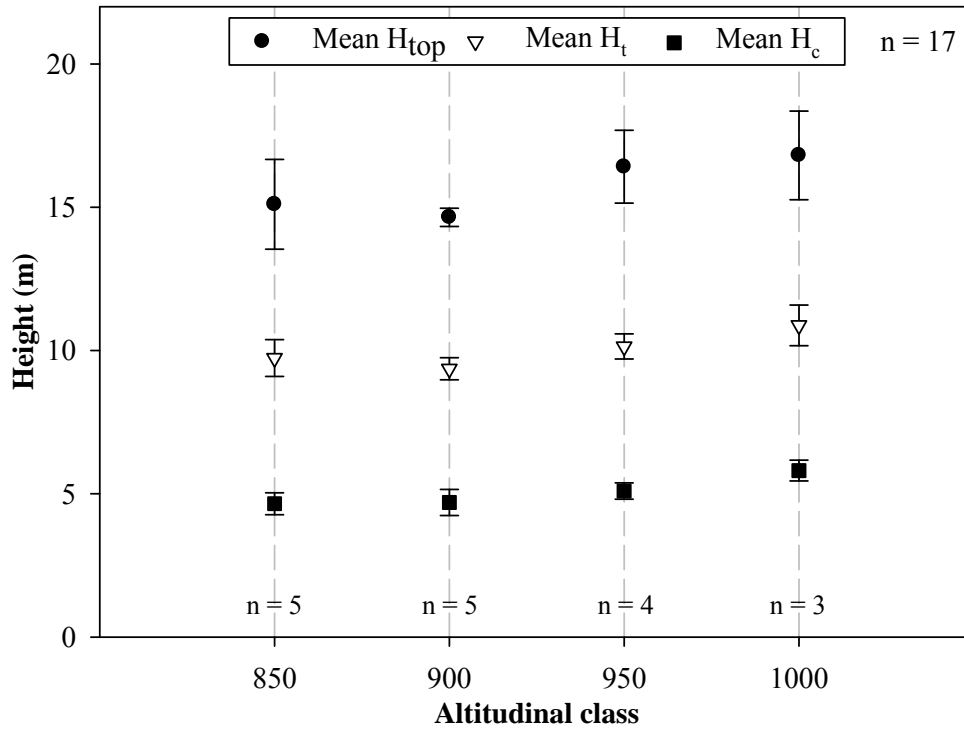
Figure 36: Mean values of tree height with respective standard errors, according to altitude class for area two.

Means of H_{top}, H_t height and H_c follow a certain trend and tend increases with altitudinal class. Mean H_{top} equaled 15.1 m (±1.57), 14.6 m (±0.32), 16.4 m (±1.27) and 16.8 m (±1.55) for altitudinal class 850, 900, 950 and 1000, respectively. Overall H_{top} for the entire area two was 15.7 m (±0.63) on average. Mean H_t ranged from 9.4 m (±0.38) in altitudinal class 900 to 10.9 m (±0.71) in altitudinal class 1000. For the entire area two, average H_t resulted in 10 m (±0.28). Mean H_c in area two equaled 5.0 m (±0.20).

With regard to mean H_{top} along the altitudinal gradient (Fig. 36), means tend to increase with increasing altitude from altitude class 900 onward. However, differences were marginal and could not be statistically approved. This observation holds equally true for H_t and H_c.

As altitudinal class presents a rather absolute measure and fails to categorize well, if the rather small category sizes and susceptibility of altitude readings to distorted GPS signals are considered, investigation of variables of a more relative nature to classify stands, i.e. position on slope, which adapt more precisely to present topographic features might be futile.

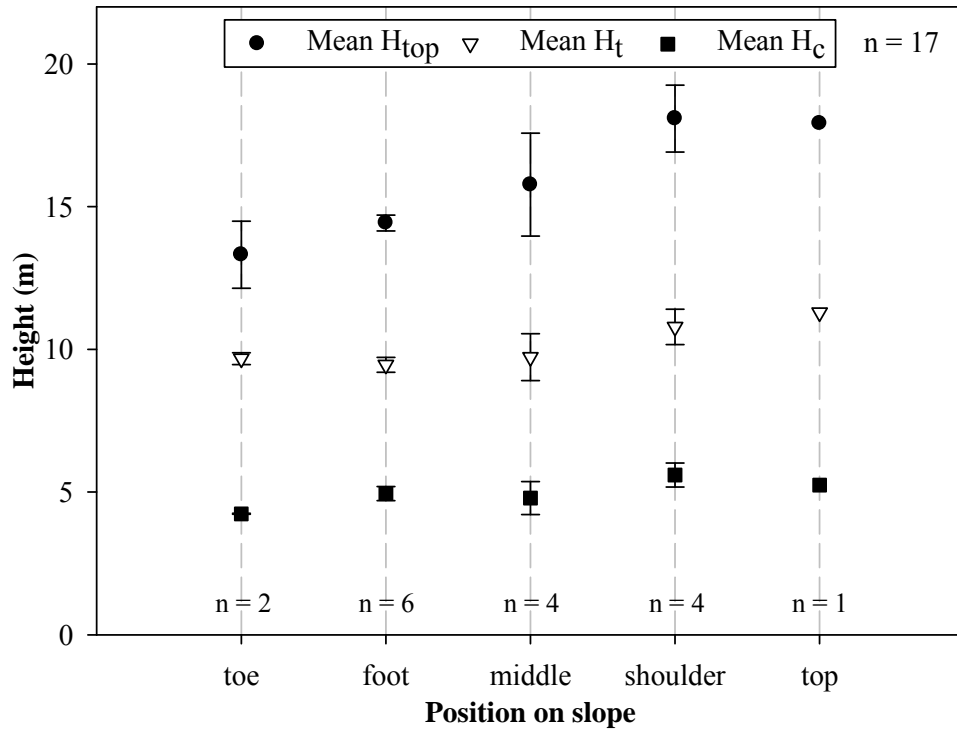Hence, means of H_{top}, H_t and H_c were compared according to position on slope (Fig. 37).

Figure 37: Mean values of tree height with respective standard error, according to position on slope in area two.

Obtained values for H_{top} ranged from 13.3 m (±1.17) at the toe of the slope and steadily increased until reaching the shoulder, where average top height was 18.1 m (±1.17). On the top of the slope, observed H_{top} resulted in 17.9 m.

Regarding average H_t per position on slope, a similar trend can be observed with the exception that the mean value slightly decreased from 9.7 m (±0.21) to 9.5 m (±0.26) between toe and foot of the slope. However, the observed augmentation of total height corresponding to position on slope continued up to the top where H_t equaled 11.3 m.

Mean H_c per position on slope followed a similar trend but far less cohesive. As displayed in figure 37, mean crown height ranged from 4.2 m (±0.02) at the toe of the slope to 5.2 m at the top of the slope. Decline of mean H_c at the middle is marginal (from 4.9 m (±0.25) at the foot to 4.8 m (±0.58) at the middle). The maximum value of mean H_c is realized at the slope's shoulder, where it equaled 5.6 m (±0.42).

Although differences in stand means at different positions of slope could not be verified to be statistically significant, some major trends can be observed (Fig. 37). Mean H_{top} tends to increase with increasing height of position on slope until reaching the top where H_{top} is slightly lowered. The same trend can be observed for mean H_t and H_c. Unfortunately, the position on top of the slope is represented by one sample plot only, which inhibits the derivation of means and thus might possibly lead to unclear results, regarding this category.

3.3.3.2 Qualifying stand parameters in area two

Distribution of qualifying parameters referring to tree stem and tree vitality, within different altitudinal strata were compared (Tab. 17).

Table 17: Mean stand parameters for four altitudinal strata in area two.

Altitudinal class	850 m (n = 5)		900 m (n = 4)		950 m (n = 5)		1000 m (n = 3)	
Variable	Mean	Std. error	Mean	Std. error	Mean	Std. error	Mean	Std. error
stem quality total (1 – 6)	3.31	(±0.18)	3.61	(±0.27)	3.68	(±0.25)	3.02	(±0.39)
Altitudinal class	**850 m** (n = 4)		**900 m** (n = 4)		**950 m** (n = 4)		**1000 m** (n = 3)	
stem quality of commercial species (1 – 6)	2.63	(±0.40)	2.48	(±0.20)	2.3	(±0.12)	2.54	(±0.27)
vitality of commercial species (1 - 3)	1.63	(±0.10)	1.60	(±0.06)	1.55	(±0.23)	1.86	(±0.12)

Although no statistically significant differences between groups means were identified means of stem quality and vitality were examined closely as they represent a valuable parameter for site quality classification with regard to timber production. Average commercial stem quality in the entire area two equaled 2.5 (±0.12), whereas mean vitality of commercial species averaged 1.64 (±0.07). Differences in mean vitality of all tree species were so marginal that they were not displayed, as they further did not allow for identification of any major trend. Mean values of vitality of commercial species however, indicated an overall decreased mean vitality of species that produce valuable timber in altitudinal class 1000.

Considering the distributions of qualifying parameters, namely total stem quality and stem quality of commercial species only (Tab. 17), stem properties of all species in altitudinal classes 900 and 950 are generally poorer than on other sites and range between intermediate and poor on average. In contrast, stems of commercial timber are of better quality in these two strata, ranging between good and intermediate. However, differences were of little account and covered ranges remained basically the same in all four altitudinal classes.

Further, mean slenderness of trees seems to increase with altitude, although differences between means in altitudinal class 850 and 900 were marginal (Fig. 38). However, as mentioned above, degree of variability of the estimates at the highest elevation is considerably high.
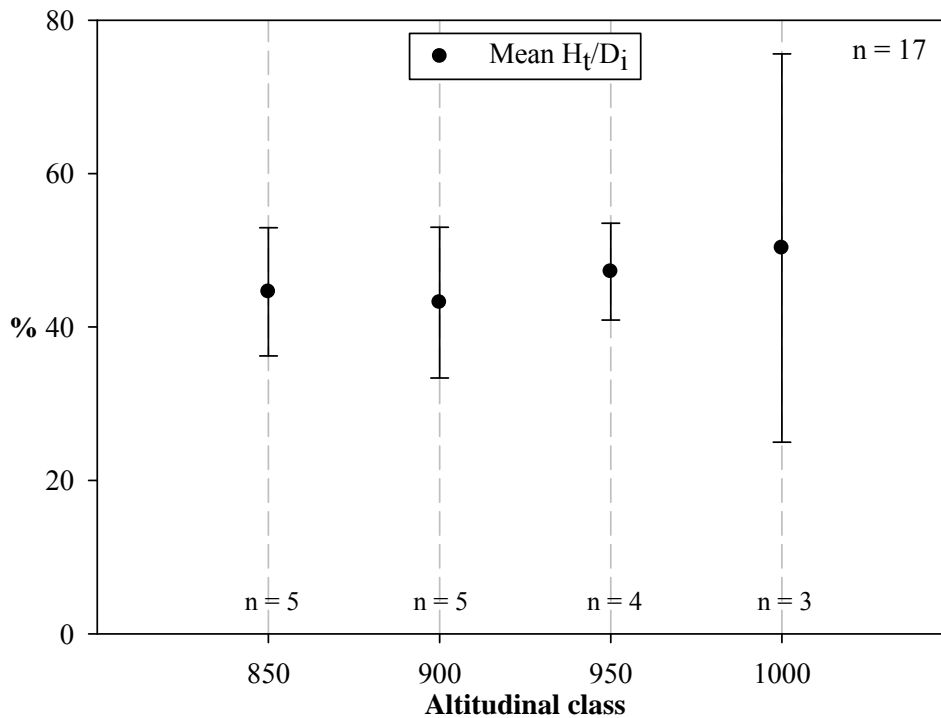
Figure 38: Mean values of tree slenderness with respective 95% confidence intervals, according to altitude class in area two.

Mean slenderness of trees seems to increase with altitude in area two of *FPC*. However, the applied ANOVA did not indicate significant differences of means between any of the classes. At the lowest altitude, mean slenderness resulted in 44.6% (±3.0) and slightly declined at the next higher altitudinal class, where a mean slenderness of 43.2 (±3.1) was observed. Thereafter, H_t/D_i increases with increasing altitude, ranging from 47.2% (±2.3) to 50.3% (±5.9) in altitudinal class 950 and 1000, respectively. Overall mean for all altitudinal classes equaled 46% (±1.6) in area two.

If mean slenderness of commercial species is scrutinized individually, only 15 plots enter the analysis (n = 15), because two plots did not host any commercial species at all. However, the observed trend resembles the one described above, ranging from 48.8% (±6.53) in altitudinal class 850 to 59.6% (±2.04) in altitudinal class 1000. On average, commercial tree species tend to display a slightly elevated degree of slenderness, as the overall mean resulted in 52.1% (±2.68) for the entire area two.

Although stand parameter distribution along the altitudinal gradient in area two indicated favorable growing conditions for tree species at higher altitudes, impact of harvest should be considered too. Surprisingly, percentage of stands in which vestiges of former harvest activities were recorded was highest in altitudinal class 1000. With a considerable share of harvested stands (67%) it surpassed well percentages observed in lower altitudinal

classes, where 20%, 0% and 20% of harvested stands were observed in altitudinal class 850, 900 and 950, respectively.

Qualifying stand parameters were further classified according to position on slope (Tab. 18).

Table 18: Mean stand parameters according to position on slope in area two.

Position on slope	toe (n = 2)		foot (n = 6)		middle (n = 4)		shoulder (n = 4)		top (n = 1)	
Variable	**Mean**	**Std. error**	**Mean**	**Std. error**	**Mean**	**Std. error**	**Mean**	**Std. error**	**Mean**	**Std. error**
stem quality total	3.6	(±0.17)	3.7	(± 0.2)	2.8	(±0.15)	3.6	(±0.24)	3.7	-

Position on slope	toe (n = 1)		foot (n = 5)		middle (n = 4)		shoulder (n = 4)		top (n = 1)	
Variable	**Mean**	**Std. error**	**Mean**	**Std. error**	**Mean**	**Std. error**	**Mean**	**Std. error**	**Mean**	**Std. error**
stem quality of commercial species	1.7	-	2.6	(±0.17)	2.5	(±0.33)	2.4	(±0.18)	2.8	-
vitality of commercial species	1.3	-	1.7	(±0.09)	1.7	(±0.10)	1.4	(±0.18)	2.0	-

In area two, overall means of stem quality and vitality of all species resulted in 3.4 (±0.13) and 2.1 (±0.05), respectively. Regarding commercial species only, mean values equaled 2.5 (±0.12) and 1.6 (±0.07) for stem quality and vitality, respectively.

Distribution of mean stem quality along different positions of slope does not follow any specific tendency (Tab. 18). However, if commercial species are considered only, mean stem qualities between excellent and good are observed at the lowest position, whereas on top of the slope mean stem quality is lowest. On intermediate positions on slope mean stem quality of commercial species ranges from good to intermediate, but even fewer samples enter the analysis and the above mentioned position (toe and top) are represented by one plot only. Thus, mean values could not be calculated and comparability of the estimates must be deemed as dubious.

