Investigation of Single Tree Parameters in Deciduous Forests

MASTER THESIS

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Handed in by

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ABSTRACT

Keywords: Mixed deciduous forest, valuable timber production, experimental thinning trial, single tree parameter, competition indices

Single tree parameters of a range of valuable broadleaved tree species were investigated in an 18-year old deciduous forest accrued from natural regeneration in Karnabrunn, located in the province of Lower Austria. Aiming at high valuable timber production in relatively short rotations this study was initiated to examine the releasing effects of different thinning intensities on the juvenile growth of a range of light demanding species such as sessile oak (*Quercus petraea* L.), common ash (*Fraxinus excelsior* L.), sycamore (*Acer pseudoplatanus* L.) and wild cherry (*Prunus avium* L.).

The silvicultural prescription and objectives are applied in the following manner: Two geometrical thinning scenarios were established with a threshold distance around the selected trees of two meters in the first variant (V_1) and three meters in the second variant (V_2). In order to analyse the management effect, the single tree parameters of the selected elite trees sycamore and sessile oak were compared between the variants after the first tending operation taking place in the year 2004. Furthermore, the study was aiming to describe individually the competitive situation of the future crop trees in the two different thinning variants and to examine whether these indices of competition are reflected in the tree growth. Additionally, the correlation between important tree parameters such as crown width and length with the diameter was investigated.

Within the given time frame of five years, no effect between the thinning variants could be stated on the single tree parameters dbh and height. Merely a difference of crown volume and the crown width/length ratio could be found. Nonetheless, the competition indices revealed a significant difference in all cases except Pretzsch's index. The relation between diameter and crown width on the one hand and diameter and crown length on the other hand were significant.

In conclusion, the naturally regenerated deciduous forest in Karnabrunn is managed for high valuable timber production and was ideal for examining the effect of thinning scenarios. The result show significant differences between thinning variants by competition indices, even though those were not strongly reflected in tree growth.

ZUSAMMENFASSUNG:

Schlüsselwörter: Laubmischwald, Wertholzproduktion, experimenteller Durchforstungsversuch, Einzelbaumparameter, Konkurrenzindizes

Einzelbaumparameter von Eiche und Edellaubhölzern wurden im Rahmen dieser Arbeit auf einer Versuchsfläche in einem 18 Jahre alten Laubmischwald in Karnabrunn (Niederösterreich) untersucht. Mit dem Ziel einer Umtriebszeitoptimierung bei der Wertholzproduktion wurden 2004 Varianten mit unterschiedlichen Freistellungsgraden der Z-Bäume angelegt. Zwei geometrisch angelegte Durchforstungsvarianten sorgten in einer ersten Variante (V_1) für einen Freistellungsradius von zwei Metern, während in einer zweiten Variante (V_2) ein Radius von drei Metern angewandt wurde. In dieser Arbeit werden die Auswirkungen der zwei unterschiedlichen Durchforstungsintensitäten auf die Entwicklung von Einzelbaumparameter der Lichtbaumarten Traubeneiche, (*Quercus petraea* L.), Esche (*Fraxinus excelsior* L.), Bergahorn (*Acer pseudoplatanus* L.) und Vogelkirsche (*Prunus avium* L.) untersucht.

Für diese Zwecke wurden eine Reihe von Baummerkmalen erhoben, abgeleitet und Zusammenhänge mittel statistischer Verfahren getestet. Des Weiteren war es Ziel die Bedrängersituation der einzelnen Z-Bäume fünf Jahre nach dem Eingriff darzustellen. Hierfür wurden verschiedene Konkurrenzindizes berechnet und zwischen den Varianten statistisch verglichen. Zudem wurde der Zusammenhang zwischen Kronenbreite und Brusthöhendurchmesser (Bhd) analysiert.

Die Resultate zeigten, dass die waldbaulichen Eingriffe nach der Wachstumsphase von fünf Jahren keine signifikanten Unterschiede im Bhd- und Höhenwachstum zwischen den Varianten hervorgebracht haben. Lediglich zwischen dem Kronenvolumen und dem Plumpheitsgrad ergaben sich signifikante Unterschiede. Trotzdem wurden signifikante Unterschiede zwischen den Varianten hinsichtlich der Konkurrenzindizes festgestellt. Die Resultate der regressionsanalytischen Untersuchungen ergaben eine Korrelation zwischen Kronenbreite und Durchmesser, sowie Kronenlänge und Durchmesser.

ACRONYMS

BA	Basal area of one single tree [m^2]
CPA	Crown projection area [m^2]
CW	Crown width [m]
CB	Crown base [m]
CL	Crown length [m]
CV	Crown volume [m^3]
W/L ratio	Crown Width-Length ratio
dbh	Breast height diameter [cm]
dg	Diameter of the mean basal area [cm]
G	Basal area per hectare [$m^2 \cdot ha^{-1}$]
h	Height [m]
h_{100}	Dominant height [m]
d_{100}	Dominant diameter [m]
CI	Competition Index
V_1	Thinning variant 1
V_2	Thinning variant 2
ME	Competition index from Martin and Ek (1974)
H	Competition index from Hegyi (1955)
CC	Competition index from Biging and Dobbertin (1992)
KKS	Competition index from Pretzsch (1995)

1 INTRODUCTION

1.1 Problem statement

Austria is known to be a country of high Alpine mountain ranges and densely growing forests. The outcome of the last inventory of 2000/2 presents a forest area of 3.96 million ha representing almost 50 % of the country size (Austrian Forest Report 2008). In remote areas and especially in mountainous regions where other industries usually lack income possibilities and job generating production, those sectors play a dominant role as a major or substantial additional source of income. In total, the production of agriculture and forestry generated a combined income of 8.4 million € in 2008, of which forestry amounts a share of 1.7 million € (Green Report 2009). Traditionally, agricultural shows a higher competiveness which is explained by a far higher net revenue and by a more diversified product amplitude. Considering the importance of income and resources supplying ability of forestry, a rural development programme was created by the Austrian Federal State and the EU in the period of 2007- 2013 with the objective to promote and support forestry and agriculture in remote areas. Among other beneficiaries 8.7 million € were invested for developing the economic value of forests (Green Report 2009).

The distribution of tree species in mountainous Austria is highly dominated by coniferous wood shown by the example of the two most common tree species Norway spruce 54 % followed by beech 10 %. Despite the surplus in distribution frequency of coniferous wood (67%) in comparison to broadleaved wood (24 %), the latter shows much higher potential to create surplus in monetary values (Facts and Figures 2010[1]). This fact evokes special interest for the above mentioned support schemes and for promoting the cultivation of broadleaved trees especially for private forest owners who represent 75 % of the ownership distribution (Austrian Forest Report 2008). In the past, broadleaved trees were neglected over time and even removed in phases of devastation being replaced by fast growing conifers in Austria and also on the European level (Hochbichler and Bellos 2004, Duchiron 2000; Schmidt 2004; Spiecker et al. 2009; Leibundgut 1983). In forestry, private forest owners in particular avoid the cultivation of broadleaved tree species and traditionally count on conifers due to easier management and lower investment costs (Leibundgut 1983). Most notably, private forest owners lacked silvicultural expertise of managing broadleaved species. Even though neglected, there still exists a special interest in noble broadleaved tree species which are