Further, mean slenderness of commercial trees on different positions on slope was investigated in area two (Fig. 39).
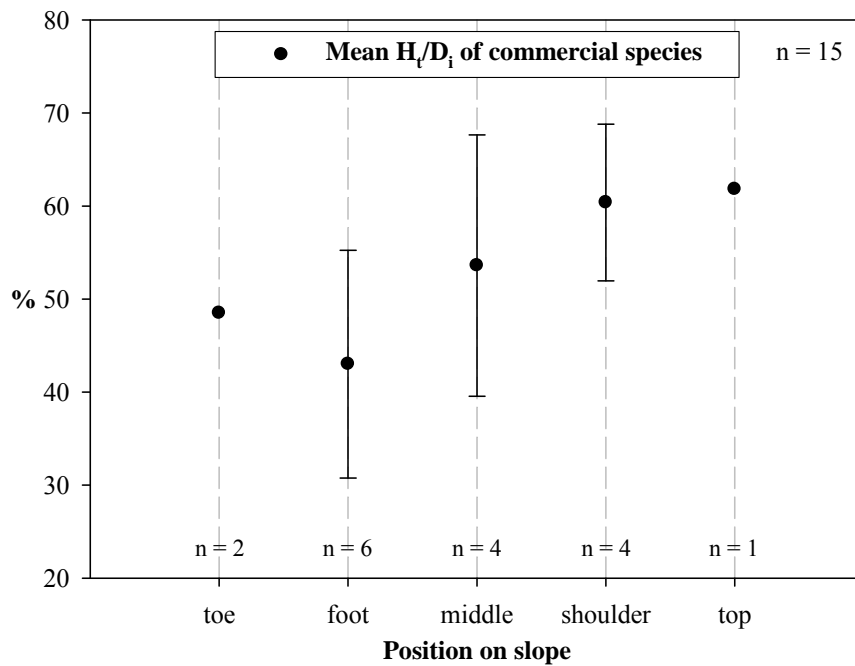
Figure 39: Mean slenderness of commercial species with respective 95% confidence interval, according to position on slope in area two.

Mean values of H_t/D_i for commercial species ranged from 43% (±4.42) at the foot of the slope to 61.8% at the top. On average, overall slenderness of commercial species equaled 52.1% (±2.68) in area two. Hence, disregarding the values calculated for toe and top position on slope, trees tend increase in slenderness along different positions upslope, describing an almost linear gradient.

In order to evaluate the above discussed findings accordingly, influence of harvest on the respective group means should be considered. At the toe of the slope the percentage of plots that showed remnants of previous harvest activities equaled 0%. Percentage of harvest steadily increased with increasing height of position on slope, resulting in 20%, 25% and 50% for positions at foot, middle and shoulder of slope, respectively. Although, the single one plot situated on top of the slope did not show any signs of former harvest activities, it should be kept in mind that skidding roads can often be observed on the top of major slopes in *FPC*, as the flat surface found here allows for an easy extension of a road network. Hence, timber extraction is most likely to have impacted stand structures in the higher positions on slope.

3.3.3.3 Canopy and crown parameters in area two

Only few stand parameters displayed decisive trends when compared according to slope class. Within group variability was very high in most cases and impeded proper identification of unambiguous tendencies. Surprisingly, maximum values with extremely broad confidence intervals were calculated for the intermediate slope class (21% - 30%) in most cases.

Distributions of means of crown and canopy parameters were examined and plotted according to different site categories (Fig. 40).
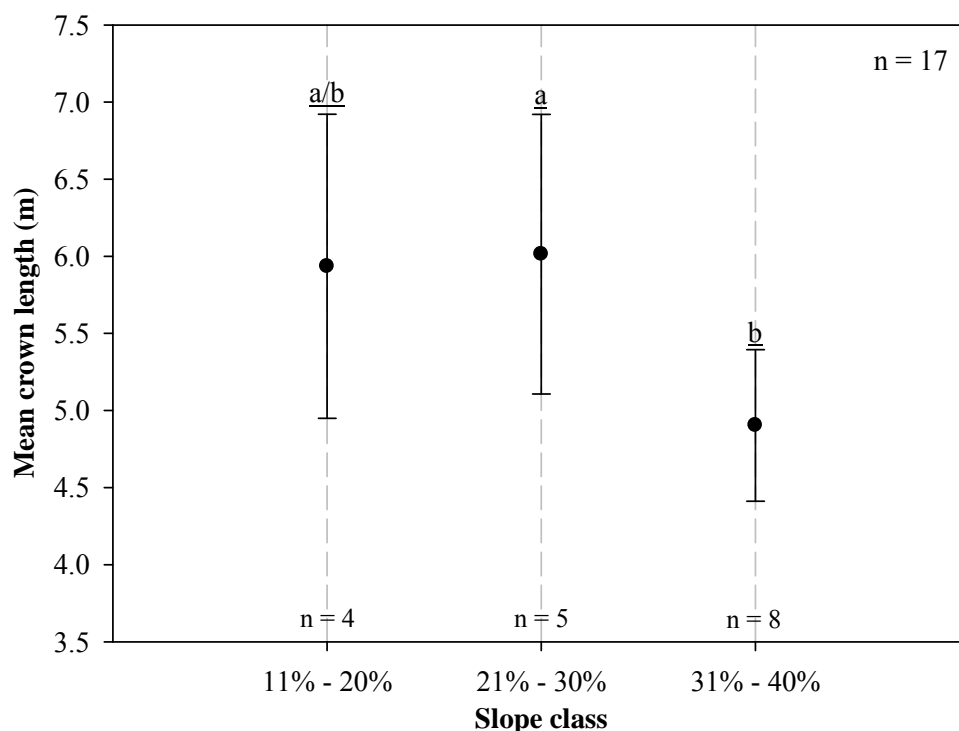
Figure 40: Mean crown length (m) with respective 95% confidence intervals in different slope classes in area two. Mean values that share the same letter are not significantly different for p ≤ 0.05.

The respective ANOVA yielded an indicative result regarding significance of differences between group means with p = 0.0013. The *post hoc* test identified mean crown length observed in slope class three (31% - 40%) to be significantly different from means present in slope class two (21% - 30%) for $p \leq 0.05$. Mean crown length in slope class one (11% - 20%) and two resulted in 5.9 m (±0.31) and 6.0 m (±0.33), respectively. The differing average crown length observed in slope class three equaled 4.9 (±0.21). Hence, average crown length seems to decreases with increasing slope gradient indicating that trees vertically extend their crowns according to inclination. Overall mean crown length for area two was 5.5 m (±0.2).

3.3.4 Stand parameter distribution in directed plots of Cedrela spp.

To determine growing conditions of each sample tree, respective stand parameters obtained in eight allocated plots were analyzed (Tab. 19).

Table 19: Descriptive statistics of tree data obtained at eight directed plots

Statistics	D_i (cm)	H_t (m)	H_c (m)	G_i (m²)	V_c (m³)	Stem quality	D_c (m)	Vitality	Social position
Total tree data set for directed plots (n = 246)									
Minimum	10	2.5	1.2	0.008	0.008	1	1	1	1
Maximum	84	25.3	14.6	0.554	2.907	6	19.4	3	5
Mean	25.3	12.3	5.8	0.066	0.293	3.2	6.3	2.0	2.7
Std. error	0.91	0.31	0.18	0.00	0.03	0.07	0.22	0.04	0.08
Std. deviation	14.27	4.91	2.79	0.08	0.42	1.14	3.47	0.70	1.22
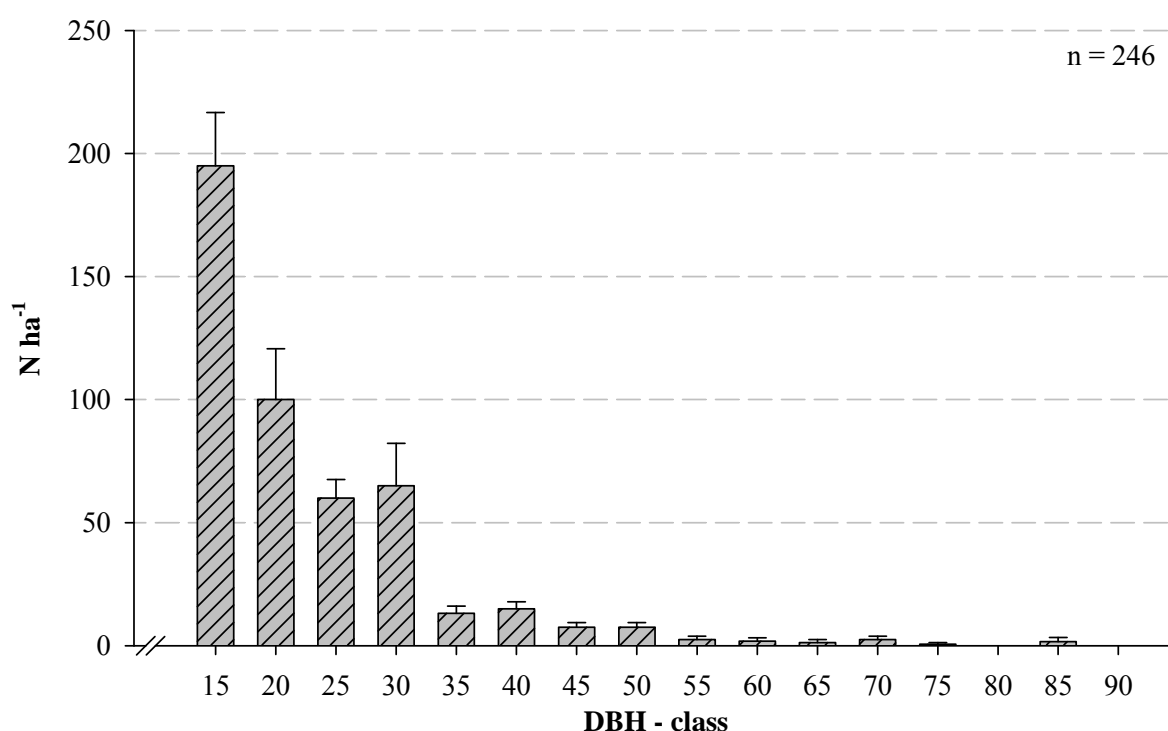
Figure 41: Mean diameter distribution in allocated plots of Cedrela spp.

Diameter distribution in plots allocated to the eight target species of *Cedrela spp*. (Fig. 41) closely resemble the distribution observed for area two (Fig. 30), with the exception that in the former no major diameter classes are missing, although 60% of the plots showed signs of previous harvest activities.

If compared to stand characteristics in area one and two (Tab. 10), it can be seen that the allocated plots surprisingly present a lower mean H_c, whilst most of the other stand variables (i.e. N ha^{-1}, G, H_{top}, etc.) were elevated as expected, due to the different sample selection procedure.

50% of all plots were located at the warmer expositions west and north, whereas 62.5% were situated at the shoulder of present slopes. With regard to species composition in terms of

N ha^{-1}, it was observed that 50% of the stands were dominated by *A. colubrina*, 12.5% by *Ocotea spp.* and 37.5% by species that could not be identified. With regard to co–dominant species, *P. excelsa* and *Ocotea spp.* accounted for 50% of all allocated sample plots. Furthermore, *E. uniflora* was recorded in 87.5% of all sampled plots, whilst just about equally frequent were *P. excelsa* and *P. americana* (75%).

Consequently, the specific site classes assigned in chapter 3.2.5 were compared with regard to mean stand parameters. Few variables displayed coherent trends. However, slope gradient and mean estimated VAI$_{True}$ displayed significant differences between site classes according to the ANOVA (Fig. 42; Fig. 43).

Figure 42: Mean slope gradient (%) according to site class, with respective standard error. Mean values that share the same letter are not significantly different for p ≤ 0.05.

The corresponding ANOVA generated a p-value of 0.001 for differences of mean slope gradient between the three site classes. The mean value for site class I was 1% (±1.0). For site classes II and III, slope gradients equaled on average 35% (±3.78) and 36% (±0.88), respectively.

Mean values concerning canopy parameters were about equally distributed with the exception of trees number one and eight, which showed comparably scattered canopy structure, whilst the latter displayed rather dense canopy closure. Percentage of gap fraction ranges from 4.6% (tree number eight) to 33%, and yielded a mean of 22.7% (± 2.88). LAI$_{True}$ estimates and calculated crown coverage ranged equaled 4.5 (± 0.24) and 1.4 (± 0.11), respectively.
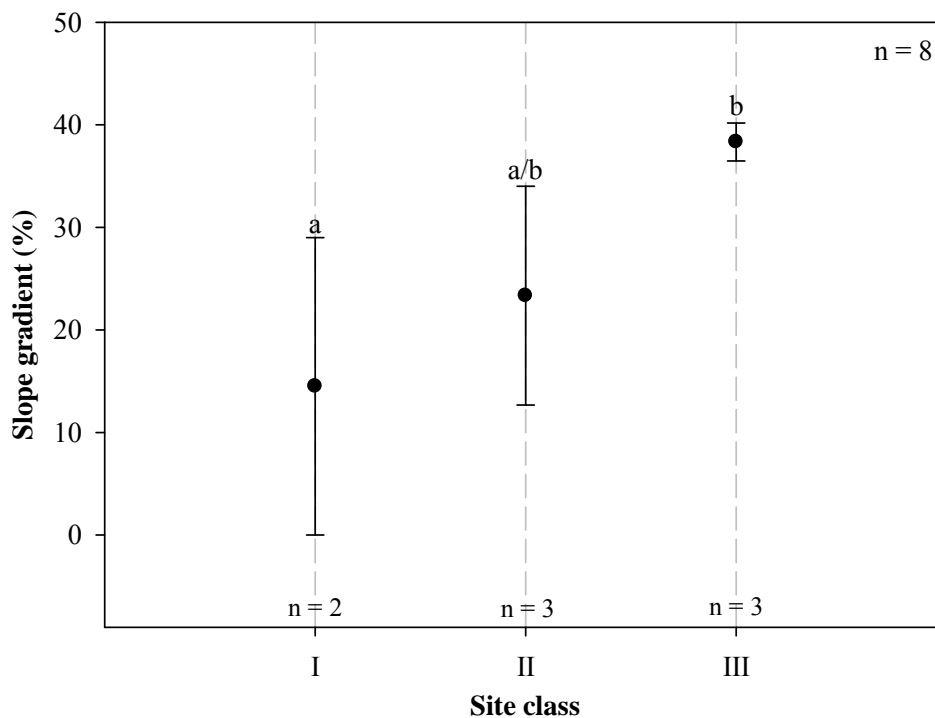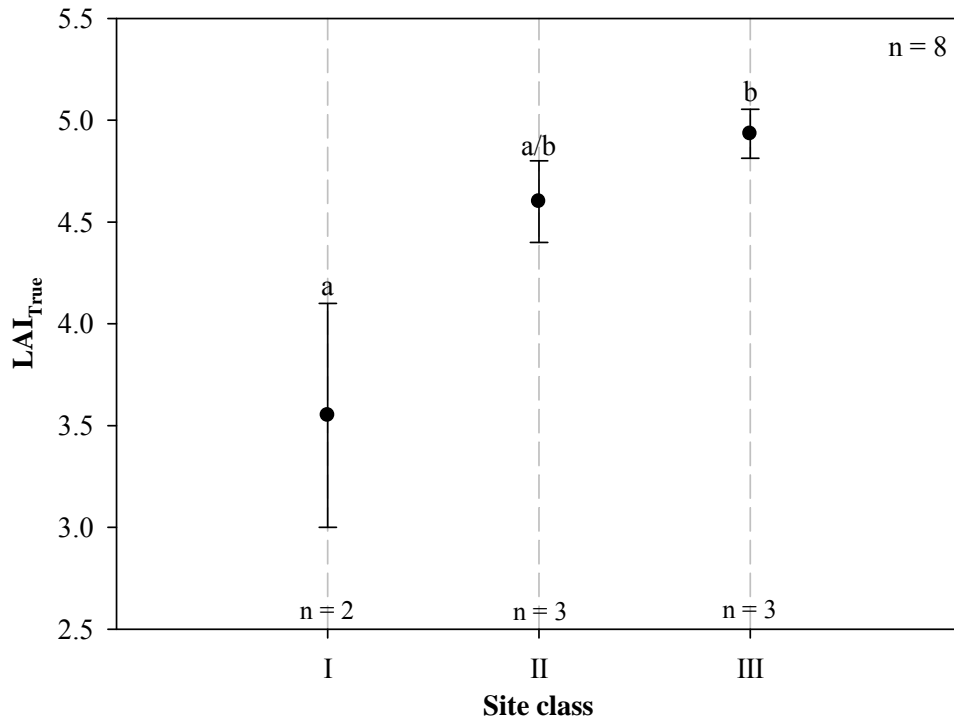
Figure 43: Mean LAI$_{True}$ according to site class, with respective standard error. Mean values that share the same letter are not significantly different for p ≤ 0.05.

The obtained p-value for differences of means between different site classes equaled 0.042. Therefore, differences of mean LAI$_{True}$ between different site classes can be regarded as statistically significant for $p \leq 0.05$. Mean value of LAI$_{True}$ resulted in 3.5 (±0.55), 4.6 (±0.20) and 4.9 (±0.12) for site classes I, II and III, respectively. Average LAI$_{True}$ for all eight sampled plots equaled 4.5 (±0.24).

Grau (2000) observed that growth of *Cedrela lilloi* was highly dependent on large scale canopy openings and therefore characterized this species as gap opportunist. This corresponds to the observed influence of existing LAI$_{True}$ on site quality for growth of *C. lilloi*, as stand history of the individuals constituting the respective site class (Fig. 43) suggests recent canopy openings as a result of previous harvest activities.

Therefore, silvicultural intervention should adapt accordingly and apply gap-based approaches, not only to promote growth of *Cedrela spp.*, but further with regard to natural regeneration in order to maximize production and recruitment and ensure sustainable management of this valuable timber species.

3.3.5 Species

In total, 49 tree species were identified, but 21.5% (216 trees) could not be identified in the field, these were combined and labeled as *not identified*. A complete list of all species observed more than 3 times in the entire sampled area is given in the appendices.

Distribution of basal area according to species was calculated and respective percentages are given in the following figure (Fig. 44) for area one and area two, respectively.

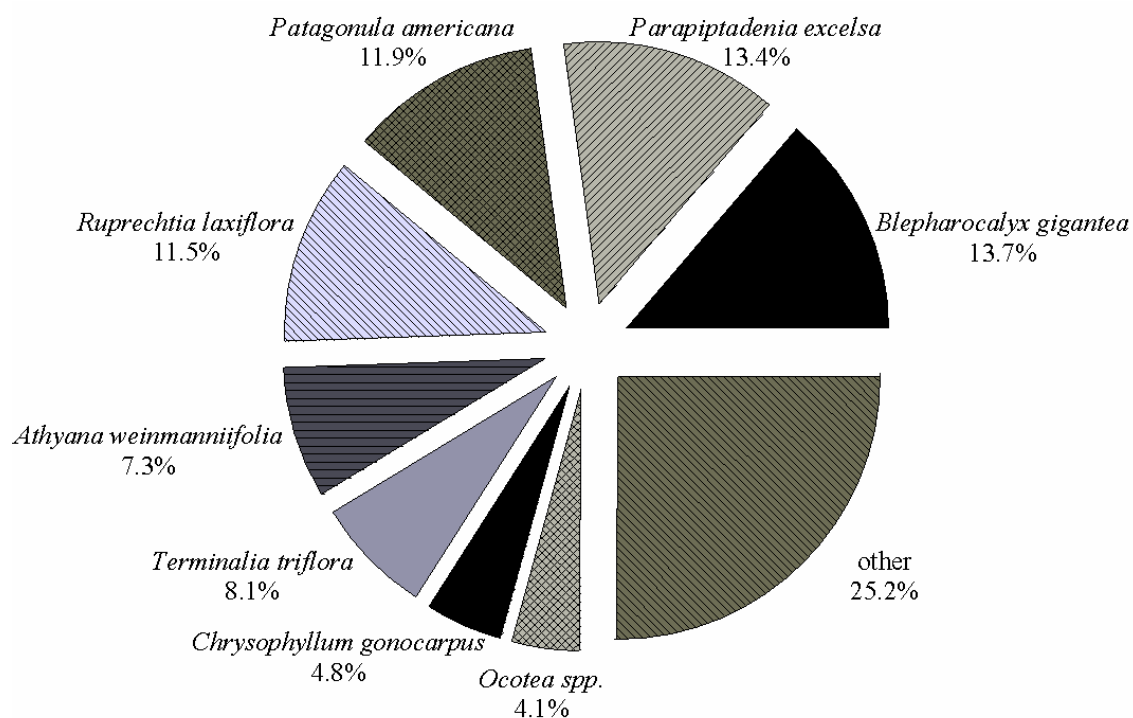*Figure 44: Mean percentage of G ha^{-1} according to tree species in area one (only species with shares of G ≥ 3% are included).*

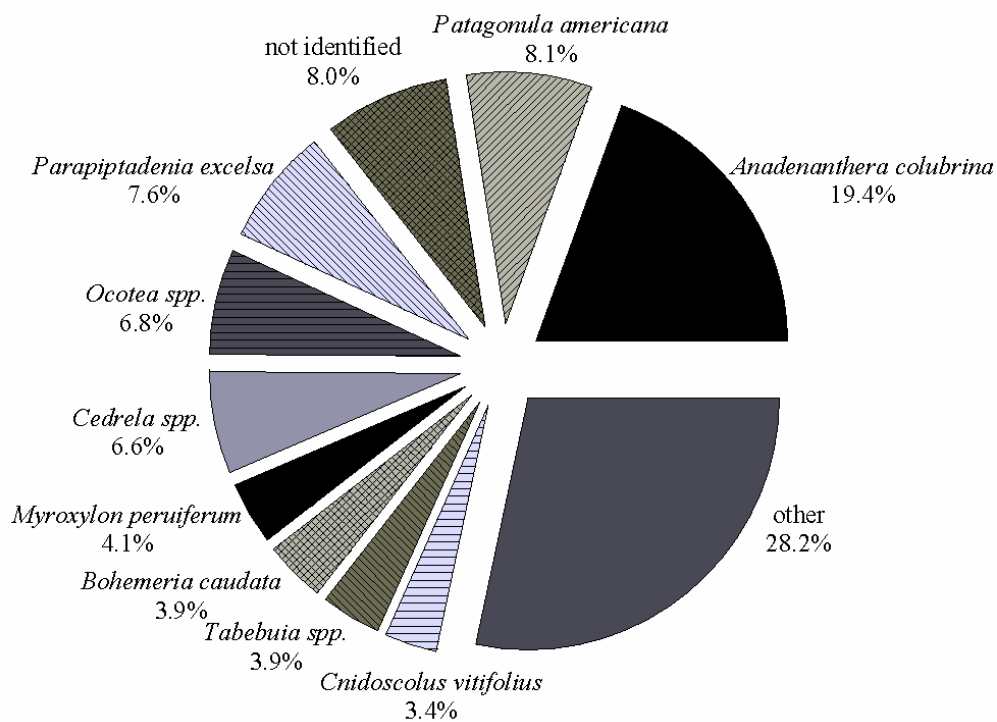*Figure 45: Mean percentage of G ha^{-1} according to tree species in area two (only species with shares of G ≥ 3% are included).*
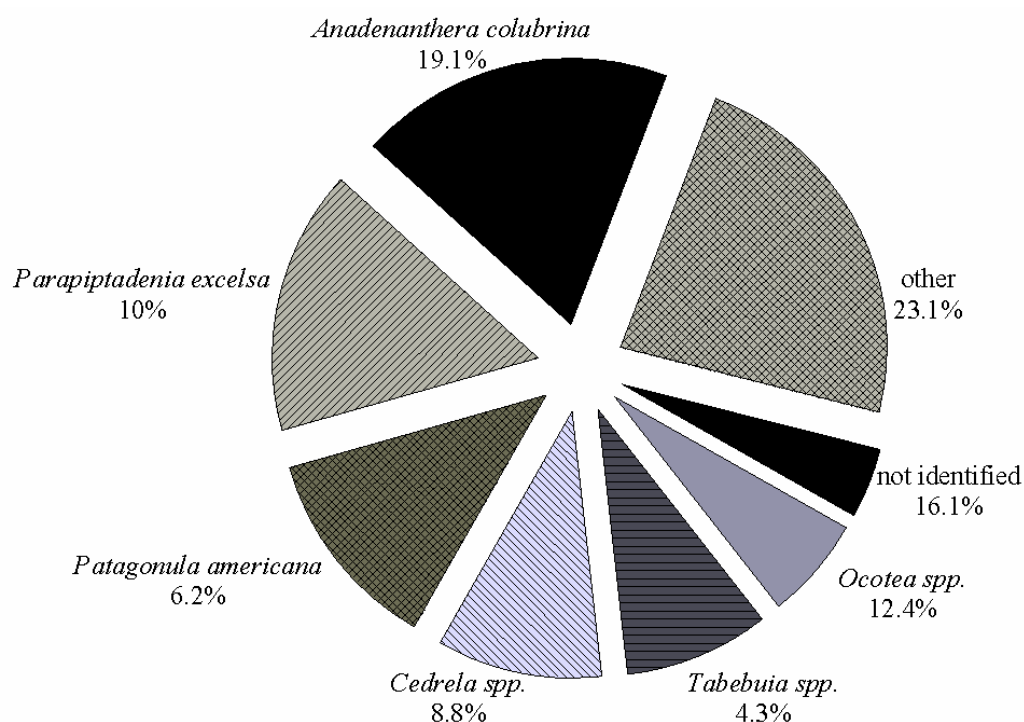
Figure 46: Mean percentage of G ha^{-1} per tree species in allocated plots of Cedrela spp. (only species with shares of G ≥ 3% are included).

As seen in figures 44 and 45, species distribution in the two areas differs to some extent. In area one, shares of commercial species sum up to 45% with 4 species present among the dominant species (with shares >3%), whereas in area two commercial species account for 50% and include six species. In contrast, shares of commercial G summed up to 50.9% of the total basal area and included eleven species in the eight allocated plots sampled around individuals of *Cedrela spp.*

With regard to species diversity based on absolute numbers of observations, it can be reported that overall 36 species were observed in area one at a corresponding sampling area of 1.1 ha, whilst merely 30 species were recorded in a total of 1.7 ha of total sampled surface in area two. These findings underline the common assumption that species richness can increase in secondary forests as the altered structural diversity fosters niche occupancy by pioneers (Pinazo et al., 2002; Kappelle et al., 1996). However, values refer to absolute number of observation and might therefore not be comparable offhand.

3.3.5.1 Species distribution according to site categories

Examining tree species distribution within various site categories allows for identification of certain trends with regard to species compositions and thus may be applicable for silvicultural planning. Common to all category comparisons was the strikingly high share of not identified species. In total, these account for 21.4% of all randomly sampled G. Although a complicated

matter, with regard to the naturally existing high species diversity in the area, proper identification of more than only about one fifth might lead to augmentation of value for the entire area, provided potential fields of usage exist or are know.

Total G calculated per site category was subdivided into shares per species (%) to examine species distribution on different sites and identify certain trends of possible formation of distinct communities (Tab. 20).

Table 20: Mean percentage of G ha^{-1} according to species in three altitudinal strata in area one (all species with share of G $\geq$ 2% are included).

Altitudinal class	800	850	900
Species	(%)	(%)	(%)
Allophylus edulis	6.8	6.9	-
Anadenanthera colubrina	-	8.4	-
Athyana weinmanniifolia	12.3	25.9	-
Blepharocalyx gigantea	8.7	4.5	5.0
Chrysophyllum gonocarpus	-	5.8	4.2
Cordia trichotoma	-	-	4.3
Eugenia uniflora	25	9.2	34.7
Fagara naranjillo	-	-	2.3
Ocotea spp.	9.9	8.3	20.1
Parapiptadenia excelsa	-	4.5	5.6
Patagonula americana	13.1		6.4
Ruprechtia laxiflora	13.1	9.5	4.9
Solanum riparium	-	-	2.4
Terminalia triflora	-	12.0	-
not identified	11.1	5.0	10.2
Total	**100**	**100**	**100**

With regard to mean species distribution in three altitudinal classes in area one, it can be observed that merely four out of fifteen species (27%) attain relevant shares of G (% $\geq$ 2) on all altitudinal levels (*B. gigantean*, *E. uniflora*, *Ocotea spp.* and not identified).

Mean percentage of G of commercial species sums up to around 26%, 30% and 21% for altitudinal class 800, 850 and 900, respectively. Mean number of relevant species at the lowest elevation is surpassed by respective numbers in the two higher elevated areas, where in both cases eleven species bear relevant shares of G. Regarding mean number of observations, it was found that the amount of observed species increases with altitudinal gradient, ranging from 5.5 species per plot (class 800) to 6 species per plot (class 900). These findings correspond to the observation of increased presence of shade tolerant species (e.g. *B. gigantea, A. edulis*) in the lower and intermediate altitudinal classes, whereas higher percentages of G are constituted by pioneers (e.g. *P. excelsa, T. triflora*) in the highest altitudinal class, possibly indicating a rising severity of canopy disturbances due to previous harvest activities (Cpt. 3.3.2).

Additionally, species distribution according to average share of G (%) was scrutinized according to position on slope (Tab. 21). In contrast to area one, site categories were manifold

in area two. Therefore, species distribution according to altitudinal class was not investigated, since differences of elevation between altitudinal classes of only 50 m might be too small to properly allow for identification of trends regarding species composition.

Table 21: Mean percentage of G ha⁻¹ per species on different positions on slope (all species with share of G ≥ 3% are included).

Position on slope	toe	foot	middle	shoulder	top
Species	(%)	(%)	(%)	(%)	(%)
Acacia atramentaria	-	-	-	12.7	**-**
Allophylus edulis	-	-	5.6	-	3.8
Anadenanthera colubrina	7.0	15.0	25.9	29.2	56.8
Athyana weinmanniifolia	-	-	-	-	8.0
Bohemeria caudata	10.1	-	-	-	-
Cedrela spp.	-	6.3	3.0	7.4	6.3
Cnidoscolus vitifolius	-	3.4	-	-	-
Flaveria bidentis	3.4	5.8	-	-	-
Lonchocarpus lilloi	1.6	-	-	-	-
Ocotea spp.	25.5	12.4	12.4	-	-
Parapiptadenia excelsa	-	-	3.8	6.3	13.2
Patagonula americana	-	-	-	5.8	-
Pisonia ambigua	-	-	-	-	4.2
Pithecellobium scalare	-	4.3	-	-	-
Siphoneugena occidentalis	-	-	-	-	-
Solanum riparium	6.7	-	5.1	-	-
Tabebuia spec.	-	-	-	4.3	-
not identified	45.5	35.0	17.0	9.9	5.7
other	0.0	17.6	27.2	24.5	2.1
Total	**100**	**100**	**100**	**100**	**100**

Regarding species distribution along position on slope (Tab. 21) it can be observed that merely one species (*A. colubrina*) realized considerable shares of G along the entire slope. The portion of G constituted by commercial species increases with slope, maybe due to hindered accessibility. The toe of the slope is pretty much dominated by the not identified species group (46%), whilst *Ocotea spp.* accounts for 26%. From intermediate positions on slope onward (middle) *A. colubrina* realizes the highest shares of G. *Cedrela spp.* is entirely absent from the toe of the slope, but accounts for more or less equal shares of G at higher positions.