[1] Source: Federal Research and Training Centre for Forests, Natural Hazards and Landscape 2010 / Austrian Forest Inventory 2000/2.

characterised by ornamental significance, a cultural heritage due to rarity or just out of their high economic timber value (Spiecker et al. 2009). Recently, this particular interest has been rising and is predicted to rise further in the future according to forest experts in recent surveys (Schraml and Volz 2009). Among those valuable broadleaved tree species named in the survey were particularly common ash (*Fraxinus Excelsior* L.), wild cherry (*Prunus avium* L.) and sycamore (*Acer pseudoplatanus* L.) being predicted to rise in importance in the future (Savill et al. 2009). Zhou Ting (2008) also reported a similar pattern in recent decades. For instance China keeps importing round wood from all over the world to meet the huge domestic demands of timber, especially big dimensioned valuable broadleaved wood. As a consequence the experimental research trial in Karnabrunn meets this zeitgeist with the results potentially helping to provide the needed expertise in handling the management of valuable broadleaves. Classical works from Assmann (1970), Kramer (1988) and Mitscherlich (1970) focus on even-aged pure stands, contrasting to new demands on tending regimes, on dynamics and on structure of this kind of diversified mixed stands such as the one in Karnabrunn (Pretzsch 2009). Deciduous forests are managed usually with multi- layered systems and in the mature stands, managed most commonly with mixtures of two or three species (Mitscherlich 1969; Assmann 1961; Pretzsch 2009). Nonetheless, in this study the 18 year old stand evoked out of natural regeneration and in total six different kinds of tree species were selected as elite trees. Obviously this requires a different silvicultural approach in comparison to the traditional management prescriptions. As a general trend in forestry, stand oriented approaches are shifting to individual tree approaches as a response to the increasing complexity of management operations (Kramer 1988; Pretzsch 2009, 2010; Spiecker 2003). In order to be useful for forest practitioners uneven-aged stands or multi-layered stands of mixed tree species need to be managed in a different way than strategies based on those growth models being applied to even-aged stands (Nutto 2005; Pretzsch 2002). For this purpose single tree models are very promising and examples include work from multiple universities such as in Freiburg in Southern Germany, Vienna in Austria, and Nancy in France (Spiecker 2009; Nutto 1999; Hein 2004; Hochbichler 2008; Krapfenbauer and Mosandl 1991, Roman-Amat 2009). This study contributes to the research project in Karnabrunn. Specifically single tree parameters of future crop trees are analysed in two individual releasing schemes so that knowledge about model approaches of tending operations in the juvenile phase can be gained. ‘The transition from stand to individual-based concepts and models is a crucial step towards a more profound understanding of population development processes’ (Pretzsch 2009).

1.2 Area of investigation

1.2.1 Geographical location

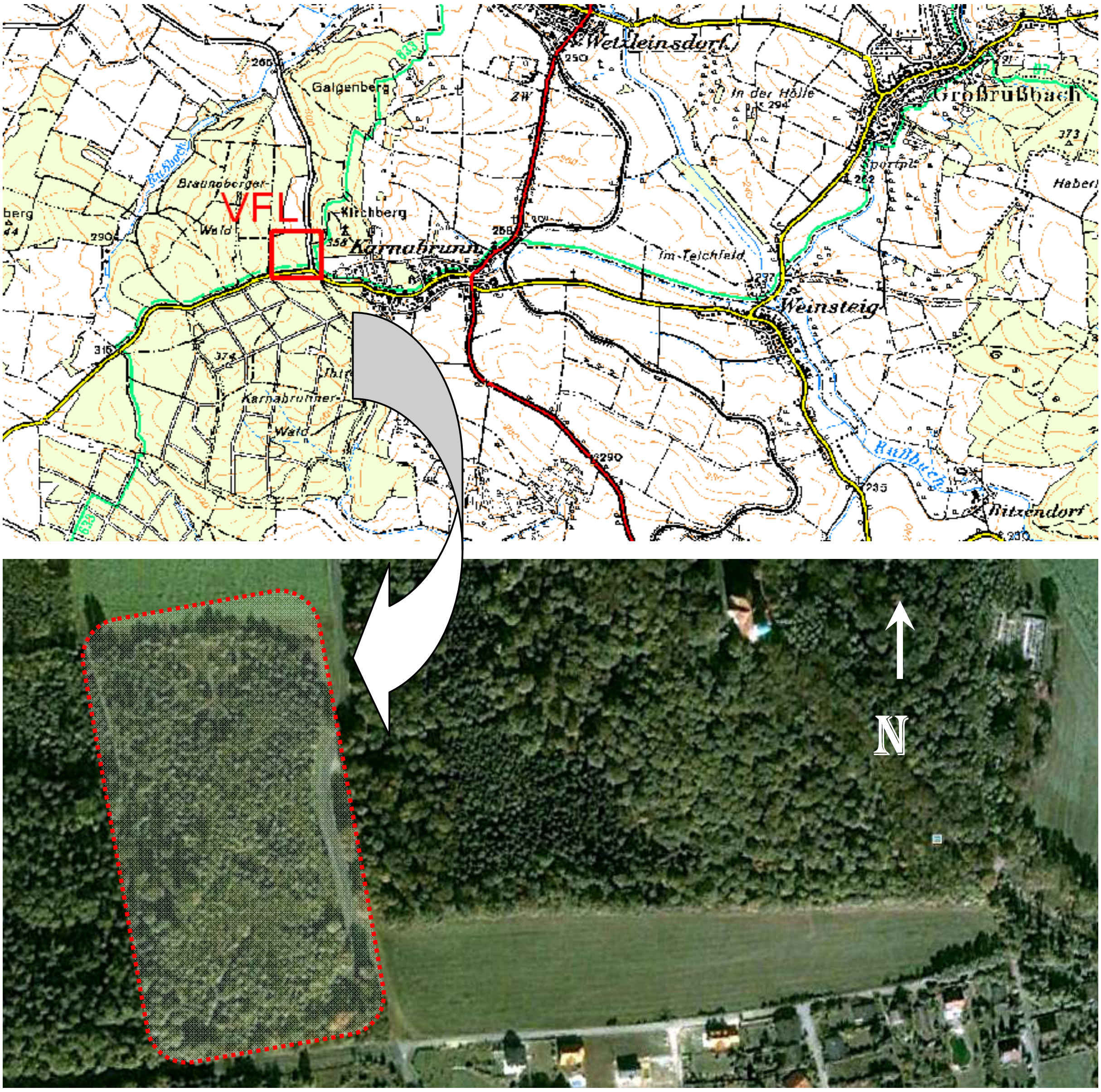

Figure 1.2-1 Map of the study area (VFL= Versuchsfläche) indicated with the red frame above and below; aerial photo of the study area in Google Earth® 2010 in bird eye view in height of 936 m, geographic location at 48.27.44.00 North, 16.21.23.51 East, date of the image at 16th of October

The research area is located in the southern Weinviertel at a mean sea level of 310 m. The stand grows on a slightly north-eastern inclined slope. More precisely, the stand is part of the Braunsberg Forest, district '5i' nearby the village Karnabrunn being held by the forest owner Ing. Hans Kollner. The landscape is shaped by the wide plane of the so called Vienna Basin ('Wiener Becken'). Even though the mountainous topography is the ruling factor, East

Austria is characterised by the sedimentary Vienna basin between the Alps and the Carpathian mountains. More than 50% of the Vienna Basin is located in Lower Austria, the rest in Vienna, the Czech Republic and Slovakia (Hochbichler 2004).