Table 22: Mean percentage of G ha^{-1} per species at different expositions sorted according to increasing solar radiation (all species with share of G ≥ 3% are included).

Exposition	south	east	flat	west	north
Species	(%)	(%)	(%)	(%)	(%)
Acacia polyphylla	-	-	4.4	-	-
Allophylus edulis	-	-	3.8	-	4.3
Anadenanthera colubrina	20.3	9.1	9.5	20.0	28.1
Athyana weinmanniifolia	-	-	-	-	-
Blepharocalyx gigantea	-	-	4.6	-	-
Bohemeria caudata	-	-	-	3.5	4.2
Cedrela spp.	3.9	3.2	-	6.3	7.2
Chrysophyllum gonocarpus	-	3.6	-	-	-
Cnidoscolus vitifolius	6.1	-	-	-	3.0
Cordia trichotoma	-	-	-	3.3	-
Eugenia uniflora	-	-	11.7	-	-
Fagara naranjillo	-	-	3.8	-	-
Flaveria bidentis	-	8.1	-	3.2	-
Lonchocarpus lilloi	-	5.8	-	-	-
Ocotea spp.	10.3	12.3	12.2	10.3	3.2
Parapiptadenia excelsa	-	-	6.1	4.1	9.3
Patagonula americana	3.0	-	5.2	-	3.9
Rapanea laetevirens	-	4.2	-	-	-
Ruprechtia laxiflora	-	-	4.8	-	-
Solanum riparium	-	4.9	-	-	-
Terminalia triflora	-	-	3.1	-	-
Tabebuia spp.	4.6	-	-	-	3.8
not identified	27.8	35.1	10.3	32.3	13.3
other	24.0	13.7	20.5	17.1	19.6
Total	**100**	**100**	**100**	**100**	**100**

In table 22, mean species distribution as percentages of G is displayed per exposition, sorted according to increasing solar radiation. Again, *A. colunbrina* accounts for considerable shares of G on all categories. The same holds true for *Ocotea spp.* and the species group that could not be identified. Generally, commercial species tend to increase their respective percentage of G with increasing amount of received radiation per site, as numbers as well as respective shares increase from flat positions onward. However, this observation could not be verified by other studies, as e.g. no statistically proven preference according to exposition was reported by Armada (2007).

Further, a fair number of species only yields considerable percentages of G at flat sites with no specific exposition, with the exception of *R. laxifolia* and *T. triflora*, these are all species of questionable timber quality. This can possibly be explained if the high degree of

depletion of valuable timber species in the predominantly flat area of *SNC* (area one) is considered.

Finally, species were grouped according to soil group on which they occurred. As distribution of investigated and classified soil profiles was limited, only plots directly adjoining the profiles were compared. As occurrence of *A. colunbrina* was limited on area one (fluvisol) its respective share of G was only marginal, whereas in stands referring to cambisol and leptosol, it can be regarded as the dominant species exceeding all other species in terms of mean percentage of G. The high share of *Cedrela spp.* is due to the fact that most plots were allocated to existing individuals of that species (Cpt. 2.2.3), leading to an over-representation in terms of basal area. Further, *Ocotea spp.* accounts for relevant shares of G one all soil groups, especially on leptosols. The high shares of *P piptadenia* in two of the three considered soil group might indicate a co-occurrence with *Cedrela spp.* (Tab. 23).

Table 23: Mean percentage of G ha^{-1} according to species for different soil groups (all species with share of G ≥ 3% are included).

Soil group	cambisol (n = 6)	fluvisol (n = 3)	leptosol (n = 1)
Species	(%)	(%)	(%)
Anadenanthera colubrina	25.9	-	33.6
Azara salicifolia	-	-	3.3
Blepharocalyx gigantea	-	22	-
Cedrela spp.	8.2	6.7	14.5
Chrysophyllum gonocarpus	-	3.5	-
Eugenia uniflora	-	8.4	-
Myroxylon peruiferum	3.5	-	-
Ocotea spp.	8.1	9.1	26.7
Parapiptadenia excelsa	12.6	15.7	-
Patagonula americana	6.2	4.5	-
Ruprechtia laxiflora	-	6.1	-
Tabebuia spp.	5.9	-	-
Tipuana tipu	-	-	3.7
not identified	12.5	11.1	14.2
other	17.1	12.9	4.0
Total	**100**	**100**	**100**

However, findings related to species composition on leptosols (n = 1) should be regarded with care, as drawing conclusions from observations based on one sample only is highly susceptible to random external factors. Nonetheless, some form of tendency might be identified and even if further studies remain for clarification. Detailed analysis of species composition by means of cluster analyses would go beyond the scope of this study.

3.3.5.2 Distribution of stem quality according to species

Subsequently, distribution of stem quality among species was examined to determine in detail major characteristics of stem formation per species. Only plots sampled by random distribution were considered for statistical reasons, as the combination of random and directed

samples would lead to blurred results (Kleinn, 2005). Further, only species represented by sufficient number of observations (n ≥ 3) were included in the comparison. Species that could not be properly identified in the field were also excluded from the comparison. Comparison was carried out separately for non-commercial and commercial species (Fig. 47; Fig.: 48).

Examining distribution of tree parameters according to species bears valuable information with regard to distribution of qualifying stand parameters and species performance in general. Investigating stem quality per species for example (Fig. 47), allows drawing inferences according to stem morphology and comparing means obtained by commercial species with values realized by other groups of tree species.
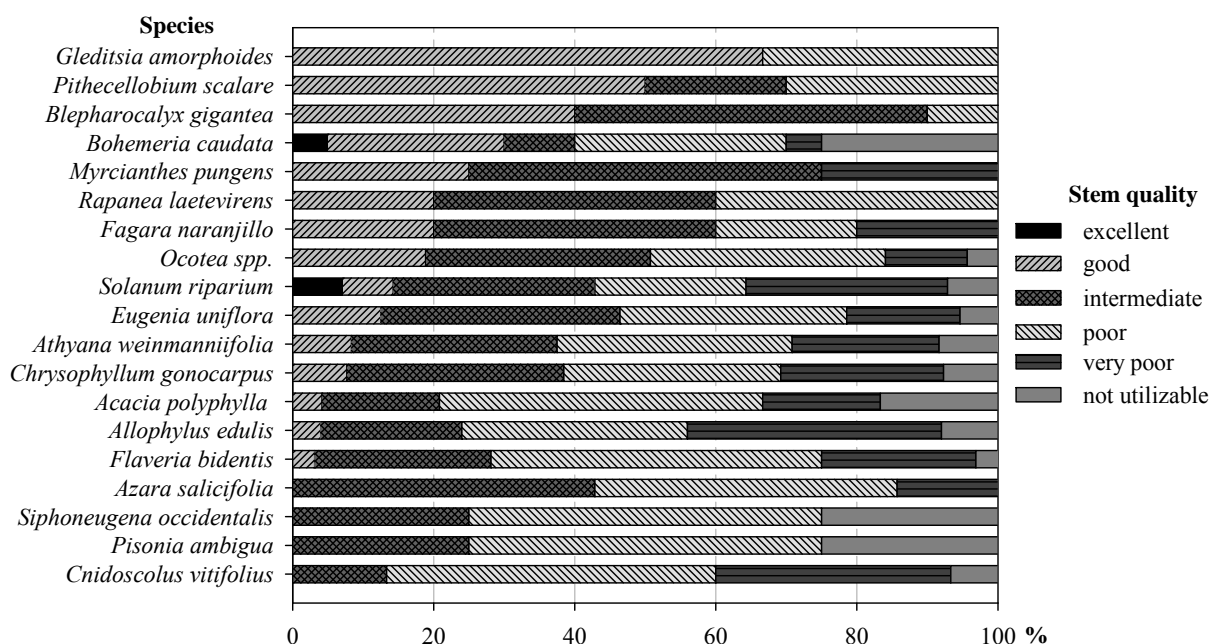

Figure 47: Distribution of stem qualities among non-commercial species (all species with n ≥ 3: n = 362).

Stem quality distribution for each non-commercial species (Fig. 47) can be divided into two groups. The first group incorporates species that display mostly good to intermediate stem qualities and stems with extremely poor (very poor and not utilizable) are usually absent. Species included in the second group are almost entirely missing in stem quality classes excellent and good.

If these findings are compared to stem quality distribution among commercial species (Fig. 48), a clear trend towards increased representation in better quality groups of the latter can be observed. *M. peruiferum* generally presents excellent to good stem qualities (80%), whereas for *T. triflora* only 25% constitute intermediate or better stem qualities. Only two commercial species are represented throughout the entire range of stem quality classes, namely *Cedrela spp.* and *C. trichotoma*. For detailed information per species about number of observation, mean stem quality etc., please refer to the appendices.
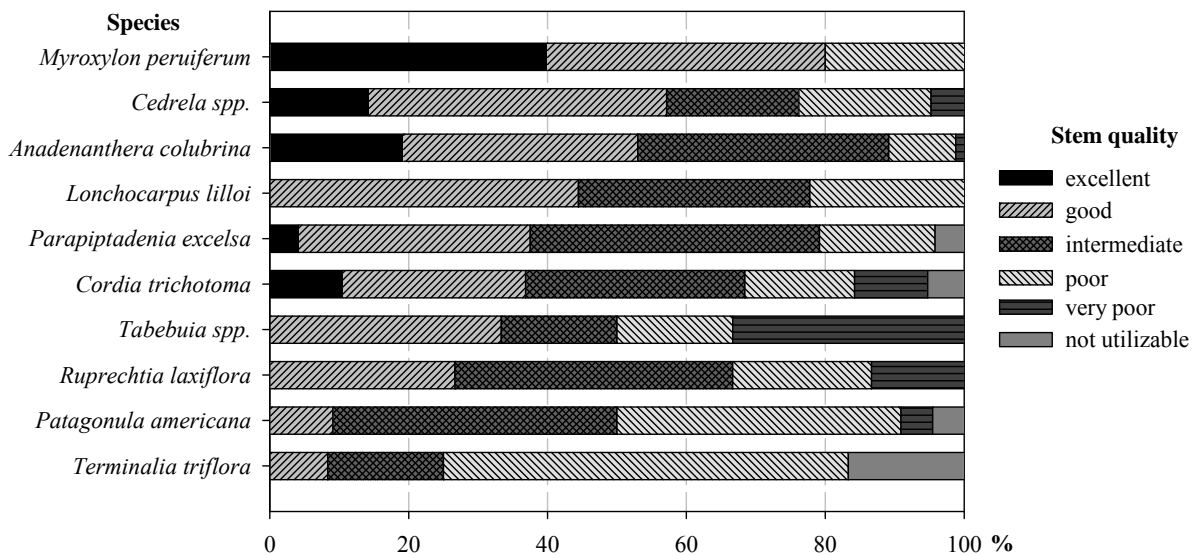
Figure 48: Distribution of stem qualities among commercial species (all species with n ≥ 3: n = 216).

3.3.5.3 Distribution of vitality according to species

Examining the distribution of vitality according to non-commercial and commercial species allows for detailed evaluation of overall growth performance per individual species in *FPC* (Fig. 49; Fig. 50). Regarding non-commercial species, a total of three species were never observed without damage (*C. vitifolius*, *S. occidentalis* and *P. ambigua*), whereas *M. peruiferum* did never display any damage and *R. laetevirens* and *B gigantea* were mostly only partly damaged.
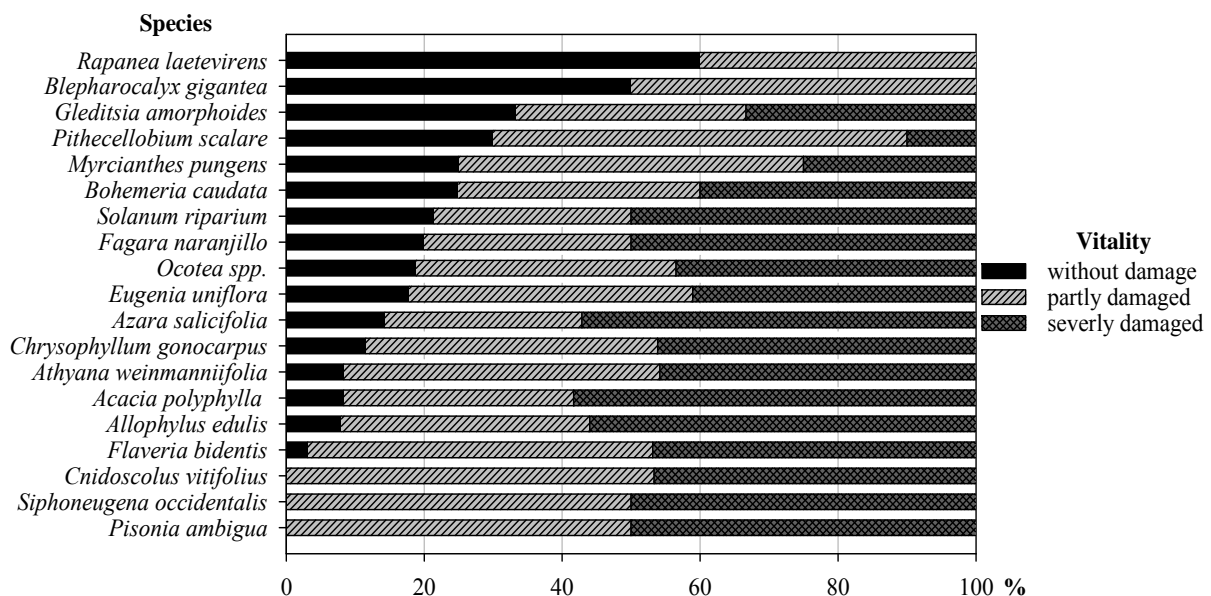

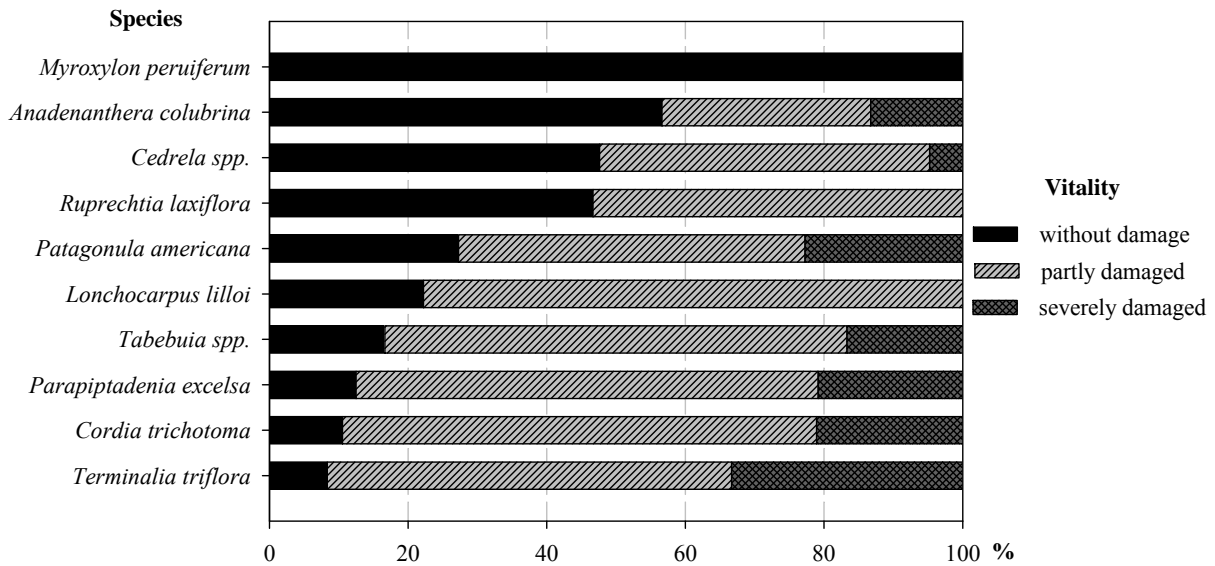*Figure 49: Distribution of vitality among non - commercial species (all species with n ≥ 3: n = 362).*

Figure 50: Distribution of vitality among commercial species (all species with n ≥ 3: n = 216).