1.2.2 Climate, geomorphology, soils

The climate of the southern Weinviertel ('wine quarter') is characterised by dry and warm weather with little precipitation during the winter months. This pannonic-subcontinental climate shows the highest probability of periods with summer drought all over Austria (Kilian et al., 1994). The mean precipitation is about 500-600 mm showing a maximum in summer. The annual mean temperature is about 9° C, with a mean July temperature of 18° C. Tertiary hilly land and gravel flats are covered with aeolian sediments such as loess or carbonate-free wind blown silt (Kilian et al., 1994). The soil is well-drained, with a medium depth suitable for root growth, composed by loose sediments such as cambisol and loess. The storage ability and drainage is medium. The soil type is loamy silt changing respectively to silty loam. The humus layer is characterised as mull humus (Hochbichler 2004).

1.2.3 Potential natural vegetation

In technical terms the area is part of growth area 8.1 (Wuchsgebiet) in the mapping of Austrian Forest Growth Areas (Kilian et al., 1994) and characterised by pannonic lowland and rolling country ('Pannonisches Tief- und Hügelland'). Naturally, the forest association is formed by oak and hornbeam (*Carpinus betulus* L.) forest of the hilly-planar altitudinal zonation. Potential oak species of the natural vegetation are *Quercus cerris* (turkey oak), *Quercus robur* (pedunculate oak) and *Quercus petraea* (sessile oak) (Hochbichler 2004).

1.2.4 Stand history of the experimental plots, Karnabrunn (Hochbichler 1991)

Previously, the management unit was dominantly formed by scots pine (*Pinus sylvestris* L.) with single larch (*Larix decidua* L.) and oak. The quality, especially of pine was not satisfying as so called 'wolves', bended trees and crown damage have decreased the economic value of the 90 year old stand. Therefore, the forest unit was harvested gradually in the years of 1982-1992 until the area was completely cleared, tilled and fenced in 1992. Additionally, the herbicide (VELPAR) was applied by the agriculturally-minded forest owner in the years 1992 and 1994. The herbicide is usually applied with one kilo per hectare after the extensive growth of herbs and grass species in coniferous forests (BFW). The current age of the stand is about 18 years.

1.3 Tree species

The stand in Karnabrunn is dominated by common ash (*Fraxinus excelsior* L.), sycamore (Acer *pseudoplatanus* L.) and hornbeam (*Carpinus betulus* L.) and mixed with a range of other valuable broadleaves as well as oak, and a few conifers. The definition of valuable broadleaves is rather unspecific as the opinion of which species is considered valuable changes in different countries and even within forest owners and their objectives. Valuable broadleaves and in particular common ash, sycamore and wild cherry (*Prunus avium* L.) are often light demanding, grow best on fertile sites, and are often rather short-lived (Spiecker et al. 2009). In this mixture they generally need intensive release and high intensity of canopy disturbance in the phase of regeneration (Savill et al. 2009). Fulfilling the aim to produce valuable timber, those species are competitive only on rare suitable sites, which is the reason why the valuable broadleaved tree species are an overlooked group of trees compared with oak (*Quercus robur* L. and *Quercus petraea* (Matt.) Lieb.) and beech (*Fagus sylvatica* L.) even though the latter two are also able to reach considerable high revenues (Savill et al. 2009). They grow individually or in groups in a mixture with other broadleaved trees and coniferous trees, after afforestation of farmland, in orchards, along roads or in agro-forestry systems (Leibundgut 1978; Mitscherlich 1969; Reeg et al. 2009; Spiecker et al. 2009). In total, less than 5 % of the total timber volume and less than 5 % of the forest cover are represented by valuable broadleaved tree species in Central Europe and in particular in Austria (Savill et al. 2009; Austrian Forestry Report 2008). The society demands for multiple purpose forestry with an emphasise on biodiversity. Additionally, also forest owners re-discovered the great potential of valuable broadleaved tree species to produce highly priced timber under the condition that a good quality is guaranteed (Leibundgut 1976; Schramml and Volz 2009; Becker and Klädtke 2009). New research projects aiming at innovative management regimes in forestry, but also at the interface with agriculture and new ways of multiple land use namely agroforestry are attempted (Reeg et al. 2009). A sustainable forest management has to produce a surplus (Leibundgut 1976). However, in the past decades the labour cost rose and the timber price decreased, and thereafter the Austrian forestry seeked for more efficient management opportunities such as high quality timber of broadleaved tree species (Schmid 2005). The higher revenue of good quality timber generates an outcome which is many times more than the costs whereas low quality does not even cover the costs (Schmid 2005). Even though the price and the wood demands depend on fashion, high quality was always demanded and highly priced (Spiecker et al. 2009). As an example, recent submissions in Austria of the years 2003 and 2005 were resulting in mean revenues of 300 € per m^3, though attaining maximal prices over 1000 € for a range of species (oak, maple, cherry, etc) (Schmid 2005).

1.4 Silvicultural technics and thinning

Thinning instructions have changed tremendously since the 19^{th} century, when quantitative reductions were prescript rather than the more specific spatial growth arrangements of single trees and the focus on individuals (Pretzsch 2009). Assmann (1961) and subsequently Mitscherlich (1969) recommended clear definitions of thinning and tending operations such as:

- the kind of thinning, for instance geometric or selective,
- the severity of thinning quantifying the removal at the respective thinning operation,
- and the intensity meaning the repetition of operations in a time scale over the entire rotation period.

The overall aim of the three thinning factors is to quantify systematically the thinning treatments for the whole stand, but as well individually for elite trees (Pretzsch 2009).

In practice, the kind of thinning defines how the selection and promotion of the most vigorous individual trees are conveyed. Over time the thinning regime is increased in two possible ways: (1) elite trees are selected due to quality, stability, vitality, spatial distribution etc. or (2) the kind of thinning is applied in a geometric way by removal of each 2^{nd}, 3^{rd}, …, the whole row or defining a threshold distance. The severity of thinning instead describes the quantity of how many trees per thinning are removed according to parameters such as target basal area, tree number per hectare, stand density index or by applying competition indices. For instance, the kind of thinning defines that the removal is applied in a geometric way namely threshold distance. Thereafter, the severity defines the radius around the central tree in meters. In contrast, the competition index defines the competitors around the central tree which has to be removed until a defined value is reached (e.g. A-Value from Johann). As a consequence the subject tree is released individually. The intensity of thinning describes the frequency during a rotation period being for instance defined by the age (or tree size) of the first and the timepoint (or tree size) of the subsequent thinnings. Those specific concepts of silvicultural prescriptions are developed in Europe in a kind, that measures for the stand and for individual trees are defined adequately.

1.5 Forest Protection

It is of particular interest whether pathological threats are menacing the objectives and aspiration of this trial which serves as a pilot study for future management plans and where a substantial monetary amount was already invested in. The good reputation built up by governance initiatives on communal and private owner level in order to choose site adapted and indigenous species is threatened and forest owners are discouraged to shift from conifers to broadleaves by pests and diseases. In the stand of research a severe dieback of the ash shoots, branches and the tip was observed, especially if clusters of merely ash grew in the stand structure. Further, bark cracks at maple were observed, leading to the dieback of several individuals of all age classes, affecting one future crop tree in particular together with all competitors nearby, so that this tree had to be removed from the list of elite trees. While the ash dieback is a recently occurring but established disease with many studies being conveyed, the phenomena of maple bark cracks at sycamore are yet at the beginning of research. Cech (2007) described the introduction of the invasive pathogen *Eutypella parasitica* from North America as causal agent for the bark cancer of maple in Austria, causing lesion invisibly underneath the bark and finally, long cracks become visible. To prove evidence of the cause of the bark cracks in Karnabrunn samples should be taken and analysed the laboratory.

Figure 1.5-2 Severe dieback of common ash in clusters (left, main affected trees are marked with red arrows) and maple bark cracks (right) in the study are in Karnabrunn; an identification of the causal agents is pending

Pathological Side Note:

In the recent decade, the **ash dieback** became a severe issue for forest protection in Austria and at European level; especially in Baden-Württemberg and North-eastern France the situation becomes more severe (Schröter 2008). The phenomenon is increasingly observed at ash of all age classes, independent of factors such as regeneration, species mixture and site factors (Kiristis and Tech 2010, Habermann 2008). In the past four years, the fungi has been isolated and described in a wide range of locations all over Austria including every federal state (Kiristis and Tech 2010, EPPO 2010). Further, many European countries reported the presence of the fungi in their forests and recognised it as the causal agent of the disease. The ash dieback causes either the death particularly of younger individuals or a dieback of shoots and branches affecting the individuals in reduced growth and predisposing the tree to other pests and diseases (Kiristis and Tech 2010). Further, bark necrosis, discoloured wood and shedding appear in the course of the disease.

It could be proven that the pathogen of the ash dieback is most likely the micro fungi *Chalaria fraxinea* being recently found and described in Poland, in 2006 (Kiristis and Tech 2010). Nonetheless, the biology of the pathogen had been a mystery as the spore-producing bodies were rarely found and the propagation and transmission had been unknown (Kiristis and Tech 2010, Queloz et al. 2010, Kowalski and Holdenrieder 2009). In 2010, it was reported that the sexual stage of *Chalaria fraxinea* was indentified as *Hymenoscyphus pseudoalbidus.* This sexual stage is almost identical to the harmless fungi *Hymenoscyphus albidus,* described since 1850 and with which the fungi was confused prior to that (Queloz et al. 2010, Kowalski and Holdenrieder 2009). The ascospores are developed and disseminated in mid June until October and transmitted in the air, so that by this mean the ash dieback was rapidly spread and propagated all over Europe (Queloz et al. 2010, Engesser et al. 2009). The extent of the damage becomes obvious especially in spring when the dieback of branches and shed leaves can be observed.

The research front currently investigates the origin of this newly described fungi and possible reasons for its sudden outbreak as a pathogen. It is not proven wether the common harmless *H. albidus* mutated or wether the anamorph *Chalara fraxinea* is an invasive species being in its telemorph stage morphologically identical with *H. albidus* or wether the climate provided an optimal starting position for its propagation (Kiristis and Tech 2010). For the study area in Karnabrunn no samples are taken so far. Nonetheless, it is of special importance that sound laboratory work examines wether or not the fungi can be isolated and therefore proves the occurrence in Karnabrunn that in the course of action respective measure can be taken.

1.6 Objectives and Hypothesis

1.6.1 Objectives of the experimental plots

The research plot in Karnabrunn is characterised by a diversity of broadleaved tree species mixed with few coniferous species, especially Scots pine and singular larch, forming an interesting and attractive deciduous forest for silviculturists and nature lovers. The forestry business of the family Koller and support of the LLWK Niederösterreich (Lower Austria) by DI Karl Schuster and DI Heinz Steindl, made it possible to establish these experimental plots to study how to use successfully the natural potential and resources of this stand in an ecological and economical way.
Generally, the aim of the study is to increase the knowledge of managing valuable broadleaved tree to optimise the species-specific production period. For this purpose, the single tree oriented management approach (Oosterbaan et al. 2009) was combined with a hierarchical selection process of the tree species. This is inevitable when shifting to a single tree oriented management plan operating with such a diversity of species. The specific objective of the trial is the growth of high valuable timber aiming at:

- a dbh of 60 cm,
- a branch less bottom log of 6-8 m (=1/3 of the total tree height of 20 to 24 m at the end of the rotation period),
- quality class of the bottom log at minimum A quality.

The production period for the different species are aiming at

- 80 to 100 (120) years for oak,
- 50 (60) years for wild cherry
- And 70 to 80 years for sycamore and common ash.

1.6.2 Objectives of the work

Embedded within this framework the study aims at the investigation of single tree parameters of the future crop trees such as dbh, height and crown characteristics. In a second step those parameters are compared between two thinning variants of different intensity. Competition indices are used so that the competitive situation in the stand per future crop tree can be expressed by a value and used for the stand analyses. The thinning variants differ in intensity defined by a growing space of 2 m in variant 1 (V_1) and 3 m in variant 2 (V_2). Aiming to examine if there developed a significant difference in single tree parameter growth between the variants in the period between 2004 until 2009, the following **hypotheses** (1-3) are tested. Therefore, the null hypothesis H_o and the alternative hypothesis H_I simplify the research questions as seen below

1) H_o: There are no statistical significant differences on average between V_1 and V_2 concerning the single tree parameters height, dbh, crown width, crown length, crown ratio, crown volume and several calculated competition indices.

H_I: There are statistical significant differences on average between V_1 and V_2 concerning the single tree parameters height, dbh, crown width, crown length, crown ratio, crown volume and several calculated competition indices.

2) H_o: No significant correlation exists between i) dbh and crown width and ii) dbh and crown length of the tree species wild cherry, sessile oak, Norway maple, sycamore and common ash.

H_I: A significant correlation exists between dbh and crown width and dbh and crown length of the tree species wild cherry, sessile oak, Norway maple, sycamore and common ash.

3) H_o: The Competition indices do not decrease with increasing growing space.

H_I: The Competition indices do decrease with increasing distance.

2 MATERIAL AND METHODS

2.1 Sampling design and stand history

In the year 1999, 10 quadratic parcels (P_1, P_n,…, P_{10}) each 1600 m² (a=40 m) were established and eight parcels were used for the trial. In the juvenile phase several types of selection were applied as listed below.

A) Negative selection (P_5&P_{10}): Removal of trees with bad quality;
B) Positive selection without pruning/stem shaping (‘Formschnitt’) (P_1&P_6): trees of good quality and vitality are selected and marked, further those selected trees should not be closer than 3 to 4 m, and within a radius of 0.5 m all trees are removed. A tree located farer than 0.5 m is only removed if it reaches the first third of the selected tree’s crown.
C) Positive selection with pruning/stem shaping (P_3&P_8): The same procedure than in B), and additionally the trees are pruned until a height of 3m.
D) Unmanaged (P_2&P_7): no treatment.