Considering the possibility that different vitality classes are naturally distributed according to D_i of the sampled tree, as e.g. young trees are increasingly exposed to competition and no yet firmly established at a specific site (Otto, 1994), vitality distribution within DBH–classes was also investigated. Thus, to determine if existing autocorrelation between DBH–class and vitality might lead to inconsistent results, distribution of vitality among DBH–classes was compared. In contrast to previous figures and with regard to facility of inspection, DBH-classes were combined to classes of steps of ten cm, e.g. DBH-class 20 includes all trees with $10 \, cm \leq D_i \leq 19 \, cm$.
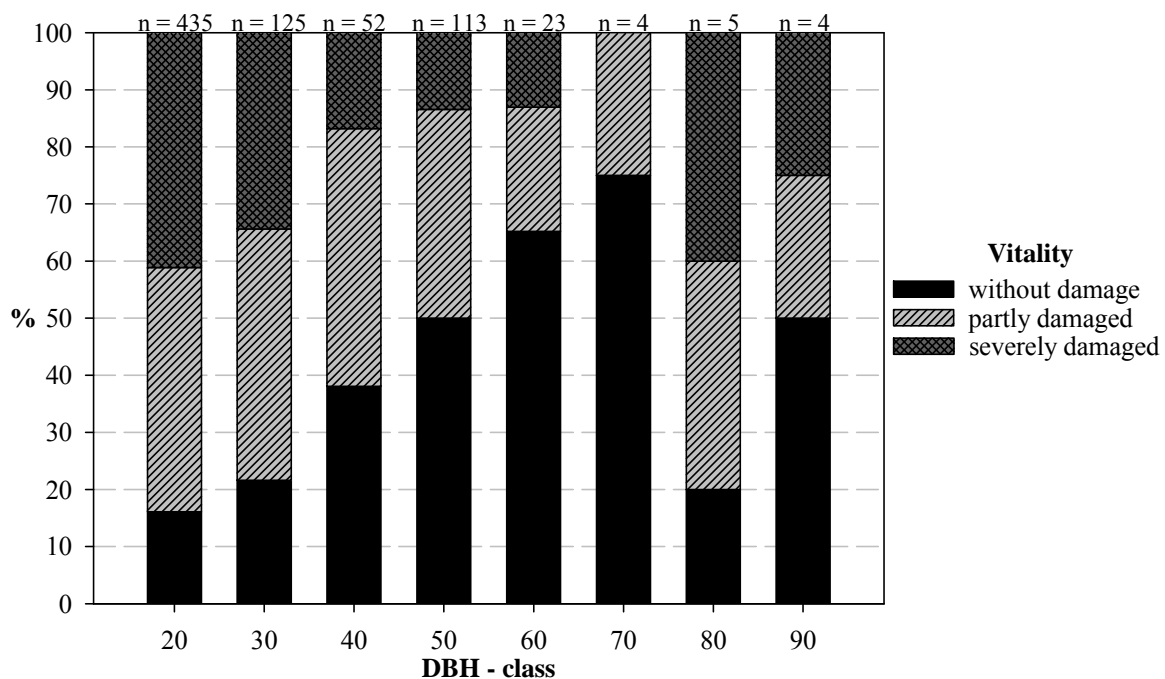

Figure 51: Distribution of vitality according to DBH–class for all trees (n = 761).

According to the assumption that vitality of trees in lower diameter classes is generally lowered, vitality distributions per DBH-class follow that certain trend as trees up to DBH-class 70 tend to display decreasing shares of damage (Fig. 51). However within the upper DBH-classes 80 and 90, respectively, shares of damaged trees sharply increase. Thus, judging vitality distribution for a specific species should be regarded in conjunction with mean DBH-class distribution of that specific species.

3.3.5.4 Distribution of social position according to species

Finally, distribution of social position (Cpt. 2.2.4.5) according to species was investigated and reviewed in detail (Fig. 52). In general, social position is valuable indicator for a species status in terms of a stand's vertical structure. Distribution of mean tree vitality within different social positions showed a clear trend (Appendices) and mean D_c displayed a similar trend. However, examining these relationships in detail would go beyond the scope of the on hand study.

Figure 52: Distribution of social position among non commercial species (all species with n ≥ 3: n = 362).

Three non-commercial species (*B. gigantean, P. scalare, R. laetevirens*) are by up to 60% represented in social position classes of 'open growth' or 'dominant' and can therefore be regarded as dominating species according to vertical stand structure composition. In contrast, species like *M. pungens, A. salicifolia, P. ambigua,* and *S. occidentalis* are entirely absent from the dominant social position classes and can therefore most likely be attributed to trees of the understory. Reviewing the D_i-H_t curves (Appendices) might give further insight on behalf of this observation. The only species represented in all social position classes are *Ocotea spp. S. riparium* and *A. weinmanniifolia.*
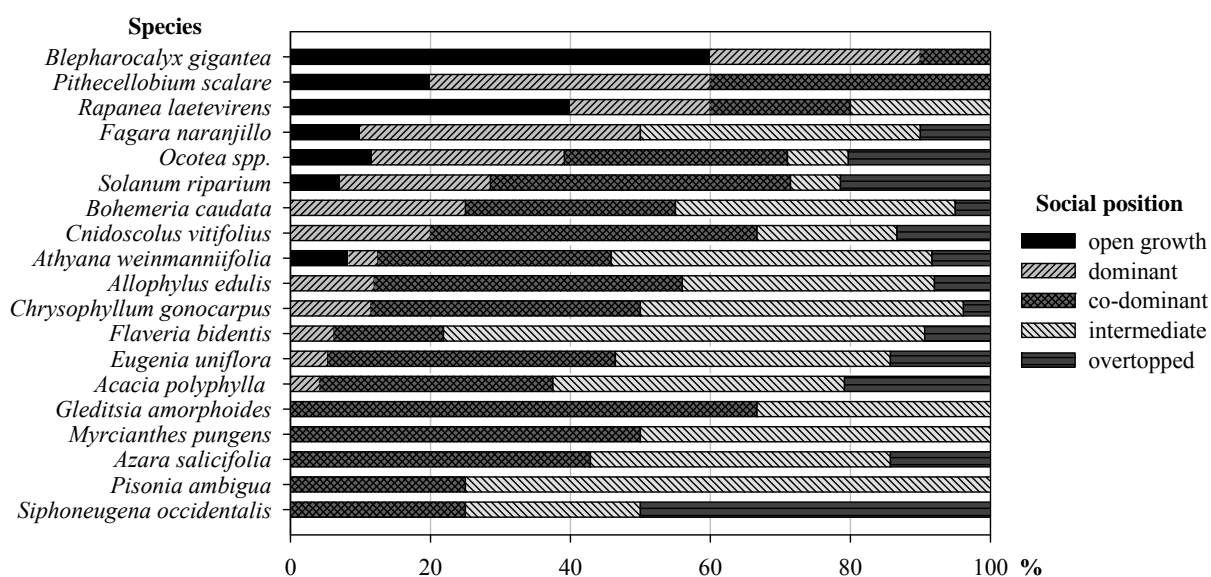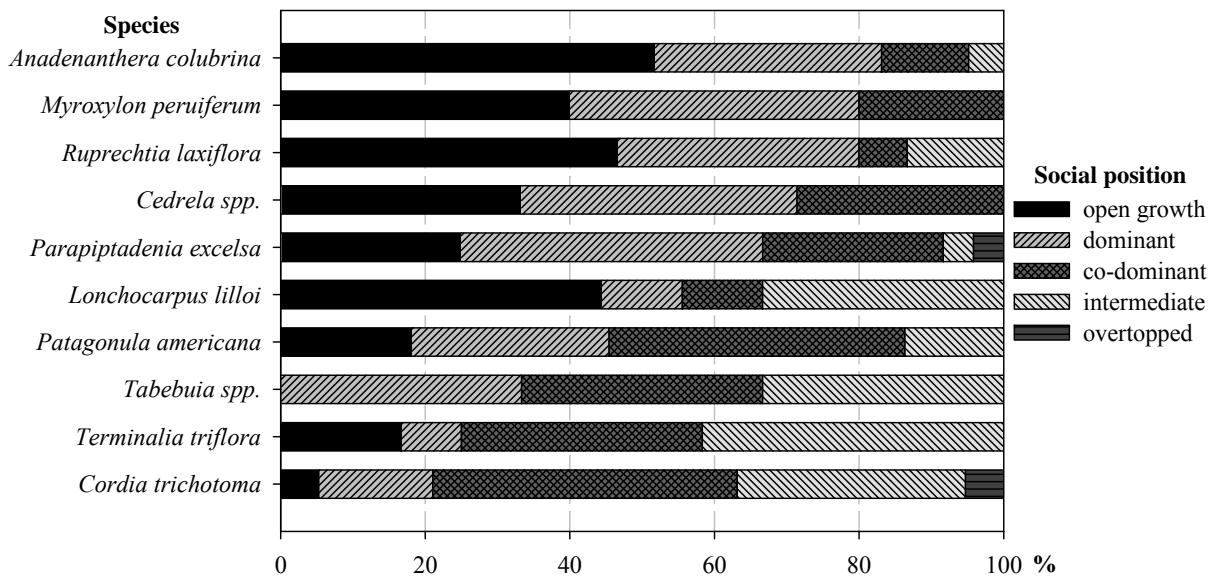
Figure 53: Distribution of social position among commercial species (all species with n ≥ 3: n = 216).

Among the commercial tree species (Fig. 53), *A. colunbrina*, *M. peruiferum* and *R. laxifolia* are clearly dominant, as up to 80% of all measured individuals of these species were attributed to upper social position classes. *Cedrela spp.* is about equally distributed in the upper three classes of social position. However, as the selected sample trees (entirely belong to classes 'open growth' and 'dominant') are also included, results regarding this species might be slightly blurred. *Tabebuia spp.* never seemed to reach status of 'open growth', whereas *C. trichotoma* is distributed among all social position classes.

Concluding, it can be stated that commercial species tend to be dominant with regard to vertical tree distribution within stands, as 80% of all commercial species were firmly established at upper social positions.

3.3.6 Natural Regeneration

In total, 432 saplings were sampled in area one and subsequently categorized according to site factors (Tab. 24).

Table 24: Descriptive statistics of natural regeneration in area one

Altitudinal class	800 (n = 3)		850 (n = 4)		900 (n = 5)	
Variable	Mean	Std. error	Mean	Std. error	Mean	Std. error
N ha^{-1}	23000	(±5252) a	17750	(±4854) b	15200	(±3437) c
N ha^{-1} of commercial species	1500	(±1258.3) a	625	(±239.4) b	1000	(±367.4) a
% commercial species	6.8	(±0. 73) a	3.5	(±0.72) b	5.9	(±0.69) a
mean vitality (1 − 3)	1.71	(±0.27)	1.66	(±0.19)	1.62	(±0.19)
mean vitality of commercial species (1 − 3)	1.44	(±0.44)	1.50	(±0.29)	1.67	(±0.24)

As shown above, differences in mean numbers of saplings per hectare were indicated as significant (p = 0.00001) for p ≤ 0.05 between the three altitudinal strata. Whereas distribution of commercial species within altitudinal classes in total numbers per hectare, as well as percentage only, significantly differed between altitudinal class 850 and 900 (p = .0001 and p = 0.005, respectively).

The highest number of saplings was observed in the lowest altitudinal class and decreased with increasing altitude, suggesting elevated growing conditions for natural regeneration in that altitudinal class.

However, distribution of mean vitality of saplings indicates that overall vitality is better in classes of higher elevation. This might be due to the increasing dominance of fewer species. In contrast, commercial species show a mean vitality which is highest in the class of 800, where sapling diversity is elevated and vitality of all species is lowest on average.

Subsequently, species distribution in three altitudinal strata was compared and is displayed in the following figures. To facilitate visual inspection, only dominant species with more than three observations per plot were included.
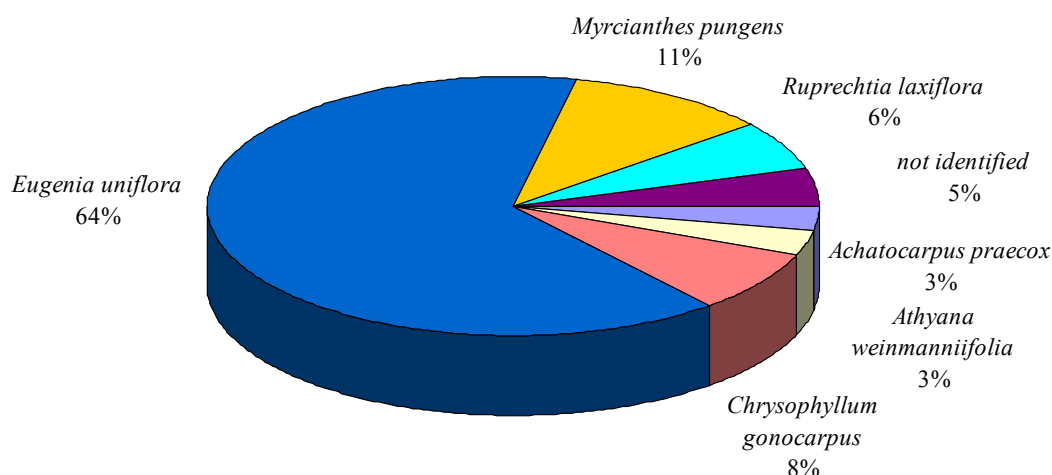
Figure 54: Tree species distribution of natural regeneration at altitudinal class 800.