In the years 1999 and 2004 in the centre of the parcel an area of 200 m² was defined for data collection (measured trees were marked with a serial number on a metal plate). Thereafter, in the year 2004 the survey areas were enlarged to the entire parcel size of 1600 m². With this

Table 2.1-1 Overview of silvicultural operations from establishment to date in a chronological order

Year	Operations	Parcel size
1991/2	Establishment	
1999	1) Tending 2) Inventory (dbh > 3 cm)	200 m²
2001	Inventory (dbh > 3 cm)	200 m²
2004	1) Future crop tree selection, thinning, pruning 2) Inventory > 8cm dbh 3) Inventory (dbh > 3 cm)	1600 m² 1600 m² 200 m²
2009	Inventory > 8 cm dbh	1600 m²

operational step the juvenile phase proceeded into the pole wood phase as the candidates became future crop trees. The sampling design was established by the initiators of this trial and therefore unchangeable. The samples taken were not randomly distributed as the growth of the future crop trees were examined and so the whole collective of future crop trees were measured. The sample size was dependent on the number of each species as future crop tree.

For a chronological overview the following
shows the silvicultural prescription of the experimental plot Karnabrunn.

2.2 Thinning factors

The presented thinning factors of chapter 1.4 are important for a clear description of the management practices. In Karnabrunn, the *kind of thinning* was done as a selection and promotion of the most vigorous individual trees in the first quarter of the rotation age. The three most dominant species were common ash, sycamore and Scots pine, even though pine was characterised by unsatisfying vigour and quality. In the course of succession, pine was outcompeted and replaced by hornbeam in the period from 1999 till 2001. The stem number increased despite thinning operations in 2001 representing the juvenile power at the time being. Candidates being selected for possible elite trees in 2001 as described above with stem numbers differing from 450 to 650 N/ha. The final elite tree selection was done in 2004.

The *severity of thinning* was kept in a way that a dense crown cover promotes height and diameter growth in the first half of the rotation period. The thinning operations in the different parcels led to a mean stem number reduction of 3900 to 3120 trees per ha (calculated from: 17 to 126 stems in the 200 m² parcels). Thereafter, in the second half of the rotation period the thinnings were intensified to promote the dimensioning of the ultimately superior trees.

The *intensity of thinning* is described as frequency of repeated operations. In the juvenile phase, the tending was done in a 3 year cycle (1999-2001-2004), and a 5 year cycle in early-pole stand phase (2009/10). The final harvest takes place after the respective target diameter is reached.

The final silvicultural prescription for the future crop trees in this study can be described as a single tree oriented management or *individual tree based thinning*, based on the following techniques (Pretzsch 2002).

- The release of central trees by managing the severity of thinning according to a defined liberation radius.

- A distance-dependent competition index can be used for the central trees in a way that competitors are removed by a planned tree removal until a defined CI is reached. In this study, the tree removal followed a defined radius and thereafter the competition index was measured aiming at comparing the two thinning variants.
- In contrast to a sequential tree removal by competition indices, pair-wise comparisons of subject tree *i* and neighbour *j* identifies whether a tree in vicinity is a competitor or not. As an example by adopting the A-value from Johann (1982) the tree is released individually in this method.

2.3 Singel tree oriented management

Future crop trees

Individuals were searched with satisfying criteria of quality, vigour and distance. The selection process for the future crop trees was applied according to a species hierarchy developed by Hochbichler et al. (2004). Sessile oak was considered to be the most desired future crop tree followed by sycamore and wild cherry, larch, common ash and lime. This specific selection hierarchy represents economic concerns in order to choose valuable and marketable crop trees, as well as scientific curiosity in order to choose uncommon species as well as the preference of certain species by the forest owner. The next constraint in the selection process is a minimum distance of at least 8 m (dbh of 40 cm) and 12 m (60 cm) between two crop trees. Furthermore, showing a branch length of 5 m, the branch diameter should be less then 4 cm for oak and cherry, and less than 3 cm for sycamore and ash.

Competitors

As a precondition every tree within a radius of 1 m around the future crop tree had to be removed. Two further thinning methods were applied:

Variant 1 (V_1): Crown liberation in a radius of 2 m (2004) and 4 m (2009/10) in three parcels (2 replicates).

Variant 2 (V_2): Crown liberation in a radius of 3 m (2004) and 6 m (2009/10) in three parcels (2 replicates).

Variant 3: Unmanaged.

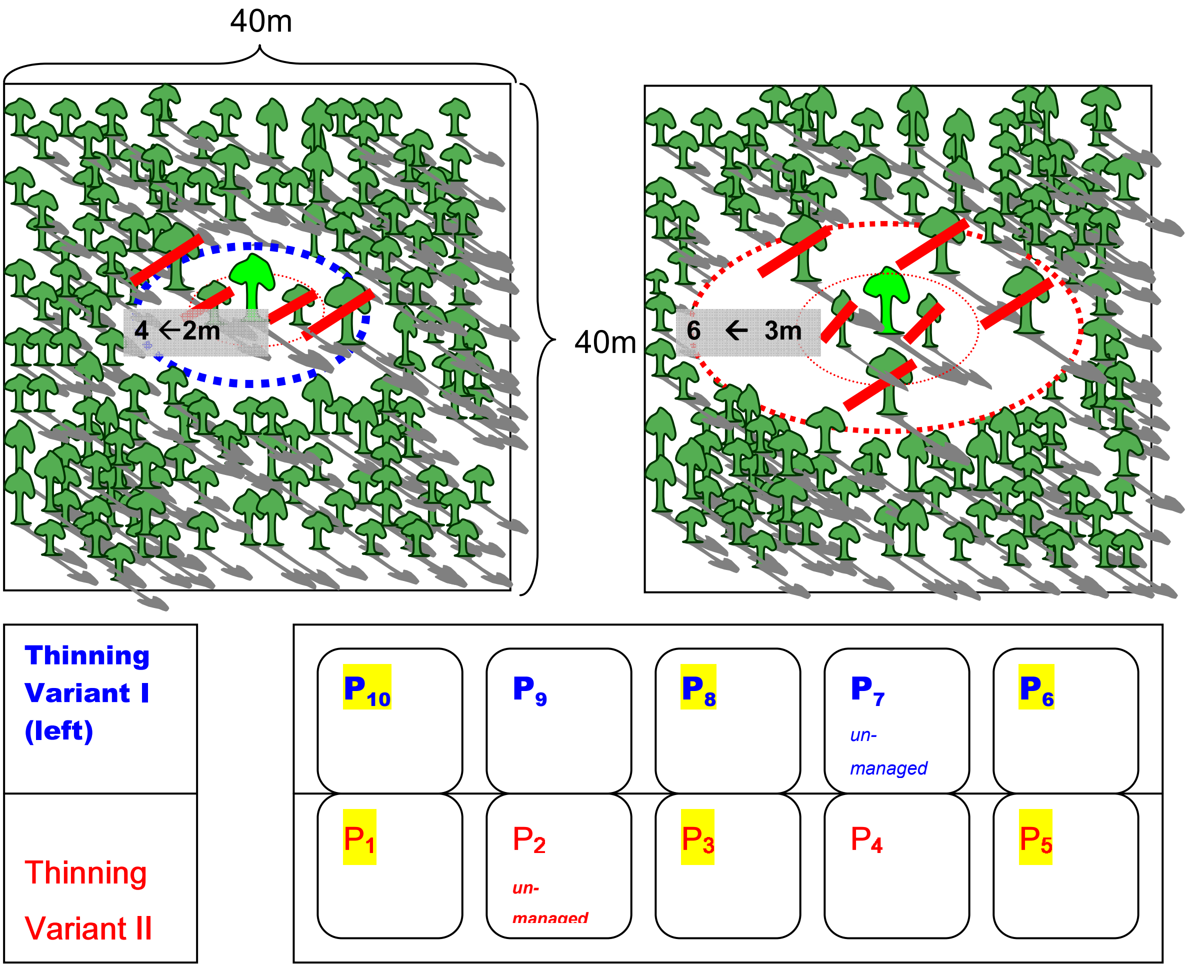

Figure 2.3-3: Illustration of the sample design by the thinning variants I and II and their respective parcels indicated by colour and font; the highlighted parcels are the sample plots for this research with three replicates for each variant; above, the individual tree based thinning is described on the left for variant I indicating the threshold distance around the subject tree from 2 m doubled to 4 m and on the right for variant II indicating the threshold distance around the subject tree from 3 m to 6 m