At 800 m asl, species diversity was highest as saplings are represented by seven species in total (Fig. 54). Again, *E. uniflora* is highly dominant and its respective observations account for 64% of all dominant species. The second most frequently observed species is *M. pungens,* which accounts for 19% of the most common species in the lowest part of area one.

Figure 55: Tree species distribution of natural regeneration at altitudinal class 850.

In the intermediate part of area one (850 m asl), four species account for 93% of all observed species. *A. weinmanniifolia* is dominant with 44% of all species that were recorded at least four times. *E. uniflora* is also represented in this strata and accounts for 23% of the dominant species (Fig. 55).
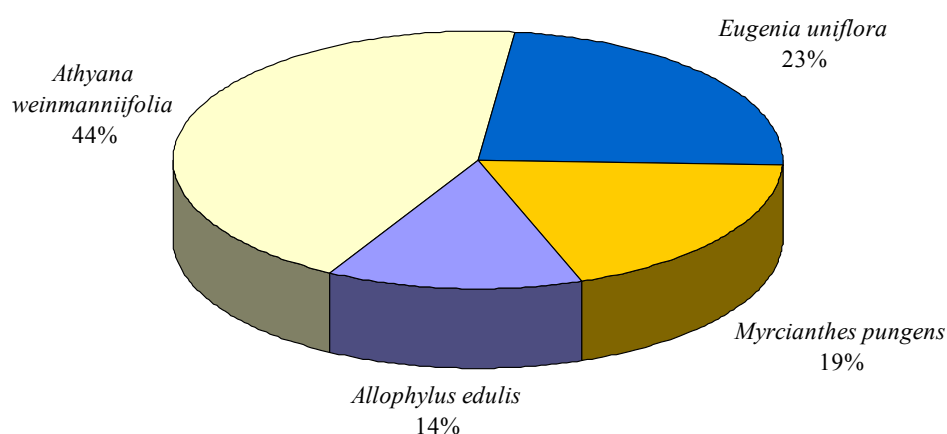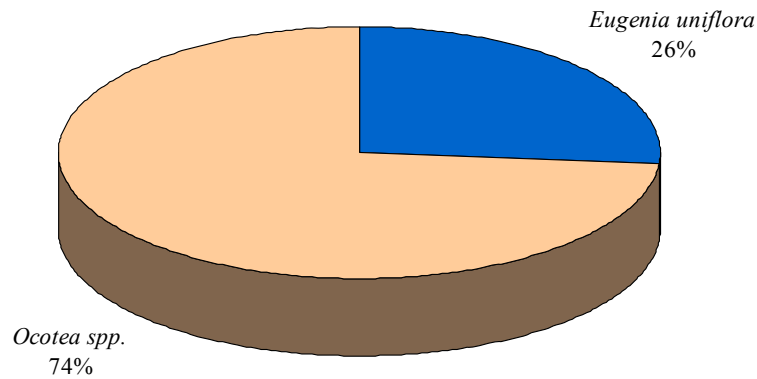
Figure 56: Tree species distribution of natural regeneration at altitudinal class 900.

At the highest elevation, the lowest diversity of saplings was observed. In altitudinal class 900 natural regeneration is strongly dominated by only two species, namely *E. uniflora* and *Ocotea spp.* (Fig. 56).

Composition of natural regeneration in three strata in area one varies not only in abundance but also in frequency of observed species. Frequency of species increases with decreasing altitude. In total, regeneration of commercial tree species in area one is minimal, accounting for only 5.3% in the entire area one (Tab. 24). The lowest share of juvenile commercial tree species was observed in the intermediate class of 850, with only 3.5%. Thus, enrichment plantings are highly recommended in area one, especially as this area showed an elevated site quality (Cpt. 3.1). Saplings of *Cedrela spp.* were only found in altitudinal classes 850 and 900, where total number of saplings per hectare accounted for 1.4% and 1.3%.

According to Grau (2000), *Cedrela lilloi* displayed a negative relationship with a large scale disturbances, which might account for its scarce abundance in the heavily logged forests of area one. He further recommends adapted silvicultural approaches based on canopy gap promotion to foster regeneration of *Cedrela lilloi* which can be regarded as gap opportunist. However, gaps resulting from harvest of individuals of *Cedrela lilloi* should be complemented by additional silvicultural actions to promote regeneration, as abundance of juvenile trees within close proximity of mother trees tend to be minimal. Thus, natural regeneration of *Cedrela lilloi* does not directly benefit from the resulting gap formations (Grau, 2000).

3.3.7 Canopy analysis

In total, 152 canopy pictures were analyzed. LAI_{True}, LAI_{eff}, gap fraction (%) and crown cover (%) were estimated from all pictures per plot and are given as mean values (Tab. 25).

Table 25: Descriptive statistics of canopy data obtained at Finca Pintascayo.

	Total data set of canopy pictures (n = 36)			
Statistics	LAI_{True}	LAI_{eff}	Gap fraction (%)	Crown cover (%)
Minimum	2.3	1.2	7	61
Maximum	4.7	2.8	39	93
Mean	3.5	2.1	19.1	80.9
Std. error	±0.09	±0.07	±1.26	±1.26
Std. deviation	0.57	0.41	7.56	7.56

Mean canopy parameters of both areas were compared (Tab. 26) and subsequently subdivided according to visible harvest activities (Tab. 27).

Table 26: Crown parameters of stands according to area in Finca Pintascayo.

Area	1 (n = 11)		2 (n = 17)	
Variable	Mean	Std. error	Mean	Std. error
mean LAI_{True}	2.01	(± 0.12)	2.04	(± 0.12)
mean LAI_{eff}	3.5	(± 0.12)	3.3	(± 0.16)
mean gap fraction (%)	19.1	(± 2.08)	14.9	(± 1.23)
mean crown coverage (ha ha^{-1})	0.67	(±0.09)	0.85	(±0.08)

Contrary to the assumption that canopy parameters in area two would reflect increased harvest impacts by means of elevated LAI_{True} values, mean values regarding LAI_{True} and LAI_{eff} are similar in both areas. However, mean percentage of gap fraction is indeed slightly lowered in area two and average crown coverage also surpasses results obtained in area one. It could possibly be argued that the relatively large time span between occurrences of selective logging activities in area two was sufficiently long enough to allow remaining trees to adapt to the altered light conditions by increased crown extension. Nonetheless, these assumptions cannot be varied and a direct comparison of stands showing signs of previous harvest and stands free from such indicators might be more futile (Tab. 27).

Table 27: Crown parameters of stands according to visible harvest in Finca Pintascayo.

Area	No harvest visible (n = 13)		Harvest visible (n = 15)	
Variable	**Mean**	**Std. error**	**Mean**	**Std. error**
mean LAI_{True}	1.8 a	(±0.12)	2.1 b	(±0.11)
mean LAI_{eff}	3.2	(±0.16)	3.6	(±0.13)
mean gap fraction (%)	14.3 a	(±1.34)	18.5 b	(±1.70)
mean crown coverage (ha ha⁻¹)	0.81	(±0.09)	0.7	(±0.06)

From comparison of mean canopy parameters between stands showing signs of harvested and stands without signs of previous harvest shows clear differences with regard to mean LAI_{True}, mean gap fraction and mean crown coverage. The respective ANOVAS yielded p-values of 0.023 and 0.046 for LAI_{True} and mean gap fraction, respectively. Hence, the calculated differences of means between the two groups are statistically significant for $p \leq 0.05$. These findings might be interesting as mean LAI_{True} in different site classes (Cpt. 3.2.5) showed coherences between growth of *Cedrela spp.* and respective LAI_{True} values. Thus, the alteration of canopy due to silvicultural intervention can be a decisive factor to enhance conditions for growth and regeneration of desired tree species.

In general, the assessment of canopy cover and LAI (Cpt. 2.2.6) by using a consumer grade digital camera yielded a satisfactory result. However, some inaccuracy pertaining to the applied concept of LAI estimations derived by digital imagery analysis has to be mentioned, as the used procedure combines all visible plant parts to derive one absolute value per picture (LAI_{True}) to which one rather would refer to as *plant area index* (PAI; Arias et al., 2007), since all vegetative plant parts are included in the estimate. Nonetheless, nomination remained unchanged throughout the document as the obtained results are merely of comparative applicability and detailed analysis of methodology would go beyond the scope of this study.

However, four LAI_{True}-value estimates (five in allocated plots of *Cedrela spp.*) were plotted against calculated crown coverage (Cpt. 2.2.8.1) of each plot to evaluate general performance of the applied methodology (Fig. 57). As canopy structure was much more heterogeneous in area one, it was excluded from the analysis.
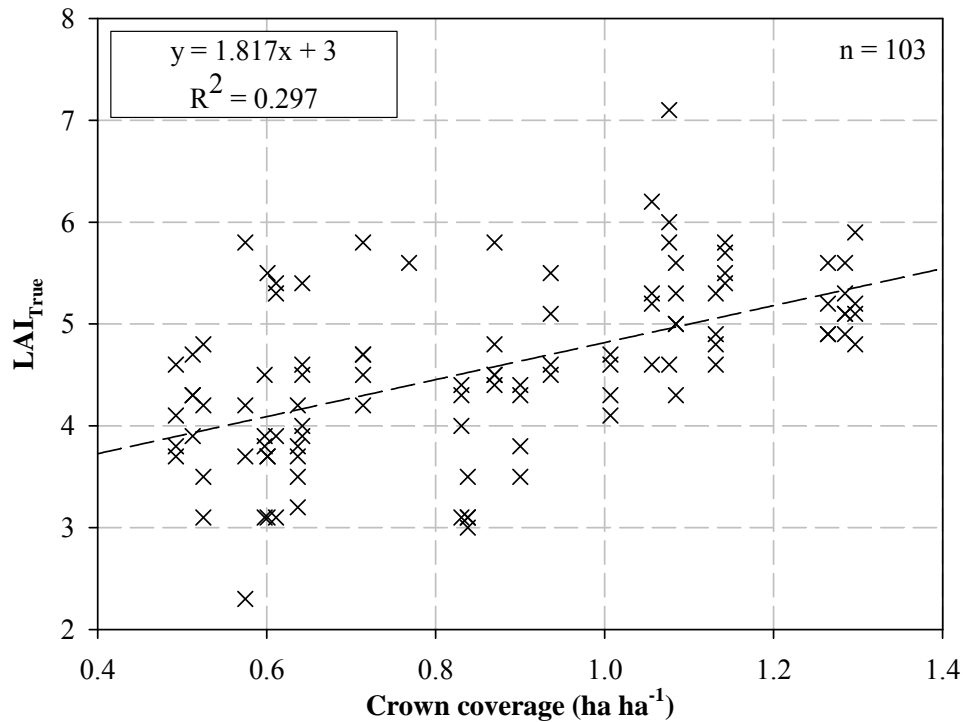
Figure 57: Estimated LAI$_{True}$ obtained from canopy pictures versus calculated crown coverage in area two.

If only plots are considered where evidence of former harvest activities are absent (n = 71), a similar correlation is observed (R^2 = 0.275). The derived coefficients of determination indicate a modest performance of the method, with estimates only accounting for around 30% of true canopy cover. However, a clear trend can be observed, indicating some explanatory value of the method, especially if the scope of investigation is rather based on relative values concerning crown cover.

Further, as horizontal distribution of crown surfaces is unknown and may show various degrees of foliage clumping (Arias et al., 2007; Macfarlane et al., 2006), crown coverage is most likely to produce distorted estimations. With regard to the difficulties and high costs usually associated with methods to estimate LAI and crown cover using fish-eye lenses, the investigated methodology may present a feasible alternative if possible sources of error are determined in detail by future investigation.

3.3.8 Stem quality assessment

Observing the results regarding tree quality assessment, a certain correlation between stem quality and tree vitality was observed (Cpt. 3.3.). In order to identify the origin of this tendency, an ANOVA was carried out to scrutinize how different vitality classes distributed within categories assigned to stem quality. Unfortunately a strong correlation was detected

between tree stem quality and tree vitality, which yielded a respective p value of 0.0001, indicating that differences in means are highly significant for $p \leq 0.01$. Therefore, stem quality classes seem to correspond to vitality classes, resulting in clumping of values attributed to the 'better' categories of both classes (Fig. 58).
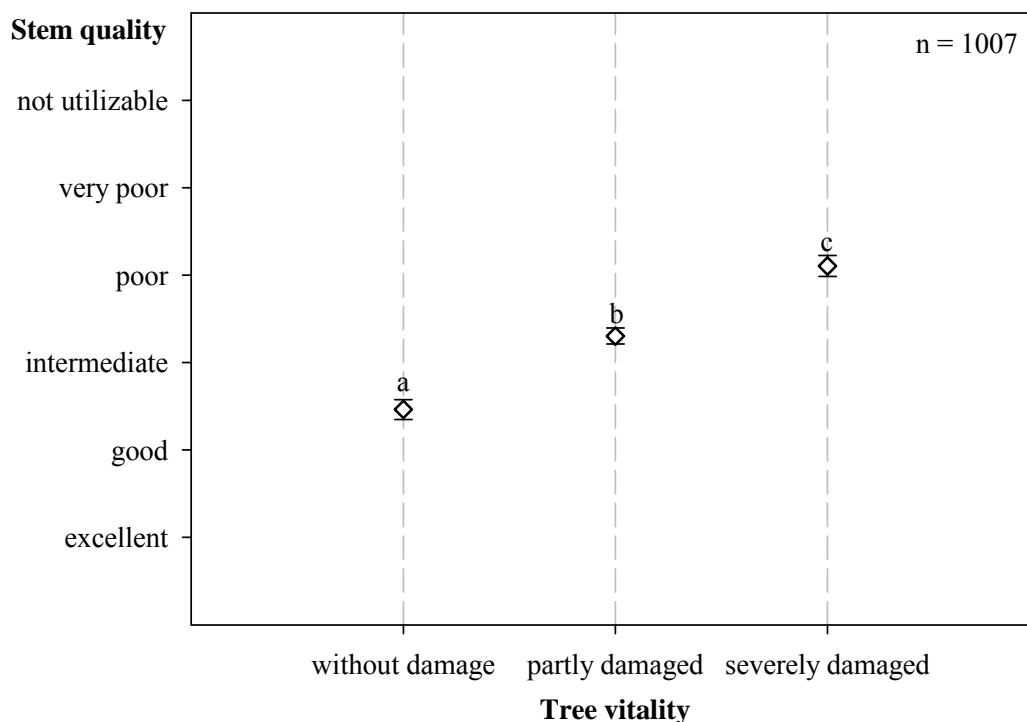

Figure 58: Overall tree vitality versus stem quality

This error might be due to ambiguous category definition prior to field work, as it is unlikely that all trees with good stem qualities are automatically free of damage. The cause might be attributed to the applied categorization scheme for stem quality assessment (Cpt. 2.2.4.3) which was developed for more or less even aged stands in temperate regions (Mahler et al., 2001). A classification scheme adapted to species and tree morphology present in *FPC*, possibly including fewer categories might be more futile.

4   Conclusions

Considering the entirely different initial situation pertaining to silvicultural and compositional aspects in both areas, site quality evaluation had to be carried out for both sites individually. As a result, the identification of parameters indicating site quality could not be related to both areas offhand, as certain trends could often not be confirmed by findings in the other area. Further, the broadened scope of this investigation led to statistical inconsistencies, due to resulting low sampling intensities. Therefore, it is highly recommended to clearly define the scope of investigation in advance and thus enhance sampling efficiency and data quality.

4.1 Soil

The described soils present in *FPC* are very suitable for forestry related land uses, however their distribution varies according to topography and location. Cambisols of varying thickness are found on the most areas that are not influenced by alluvial or fluvial deposits and that occupy lower parts of predominant slopes.

Braided river systems are a common sight in the entire area and can be associated with fluvisols, which form in areas that are or have been subject to deposition by these water ways. Finally, leptosols occupy the higher elevated parts of the present slopes, where frequent surface run-off by heavy rainfall impedes the formation of thick soil layers.

With regard to site evaluation the application of a geocentric method based on soil properties which determine tree growth produced some applicable results. Apart from evidence on the commonly known observation that thickness of humus layer and its indicative valor for biological activity present in the respective soil (Schachtschabel and Scheffer, 2002), the soil analysis showed that thickness of humus layer and pH-value of 30 cm of topsoil are correlated which in turn yielded satisfactory results when used as predictor variable for variances in height growth between the eight analyzed trees of designated target species. Thus, thickness of humus layer present on a site might serve as a preliminary indicator for site quality with regard to growth of *Cedrela spp*.

4.2 Growth of Cedrela spp.

Relatively little is known about growth of the valuable commercial timber species *Cedrela spp.* in north western Argentina (Del Castillo et al., 2005). According to the findings presented in this study, two observations can be concluded with regard to diameter growth of *Cedrela spp.* under natural circumstances. On one hand, present competition influences increase of D_i over time, but the negative impact decreases with increasing D_i of the considered tree. On the other hand, diameter growth was accelerated in stands where *Cedrela spp.* already constituted a high percentage of G. With regard to findings reported by other authors (e.g. Grau, 2000), diameter growth is further strongly fostered by proper crown illumination. Thus, by adapted silvicultural interventions, such as directed gap openings or early exemption of potential crop trees, foresters may improve growing conditions of the target species and hence promote volume production of valuable timber.

Further, H-growth was strongly determined by the exposition of the respective target trees. Altered growth rates seem to occur at expositions with increased solar radiation. As indicated by the generated model (Cpt. 3.2.7), altitudinal class also explained growth rates to

some extent, however stratification of 50 m elevation classes might be prone to variances caused by distorted GPS readings.

Furthermore, culmination of volume growth of *Cedrela spp.* can be expected to occur between 60 and 70 years of age, as indicated by the analyzed data. However, this species was previously characterized by other authors to be a gap opportunist (e.g. Pinazo, 2005) due to its potential to adapt to increased light availability by enhanced growth. Hence, the point in time of culmination of V-growth for this species most likely shows some degree of variation dependent on external factors present in a specific site.

Nonetheless, considering the small sample size and modest quality of the analyzed data in conjunction with few previously conducted studies focusing on growth of *Cedrela spp.*, these findings should rather be regarded as point of reference than absolute findings. For information on the subject might be acquired from publications of Grau and Pacheco (1997) and Pacheco and Brown (2006).

4.3 *Natural regeneration in area one*

With regard to species distribution within different altitudinal classes, the distinct numbers of saplings and the corresponding percentages of saplings of commercial species, all three altitudinal levels require adapted silvicultural treatment in order to stabilize and enhance natural regeneration to ensure sustainability. Whereas natural regeneration in altitudinal class 900 seems to be firmly established and large in numbers, which can probably attributed to comparably large canopy openings, shares of commercial species could be increased if sufficient mother trees are left on site or implemented by enrichment plantings. The same holds true for altitudinal class 850, where percentages of commercial species are extremely low. Structural composition and light conditions at ground level of altitudinal class 800 might serve as a reference. However, the underlying causes for the observed situation in all altitudinal classes in area one yet remain unknown and further investigation of regeneration dynamics in the *Yungas* is highly valuable for sustainable silviculture.

4.4 *Site quality evaluation in Finca Pintascayo*

Various possible indicators for site quality evaluation i.e. H_{top}, mean stem quality, etc. suggest that in the lower elevated area of the alluvial plain of *SNC* factors influencing tree growth are more favorable for tree growth in general. Although no growth data could be related to these sites, conducted soil evaluation confirmed these findings as in the lower altitudinal strata the soil showed a comparably high pH-value and rootability was not impeded by high groundwater levels. However, the extent of impact caused by selective harvesting could not be

assessed and validation by means of growth analysis of *Cedrela spp.* in the lower altitudinal classes, as well as possible permanent plots for monitoring is strongly recommended.

In area two, site quality seems to be improving with increasing altitude from 900 m onward, as means of V_c ha^{-1}, H_{top} and tree slenderness indicated favorable growing conditions at higher elevations. H_c, serving as an indicator for stem lengths free of branches further augmented along the elevation gradient. Further, it can be concluded that mean H_{top} and mean H_t tend to increase with increasing position on slope, although on average stem quality is usually poorer at higher positions on slope. Nonetheless, the observed changes are somewhat marginal and probably related to specific exposition. This assumption however, could not be verified as distribution of plots did not allow for inferences according to site quality with regard to different rates of solar radiation. In contrast, comparably high growth rates were observed at the toe of slope (tree number three), where pedogenic site factors probably support the elevated growth of *Cedrela spp.*

Prevalent slope gradient proved to be a good indicator of site quality. Not only distribution of means of qualifying parameters, but further average of H_{top} and H_t showed an clear trend that indicated decreasing tree growth with increasing inclination. However, the identification of a decisive threshold remains subject to possible future studies. Hence, predominantly flat areas can be generally considered to be suitable for tree growth, keeping in mind that various other factors should be thoroughly considered, too.

In general, it must be concluded that the respective sample size for area two (n = 17) was not sufficient to allow for a clear categorization of the multitude of possible influencing site factors. Even though the assigned classes appear suitable to adequately categorize different sites, more samples are required to increase the chances of covering the majority of possible combination of site factors present in *FPC*.

To ensure sound application of possible predictors of site quality in *FPC* long term investigations by means of permanent plots are required to provide reliable validation (Vanclay, 1994). In order to guarantee sustainability of forest management, particularly with regard to the low information scenario given in north western Argentina, detailed data bases monitoring all ecological coherences for silvicultural actions are essential. Therefore, permanent plots should be established not only to quantify different site qualities, but further to amplify transparency of possible impacts related to a wide array of possible silvicultural interventions.

To facilitate site quality evaluation by means of long term observations, permanent plots should be established at well selected sites that encompass a wide array of influencing site

factors. Sizes, sufficiently large enough to include all occurring site characteristics found in *FPC* are recommended, but homogeneity of each plot should be granted to ensure proper classification for comparative analyses. Mean V-production per hectare on stands is most likely to properly identify the sites productivity and hence it's suitability for tree growth. Further, mean H-growth within a specified age interval might also account for the site's respective quality, but long term observations are inevitable. This on hand study may serve well as reference with regard to fundamental factors that are to be considered in the process of selecting sites for designated permanent plots for long term investigation.

5 References

ARIAS, M. and **BIANCHI, A., R**., 1996: Estadísticas climatológicas de la provincia de Salta. Salta. Dirección de Medio Ambiente y Recursos Naturales, Gobierno de Salta. Argentina, p. 189.

ARIAS, D., CALVO-ALVARADO and **DOHRENBUSCH, A**., 2007: Calibration of LAI-2000 to estimate leaf area index (LAI) and assessment of its relationship with stand productivity in six native and introduced tree species in Costa Rica. Forest Ecology and Management, vol. 247, No.3, p. 185 – 193.

ARMADA, N., R., 2007: Diferencias entre composición y estructura forestal en dos sitios de selva de montaña en Salta, Argentina. Doctoral dissertation. Universidad Nacional de Salta, Argentina, p. 93 – 98.

BAVA, J., 1990: Analisis structural con enfasis en la diversidad en dos sectores de bosque semideciduo en el Noroeste Argentino, Msc. thesis, University of Göttingen, pp. 61.

BRINK, C. and **v. GADOW, K.**, 1983: Modeling stem profiles. South African Journal. 127, p. 23 – 25.

BROWN, A., D., 1995: Las selvas de montaña del noroeste de Argentina: problemas ambientales e importancia de su conversación. Investigación, Conversación y Desarollo en Selvas Suptropicales de Montaña, Inst. Miguel Lillo, Argentina, pp. 9.

BROWN, A., D., GRAU, H., R., MALIZIA, L., R. and **GRAU, A**., 2001: Argentina, in Kapelle, M. and Brown, A., editors. Boques nubaldos del neotrópico. Instituto Nacional de Biodiversidad, INBio, San Jose, Costa Rica, p. 623 – 659.

BROWN, A., D. and **MALIZIA, L., R.**, 2007. Lista comentada de árboles de las Yungas de Argentina. Fundación ProYungas. Tucumán, Argentina.

BROWN, A., MALIZIA, L., R., PACHECO, S. and **CRISTÓBAL, L.**, 2006: Estrategia ambiental de Finca Pintascayo de Fundación ProYungas para GMFLatinoamericana S.A., (unpublished), pp. 15.

BROWN, A., PACHECO, S., LOMÀSCOLO, T. and **MALIZIA, L.**, 2005: Situación ambiental en los bosques andinos yungueños, Laboratorio de Investigaciones Ecológicas de las Yungas, Universidad Nacional de Tucumán y Fundación ProYungas, p. 53.

CABRERA, A., L., 1976: Regiones Fitogeográficas Argentinas. ACME, Buenos Aires, Argentina, pp 85.

CELLINI, J. M., MARTÌNEZ PASTUR, G., WABÖ, G. and **LECINAS, M., V.**, 2002: Modelos de perfiles de tronco para Nothofagus pumilio y su utilización en el cálculo del volumen total. Revista de Investigación Agraria: Sistemas y Recursos Forestales. vol. 11 (2), p. 245-261.

CIA WORLD FACTBOOK, 2007: World Fact book: Argentina, Available online: http://www.cia.gov/cia/publications/factbook/print/ar.html, accessed on May 29th, 2007.

DAUBER, E., FREDRICKSEN, T., PENA-CARLOS, M., LEANO, C., LICONA, J., C. and **CONTRERAS, F.**, 2003: Tasas de Incremento Diamétrico, Mortalidad y Reclutamiento con base en las Parcelas Permanentes Instaladas en Diferentes Regiones de Bolivia, Proyecto de Manejo Forestal Sostenible (BOLFOR), Bolivia, pp. 14.

DEL CASTILLO, E., M., ZAPATER, M. and **GIL, M.**, 2005: Distribución, ecologia y silvicultura de los cedros en la selva subtropical de Salta y Jujuy, INTA, Argentina.

DEL CASTILLO, E., M., ZAPATER, M., GIL, M. and **TARNOWSKI, C.**, 1992: Selva de Yungas del Noroeste Argentino (Jujuy, Salta, Tucumán) Recuperación ambiental y productiva, INTA, Argentina.

DIGILIO, A. and **LEGNAME, P.**, 1966: Los árboles indígenas de Tucumán. Opera Lilloana 15, Tucumán, Argentina.

DOHRENBUSCH, A. and **HÄGER, A.**, 2006: Forests in the Clouds. German Research, vol. 28 No. 1, pp. 4-8.

EASDALE, T., A., GURVICH, D., E., SERSIC, A., N. and **HEALY, J., R.**, 2007: Tree morphology in seasonally dry forests in Argentina: Relationships with shade tolerance and nutrient shortage. Journal of Vegetation Science Vol. 18, Opulus Press Uppsala, pp. 313 – 326.

FAO, 2006: World reference base for soil resources 2006, A framework for international classification, correlation and communication, Food and Agriculture Organization of the United Nations, Rome, pp. 7.

FUNDACIÓN PROYUNGAS, 2006: Boletín forestal de Yungas, Fundación, Programa de Certificación Forestal de Yungas. Fundación ProYungas, año 2 No. 1.

GADOW v., K., 2004: Waldstruktur und Wachstum, Beilage zur Vorlesung im Wintersemester 2003 / 2004, Lecture Notes, Universitätsdrucke Göttingen. pp. 70.

GMF LATINOAMERICANA S.A., 2006: Plan de manejo forestal 2006-2015 Finca "Pintascayo" (unpublished). pp. 8-14.

GMF LATINOAMERICANA S.A., 2006: Manual de Parcelas Permanentes de Muestreo (PPM). (internal document).

GMF LATINOAMERICANA S.A., 2005: Informe Inventario Finca Pintascayo. (internal document).

GRAU, H., R., 2000: Regeneration patterns of Cedrela lilloi (Meliaceae) in northwestern Argentina subtropical montane forests. Journal of Tropical Ecology, vol. 16, Cambridge University Press, p. 227 - 242.

GRAU, H., R. and **GOYA, J. F.**, 2005: Modelos de crecimiento de Cedrela lilloi en el sector norte de las Yungas argentinas. Ecología y producción de cedro (género Cedrela) en las Yungas australes. Pacheco, S. and A. Brown (Eds.). LIEY-ProYungas. Argentina.

GRAU, H. R. and **PACHECO, S., E.**, 1997: Demografía y crecimiento de renovales de Cedrela lilloi en un bosque subtropical de montana de Tucumán, Argentina. Laboratorio de investigaciones ecológicas de las Yungas – LIEY, Argentina.

GRAU, H., R. and **VEBLEN, T., T.**, 2000: Rainfall Variability, Fire and Vegetation Dynamics in Neotropical Montane Ecosystems in Northwestern Argentina. *Journal of Biogeography*, vol. 27, No. 5, p. 1107-1121.

HUECK, K., 1966: Die Wälder Südamerikas. Gustav Fischer Verlag, Stuttgart, pp. 75.

HUSCH, B., MILLER, C, I. and **BEERS, T., W.**, 1993: Forest Mensuration 3rd ed. Krieger, Malabar, FL., USA.

IMAGEJ, IMAGE PROCESSING AND ANALYSIS IN JAVA, 2004: Research Services Branch, National Institute of Mental Health, Bethesda, Maryland, USA, http://rsb.info.nih.gov/ij/, accessed on March 9th, 2007.

INTA, 2007: Informe análisis de suelo del laboratorio central de análisis, Instituto Nacianal de Tecnología Agropecuaria, Salta, Argentina (unpublished).

KAPPELLE, M. and **BROWN, A., D.**, 2001: Boques nubaldos del neotrópico. Instituto Nacional de Biodiversidad, INBio, Costa Rica, p. 623 – 659.

KAPPELLE, M., GEUZE, T., MIGUEL, E., LEAL, M., E. and **CLEEF, A., M.**, 1996: Successional Age and Forest Structure in a Costa Rican Upper Montane Quercus Forest. Journal of Tropical Ecology, vol. 12, No. 5.

KLEINN, C., 2005: Forest inventory. lecture notes, Institute of forest management, University of Göttingen, (unpublished), pp. 51.

KRAMER, H. and **AKÇA, A.**, 2002: Leitfaden zur Waldmesslehre. J.D. Sauerländer's Verlag, Frankfurt am Main, Germany, pp. 177.

LAAR VAN, A. and **AKÇA, A.**, 1997: Forest Mensuration. Cuvillier Verlag, Göttingen, Germany, pp. 245.