After 5 years, the liberation radii are doubled, so that the future crops trees in thinning method 1 are released within a 4 m radius before the current growing season in 2010, and in thinning method 2 within a 6 m radius. The specific sample design is illustrated in the model of Figure **2.3-3**. In this work, only the effect of the first liberation radius of 2004 can be examined. The current wider liberation radius of 2010 is examined concerning the competition of the removed trees on the future crop tree, so that in ongoing research the effect of their removal can be analysed in further studies.

To date, the future crop trees experienced two different types of liberation radius with a difference of one meter. This difference of the radii amounts in a spacing difference around the future crop trees of 12.6 m² in V_1 and 28.3 m² in V_2. The reactions to the applied thinning operations doubling the radius from 2 to 4 and from 3 to 6 m will be analysed at the next tending interval and can not be object of this study.

2.4 Tree measurement

Around the future crop trees, a radius of competition was defined in 2004 and enlarged after five years as explained above. For all competitors inside the circle the basic tree measurements were taken such as dbh (> 8 cm), height, crown base as well as the distance and angle to the competitor. The measure tools used are:

- dbh measure tape
- Vertex® height measure tool
- Tape measure (50 m)
- Suunto® compass

The crown extension was measured in 8 solar azimuths from north-east to south-west for all future crop trees. The procedure was done by two persons: one person holding the measure tape, the Suunto® compass plus the writing board close to the stem and the second person, being instructed concerning the direction, was standing underneath the greatest extension of the crown and reading the distance from the stem on the measure tape. Additionally, 15 trees per parcel and per species of the competitor collective were selected in order to measure height, crown base and crown extension for the calculation of the height curves. Regression models were used to predict out of the sample the remaining unmeasured individuals. The measurements of the future crop tree collective were done in October 2009 and the competitor collective in March/April 2010.

2.5 Calculation of tree measures

The basic measurements are used to calculate more variables which are important for stand characteristics and single tree parameters. In the following a list of the calculated parameters is given:

Slenderness

The slenderness defines the relation between height and diameter and is computed

$$\frac{h}{d_{1.3}}$$

where h is height and $d_{1.3}$ is the diameter at breast height. In a pure even aged forest, the h/d would decrease with increasing diameter (Kramer and Akça 1982).

Basal area

The stand density characterises the productivity of a stand in order to estimate its yield (Sterba 1981). In central Europe, mainly the stand basal area per hectare is used to describe the stand density (Kramer 1988)

$$BA = {d_{1.3}}^2 \cdot \frac{\pi}{4} \div 100$$

where BA is the basal area per hectare and $d_{1.3}$ the diameter in breast height.

Form factor

In order to obtain the tree volume we assume a cylinder form of the stem with height h and a basal area $ba_{1.3}$ at 1.3 m height. The form factor $f_{1.3}$ gives the reduction factor from the cylinder volume to the real tree volume (Pretzsch 2009). As the morphology of the stem is different for each tree species, Pollanschütz (1974) calculated the form factors for the important tree species in Austria according to the following function

$$f\ (x) = b_1 + b_2 \cdot \ln^2 dbh + b_3 \cdot \frac{1}{h} + b_4 \cdot \frac{1}{dbh} + b_5 \cdot \frac{1}{dbh^2} + b_6 \cdot \frac{1}{dbh \cdot h} + b_7 \cdot \frac{1}{dbh^2 \cdot h}$$

where b are constants given for each species and diameter class in form factor tables and dbh is the diameter at breast height.

Stem volume

The volume of a stem is calculated with previously defined form factor, including the division of 10.000 in order to obtain m^3 (Pretzsch 2009):

$$V = d^2 \cdot \frac{\pi}{40.000} \cdot h \cdot f_{1.3}$$

where V is the volume, d the diameter at breast height, h the tree height and $f_{1.3}$ the calculated form factor (Pollanschütz 1974).

Crown length

The crown length is defined from the base of the first green branch for broadleaves and from the base of the first three green branches for conifers to the tip of the tree

$$cl = h - cb$$

where cl is the crown length, h the total height and cb the crown base (Kramer and Akça 1982).

Crown projection area

The projected area of the crown is calculated

$$cpa = r^2 \cdot \pi$$

where cpa is the crown projection area and r the quadratic mean of the radius(Kramer and Akça 1982).

Crown length/width ratio

$$l / w = r^2 \cdot \pi$$

where l/cw is the crown length/width ratio and r the quadratic mean of the radius (Kramer and Akça 1982).

Volume of the truncated cone

This variable is used for calculation of the volume of the shade crown

$$V_{tc} = \left(\frac{h \cdot \pi}{3}\right) \cdot \left(R^2 + R \cdot r + r^2\right)$$

where V_{tc} is the volume of a truncated cone and R & r are the radii of the two bases (Assmann 1961, Pretzsch 2009).

Volume of the cone

The volume of the cone is used to compute the light crown of coniferous tree species

$$V_c = \left(\frac{1}{3}\right) \cdot r^2 \cdot \pi \cdot h$$

where V_c is the volume of a cone; and r is the radius of the bases and h the height (Kramer and Akça 1982, Assmann 1961, Pretzsch 2009).

Volume of the paraboloid

For broadleaved tree species, the volume of the light crown is calculated

$$V_p = 0.5 \cdot r^2 \cdot \pi \cdot h$$

where V_p is the volume of a rotating paraboloid and r is the quadratic mean of the crown radius of the bases and h the height (Kramer and Akça 1982; Assamann 1961; Pretzsch 2009).

Volume of the ellipse

For simple approaches to calculate the crown volume of broadleaved tree species the form of a rotating ellipse is assumed

$$V_e = r^2 \cdot cl + \frac{\pi}{3} \cdot$$

where V_e is the volume of a rotating ellipse, r the quadratic mean of the crown radius and cl the crown length (Hagemann 2002; Kramer and Akça 1982).

Crown shape model

The description of the crown form first distinguishes between shade and light crown. The volume is separately calculated according to specific parameters for different tree species (Pretzsch 2009; Gadow 2003). The two segments are calculated applying mathematical formulas of geometrical forms already described.

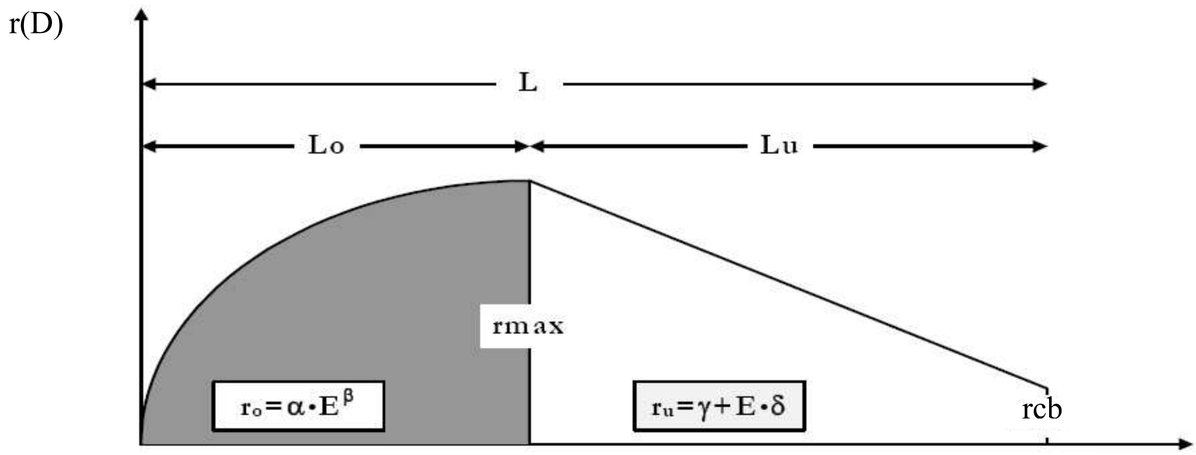

Figure 2.5-4 Cross-section of a laying crown where r(D): crown radius at a certain distance from the top; r(u): crown radius at the area of the light or shade crown; rmax: maximal crown radius, rcb: crown radius at the crown base; α, β, γ, δ: tree specific parameters (Hussein, 2001; Gadow 2003)

The tree specific parameters are given by Pretzsch (1991, in 2009) for the important tree species in central Europe (see Appendix).

Mean height (Lorey 1878)

Lorey's mean height h_L (1878) is weighted by the basal area of diameter classes and corresponds to the mean basal area of the tree (Lorey 1878, in Kramer and Akça 1982). Lorey' mean height is calculated from

$$h_L = \frac{n_1 ba_1 h_1 + n_2 ba_2 h_2 + ... + n_k ba_k h_k}{n_1 ba_1 + n_2 ba_2 + ... n_k ba_k} = \frac{\sum n_i ba_i h_i}{\sum n_i ba_i}$$

where n_i represents the number of trees in diameter class i, ba_i is the basal area of a tree in the given diameter class, h_i is the mean height in the diameter class and k the number of diameter classes. The stand height curve provides the height in the diameter class h_i in relation to the corresponding diameter d_i. The simplification of the Lorey height stratifies the stand into five classes with the same tree number of same basal area

$$h_L = \frac{h_1 + h_2 + h_3 + h_4 + h_5}{5}$$

where h_1,…, h_1 represents mean heights in classes with the same tree number or same basal area.

The Loreay mean height is famous being used in many yield tables as a robust description of the stand height (Kramer and Akça 1982; Pretzsch 2009).

Height curve

The height and the diameter of a tree show a non-linear statistical correlation due to the normal physiological behaviour of a tree (Pretzsch 2002). The diameter-height correlation of an even-aged stand can be modelled graphically by regression analyses on basis of the characteristic increase of the height with increasing diameter. The applied height curve of a stand results in a statement of the characteristic correlation of the two variables diameter and height at the specific time when the samples are taken. Hence, the height measurement can be reduced so that the non-measured heights can be calculated by the compensating curve in dependence of the diameter. Peterson's (1955) and Korsun's (1935) function for even-aged and –structured stands provide the best-fit regression-analytical model (Pretzsch 2002). In order to predict the height, the height curve of Peterson and Korsun are applied. Therefore, the measured diameters and heights have to be transformed.

Peterson (1935):

$$h = \left(\frac{1}{h-1.3}\right)^{\frac{1}{3}} \quad ; \qquad d = \frac{1}{d}$$

Resulting in the linear equation:

$y = a_0 + a_1 \cdot x$ with $y = h \; and \; x = d$

The so derived constant a_0 and the slope a_1 are used for the height calculation seen in the following equation:

$$h = 1.3 + \left(\frac{d}{a_0 + a_1 \cdot d} \right)^3$$

2.6 Competition

The forest ecosystem is an expression of multiple organisms reflecting a living interface of each other and the environment (Burschel und Huss 1986). The single tree growth is an expression of a combined set of factors expressing the competition for scarce resources such as light and nutrients (Burschel und Huss 1986, Leibundgut 1983). The competitiveness of each single plant is the engine for the progressive succession of plant communities which have different demands on the ecosystem (Burschel und Huss 1986). For a successful operational silvicultural prescription those demands needs to be comprehended and only with sufficient knowledge about the age, site and tree competition of the respective community the natural process can be steered according to human objectives (Burschel und Huss 1986, Pretzsch 2009). The social position of a tree within a stand represents the competition it experienced in the past. In contrast, the actual competition altered by liberation induces a reduced stress for the tree and therefore effects the tree growth in the future. Early attempts to describe the social position were described by Kraft (1884) categorising the trees in five crown classes which express the dominant, co-dominant and suppressed position within a stand. Nowadays, thinnings and stem number reductions are not merely dependent on the vigorous growth rather than a set of decision factors including biological and technique-economic parameters. The shift from a stand view to single tree management and concentrating on a few individuals of outstanding quality reduces the impact on site and guarantees especially in deciduous forest a successful yield where high valuable timber is produced (Pretzsch 2009). Altering the competition is the crucial factor in order to steer the growth in fulfilment of the quality and dimension requirements. Therefore, a variety of competition indices were developed in order to quantify the stress and to describe the growth conditions of a tree in its proximate surrounding expressed by a numeric dimensionless value (Mugasha 1989, Pretzsch 2002 & 2009, Ledermann and Stage 2002). This index describing the competition is able to express the change of pressure on a subject tree by thinnings whereas the social positioning from Kraft would still characterise the liberated tree with a high value representing only its dominant position.

For each subject tree, the number of competitors is defined and their effect is quantified depending on the distance between the competing trees (Mugasha 1989). As a result, neighbouring trees of our subject tree represent a competitive value so that in our models the optimal competitive situation for the growth of the subject tree can be predicted (Petzsch 2002, Radke 2002).

All types of CI's represent effects which are explained by distance between competing trees (Radke 2002). However, the competition indices can be differentiated into distance-dependent and distance-independent measurement schemes (Radke 2002, Ledermann and Stage 2002). Distance-dependent CI's include direct distance as a variable in the model while distance-independent CI's assume that single tree parameters such as height or dbh are relying on the available growing space and growth conditions. Hence, the distance between a subject tree and its neighbour is indirectly reflected in the computed distance-independent index (Radke 2002). In this work, only distance-dependent CI's are used as distance serves as a weighting factor when sum of ratios of subject tree dimensions to competitor tree dimension are compared (Ledermann and Stage 2001).

Concluding the above said, the indices are calculated in two steps: (1) Identification of competitors and (2) quantifying the strength of competition resulting in a dimensionless value. Being identified as a competitor once, the same tree can be marked twice as the tree might interact not merely with a single future crop tree. In the following, the relevant CI of this study are listed and shortly described.