LAMPRECHT, H., 1992: Silvicultura en los Tropicos. GTZ, Eschborn, Germany, pp. 335.

LEGNAME, P., R., 1982: Arboles indigenas del Noroeste Argentino, San Miguel de Tucuman, Argentina.

MACFARLANE, C., HOFFMANN, M., EAMUS, D., KERP, N., HIGGINSON, S., MCMURTIE, R. and **ADAMS, M.**, 2006: Estimation of leaf area index in eucalypt forest using digital photography, University of Western Australia, Agricultural and Forest Meteorology 143, p. 176 – 188.

MAHLER, G., WILLMANN, U., and **WURSTER**, **M**., 2001: Güteansprache am stehenden Stamm, Bundeswaldinventur II in Baden-Württemberg, Forstliche Versuchs- und Forschungsanstalt Baden-Württemberg, Germany.

MALIZIA, L., **R.**, 2004: Diversity and Distribution of tree species in subtropical Andean Forests. Doctoral dissertation at the University of Missouri − St. Louis, USA, p. 45 – 90.

MARQUARDT, D., W., 1963: An algorithm for least square estimation of nonlinear parameters. J. Soc. Ind. Appl. Math., vol. 11, No. 2, pp. 431-441.

MENDOZA, G., A. and **GUMPAL, E., C.**, 1987: Growth projection of a selectively cut-over forest based on residual inventory. Forest Ecology and Management, vol. 20, No.3, pp. 253 – 263.

MINETTI, J. M., 2005: Características de la comercialización de maderas nativas en Orán y Tartagal (Salta), Instituto Nacional de Tecnología Agropecuaria, Argentina. Available online: http://www.inta.gov.ar/yuto/info/documentos/entomologia/maderas.pdf, accessed on May 29th, 2007.

MORALES, J., M., SIROMBRA, M. and **BROWN, A., D.**, 1995: Riqueza de árboles en las Yungas Argentinas, p. 163 - 174. In A.D. Brown y H.R. Grau. (eds.). Investigación, Conservación y Desarrollo en Selvas Subtropicales de Montaña. LIEY, Tucumán, Argentina.

MUHAIRWE, C., K.; 1993: Examination and Modeling of Tree Form and Taper Over Time for Interior Lodgepole Pine. Doctoral dissertation at the University of British Columbia, Canada.

MUHAIRWE, C., K.; 1999: Taper equations for Eucalyptus pilularis and Eucalyptus grandis for the north coast in New South Wales, Australia. Forest Ecology .and Management, vol. 113, No 2, pp. 251-269.

NADIR, A. and **CHAFATINOS, T.**, 1990: Los suelos del NOA (Salta y Jujuy). UNSa. Salta.

OTTO, H., J., 1994: Waldökologie, Ulmer Verlag, Stuttgart. pp. 262.

PACHECO, S. and **BROWN, A., D.**, 2006: Ecología y producción de los Cedros (género Cedrela) en las Yungas de Argentina. Fundación PROYUNGAS, Tucumán, Argentina.

PINAZO, M., GASPARRI, N., GOYA, J. and **ARTURI, M.**, 2003: Cambios estructurales causados por el aprovechamiento selectivo en el bosque montano de norte de Salta, Argentina. Rev. Biol. Trop. 51(2), p. 361-368.

PINAZO, M., A., 2001: Verjüngung von *Cedrela lilloi* C.D.C. und *Juglans australis* Griseb. in den Yungas von Argentinien unter besonderer Berücksichtigung des Lichtfaktors. Msc-thesis, Georg August Universität, Göttingen, (unpublished) p. 17.

RIEMER, T., GADOW v., K. and **SLOBODA, B.**, 1995: Ein Modell zur Beschreibung von Baumschäften. Allg. Forst-und J.-Ztg. 166 (7), p. 144 -147.

SAS INSTITUTE INC., 2000 SAS/STAT™: User's guide, Release 8.2, Cary, NC, USA.

SCHACHTSCHABEL, P. and **SCHEFFER, F.**, 2002: Lehrbuch der Bodenkunde, Spektrum Akademischer Verlag, 15. Aufl., pp. 494.

SCHOENEBERGER, P., WYSOCKI, D., BENHAM, E. and **BRODERSON, W.**, 1998: Field book for describing and sampling soils (ver. 1.1). National Soil Survey Center, US Department of Agriculture, Lincoln, Nebraska, USA. pp. 10.

SCHWEINGRUBER, F., H., 1993: Trees and Wood in Dendrochronology. Morphological, anatomical and tree – ring analytical characteristics of trees frequently used in dendrochronology. Springer Series in wood science, pp. 370.

SMARTWOOD, 2007: Informe de Evaluación para la Certificación del Manejo Forestal de: GMF Latinoamericana SA en Isla de Cañas, Departamento Iruya, Salta, Argentina, from Jan. 24th, 2007.

VANCLAY, J. K., 1992: Assessing site productivity in tropical moist forests: a review. Forest Ecology and Management, Vol. 54, No. 1-4, p. 257 - 287.

VANCLAY, J. K., 1994: Modeling Forest Growth and Yield, Applications to Mixed Tropical Forests. CAB International, Wallingford UK, pp. 134.

VILLALBA, R., BONINSEGNA, J. and **HOLMES, R.**, 1985: *Cedrela angustifolia* and *Juglans australis*: two new tropical species useful in dendrochronology. Tree Ring Bulletin, vol 45.

VILLALBA, R., GRAU, H., BONINSEGNA, J., JACOBY, G. and **RIPALTA., A.**, 1998: Tree-ring evidence for long term precipitation changes in subtropical South America. Int. J. Climatol. 18: 1463–1478.

WEISS, M., BARET, F., SMITH, G., J., JONCKHERE, I, COPPIN, P., 2003: Review of methods for in situ leaf area index (LAI) determination Part II. Estimation of LAI, errors and sampling; Agricultural and Forest Meteorology 121 (2004), pp. 37-53.

ZAPATER, M., DEL CASTILLO, E. and **PENNINGTON, T.**, 2003: El genero Cedrela (Meliaceae) en la Argentina. INTA, Estación Experimental de Cultivos Tropicales Yuto, Argentina. pp. 7.
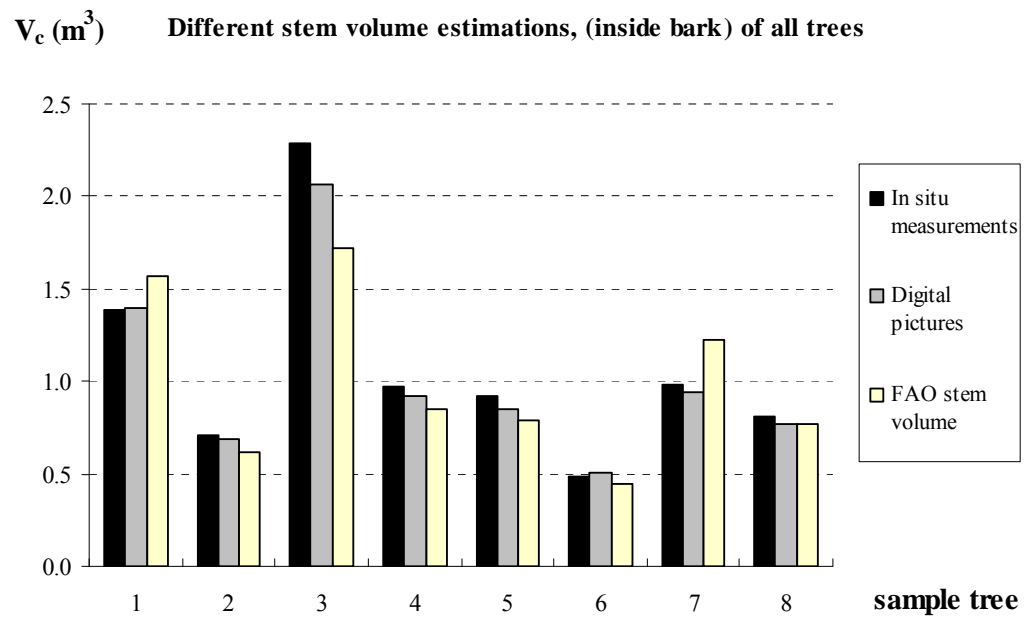
6 Appendices

V_c (m³) **Different stem volume estimations, (inside bark) of all trees**

V_c (m³)   **Different stem volume estimations, (inside bark) of all trees**

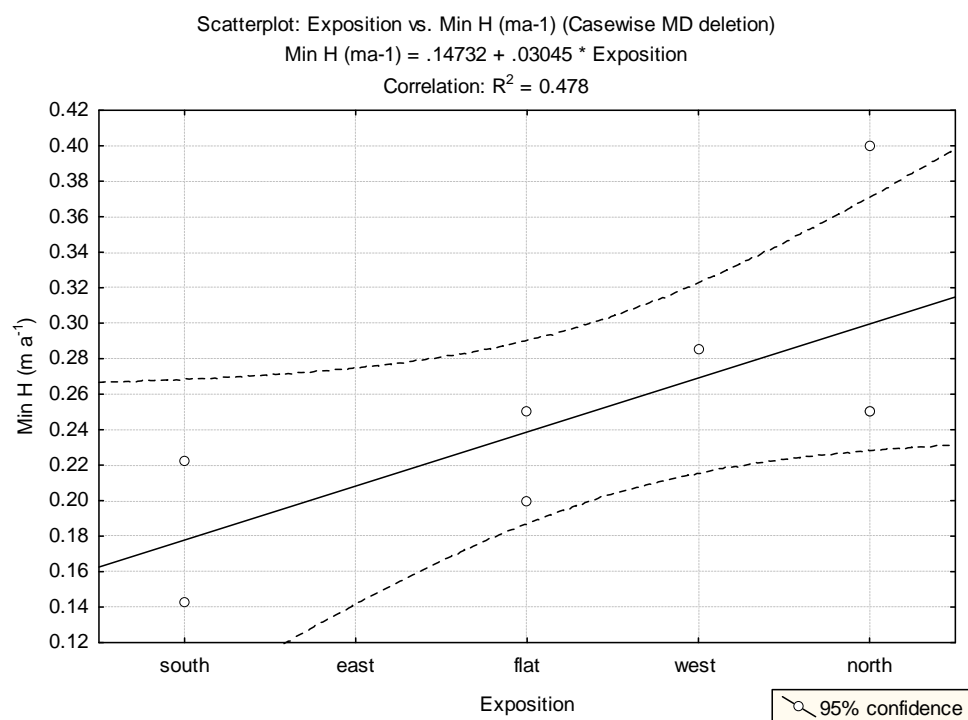
Figure 59: Different estimators for V_c (m³) of eight sample trees

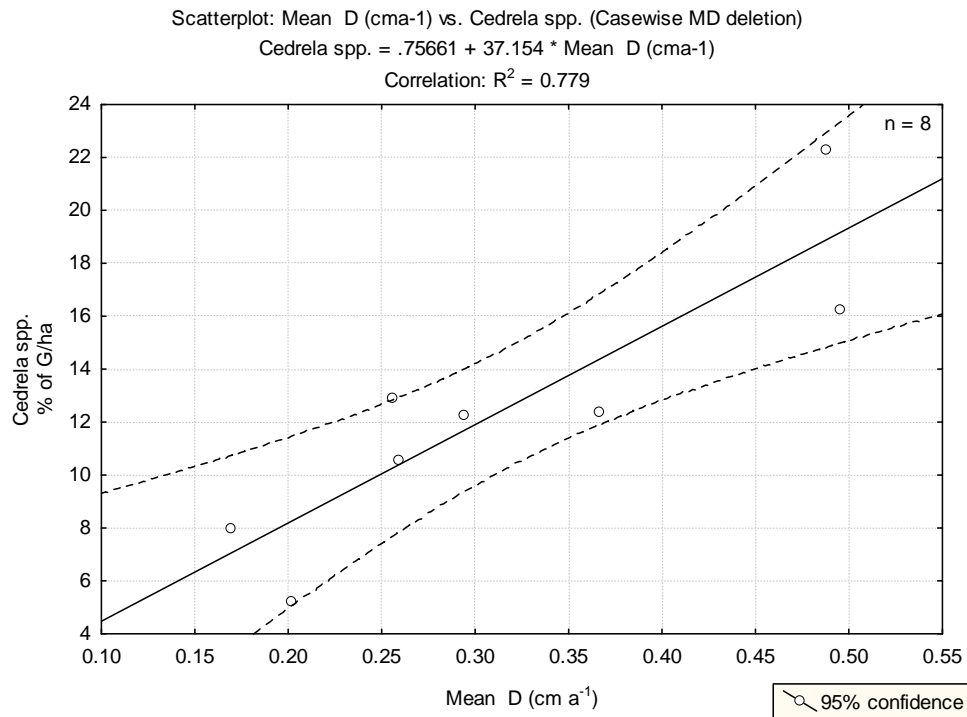*Figure 60: Minimum height growth of Cedrela spp. according to exposition*

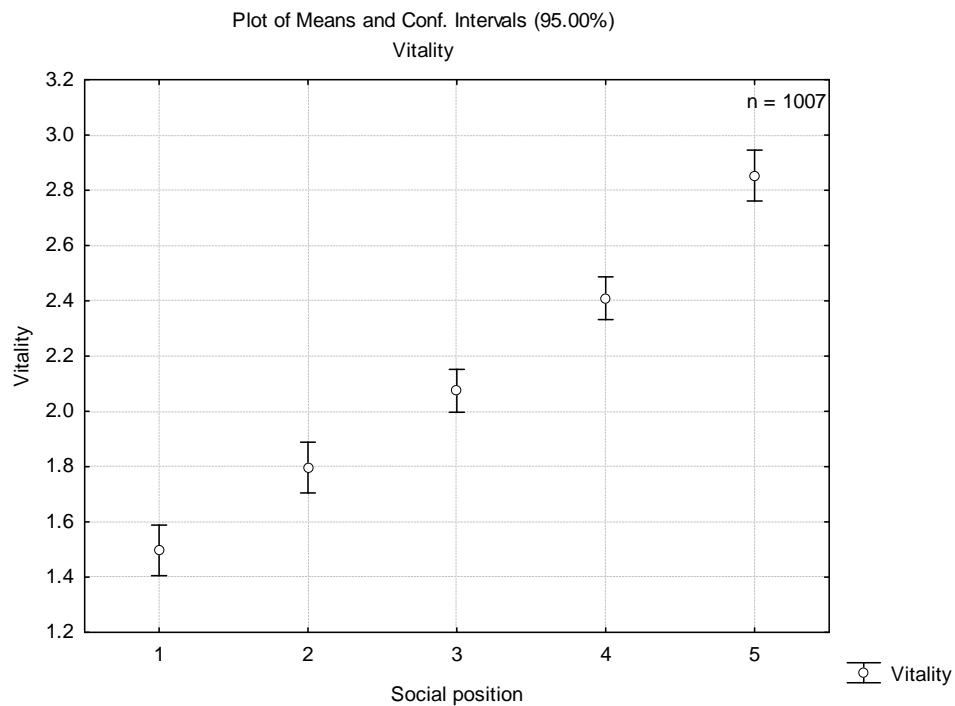*Figure 61: Percentage of Cedrela spp of G (m² ha⁻¹) versus mean diameter growth of sample tree.*

Figure 62: Mean vitality according to social position