Hegyi (1974)

Hegyi uses a ratio of dbh of the competitor and the subject tree,

$$H = \sum_{i=1}^{n} \frac{D_i}{D_j \left(Dist_{ij} + 1\right)}$$

where H is the computed index value, D_i is the diameter at breast height of the competitor, D_j is the diameter at breast height of the subject tree, $Dist_{ij}$ is the distance between the subject tree and its competitor.

Martin & Ek (1984)

Martin and Ek compute the CI as an exponential weighting scheme for relative diameters,

$$ME = \sum_{i=1}^{n} \frac{D_i}{D_j} \cdot e^{-\frac{16 Dist_{ij}}{D_i + D_j}}$$

where ME is the computed index value, D_i is the diameter at breast height of the competitor, D_j is the diameter at breast height of the subject tree, $Dist_{ij}$ is the distance between the subject tree and its competitor and e is the exponential factor.

Biging and Dobbertin (1992)

The CC from Biging and Dobbertin is a similar approach to examine the competition than Hegyi's index, but a ratio is used based on the crown cross sectional area instead on the diameter

$$CC = \sum_{i=1}^{n} \frac{CC_i}{CC_j \left(Dist_{ij} + 1\right)}$$

where CC is the computed index value, $CC_{i/j}$ is the crown projection area of the subject tree and the competitor and $Dist_{ij}$ is the distance between subject tree and competitor.

Pretzsch (1995)

The KKS from Pretzsch uses crown geometry and vertical angles to calculate the index,

$$KKS = \sum_{i=1}^{n} \beta_{ij} \left(\frac{CC_i}{CC_j} \right)$$

where KKS is the index, β_{ij} is a cone set on the subject tree at 66 % of its height with an opening angle of 60°, $CC_{i/j}$ is the crown cross sectional area of the subject tree and the competitor.

A – Wert by Johan (1983)

The A-value from Johann (1982) draws a pair-wise comparison of a subject tree *i* and its neighbour *j* to identify whether a tree in vicinity or is a competitor or not

$$DIST_{ij} < T_{Dist}$$

$$DIST_{ij} < \frac{h_j}{A} \cdot \frac{d_i}{d_j}$$

where T_{Dist} is the threshold distance below which the competitor is removed. A-values which are recommended by Johann are 4, 5 and 6 for even aged pure Norway spruce stands for heavy, moderate and light releases.

2.7 Statistical Analysis

2.7.1 Estimated variables of the collective of competitors

Statistical inference is the scientific approach to represent the whole population by samples as the collection of the entire data range is unfeasible. For the individual tree based analyses for the future crop trees, the samples were taken within the radius of competition defined in chapter 2.6. The dbh of every competitor was measured, in contrast to the height being measured for at least 15 individuals per tree species and plot. The function derived from the linear regression of the variables dbh and height (derived from the height curves from Peterson (1955)), the dbh and the crown length, the dbh and the crown width resulted in the estimated non-measured variables. For the heights derived from the height curve from Korsun (1935) a multiple linear regression was used (see chapter 2.5). Further linear regression was applied in order to analyse the correlation of dbh and crown width and dbh and crown length. The program SPSS 14.0® was used to convey all the statistical analysis.

2.7.2 Analysis of the collective of competitors

The collective of competitors were analysed by descriptive statistics merely not distinguishing between the two variants. Stand data such as dbh, height, d_{100}, h_{100}, slenderness, as well as the mean values of those variables and also the stem number per hectare and the frequency of each species are presented. The stem number is derived from stem counting in sample circles and extrapolating the sample area into hectare. In this case, the radii around the future crop trees provide already the required samples so that no additional sample plots were established. The stems are counted either in the four meter or six meter radius in variant 1 and 2, and then extrapolated into hectare. In case of an overlap of two radii, the sample radii were differentiated and only one sample radius was taken to mitigate double counting of the same trees. Obviously, the 6 m liberation radius in V_2 is characterised by a higher chance of an overlap due to the larger size. Hence, in the respective cases the sample radius of 6 m was reduced to 4 m and by that the overlap was mitigated. The reduced samples of 4 m radii which still showed an overlap were not considered for the calculation.

2.7.3 Collective of future crop trees

The objectives and the resulting hypothesis were explained in chapter 1.6 pointing out the origin of establishment and the resulting diversity after natural regeneration. The practical hierarchical selection method of the future crop trees explained in chapter 1.2.4 guaranteed the highest quality of trees available in this diverse range of species. As a matter of fact, this led to a low stem number per species in the two thinning variants that a sound statistical analysis could not be conveyed for each species. In order to compare the effect of the thinning intensity on each tree species a minimum sample of 7 individuals per variant was set.

As the assumption of equality of variances was not proved, a non-parametric method was conveyed being independent of the distribution of variances to ensure sound results and secure statistical power. The Mann-Whitney U test is a non-parametric test equivalent to the t-test comparing whether or not two independent samples are from the same population by grouping the cases into rank orders (Sachs 1967). Therefore, a transformation of the numerical scale into an ordinal level of measurement is required, so that the statistical inference is based on whether or not the ranks seem to be randomly distributed among the experimental groups (Dowdy et al. 2004). U is the number of times a value in the first rank group precedes a value in the second rank group, when values are sorted in ascending order (SPSS 14.0®). The level of significance (*P*) for all statistical readings is defined as $P \leq 0.05$. The programmes which were used to convey the analyses were Microsoft Excel and SPSS 14.0®.

3 RESULTS

3.1 General view on the collective of competitors

3.1.1 Stand data

The stand data for the collective of competitors are presented in the following table in order to characterise the stand at the time of inventory in 2009/10 with an age of 18 years.

Table 3.1-2 Stand data of the collective of competitors at the age of 18 years in 2009/10 with variables such as tree number per study area and hectare, the mean dominant height and the mean dominant dbh of the 100 most vigorous trees, the slenderness of the dominant trees, the means of diameter, height, slenderness and the stand basal area per hectare

Variable	Short cut	Value	unit
Year of the survey		2009/10	-
Age		18	year
Number of parcels	N	6	
Tree Number per ha	N/ha	3240	-
Dominant height	h_{100}	13.7	m
Dominant diameter	d_{100}	14.6	cm
Slenderness of dominant trees	h_{100}/d_{100}	94	m/cm
Mean diameter	d_q	7.5	cm
Mean height	h_q	10.5	m
Slenderness of mean tree	h_q/d_q	139	m/cm
Total stand basal area	BA	1.2	m²/ha

The total tree number of 3240 N per hectare in the six parcels of the experimental plot lead to a basal area of 1.2 m². The hundred dominant trees show a strong discrepancy in diameter and height to the mean values: for diameter 7.1 cm for height 3.2 m. The slenderness is calculated for the dominant tree and the mean tree. As a result the dominant tree with a slenderness of 94 surpasses significantly the value for the mean tree with an h/d ratio of 139. The stability of a stand is considered to be secured by a value of slenderness below 90 (Hochbichler 2008).

3.1.2 Species distribution and frequency per parcel

The research plot Karnabrunn is characterised by a diversity of species as evolved from natural regeneration. The different species occurring in the stand and their frequency per hectare are shown in the following diagram.

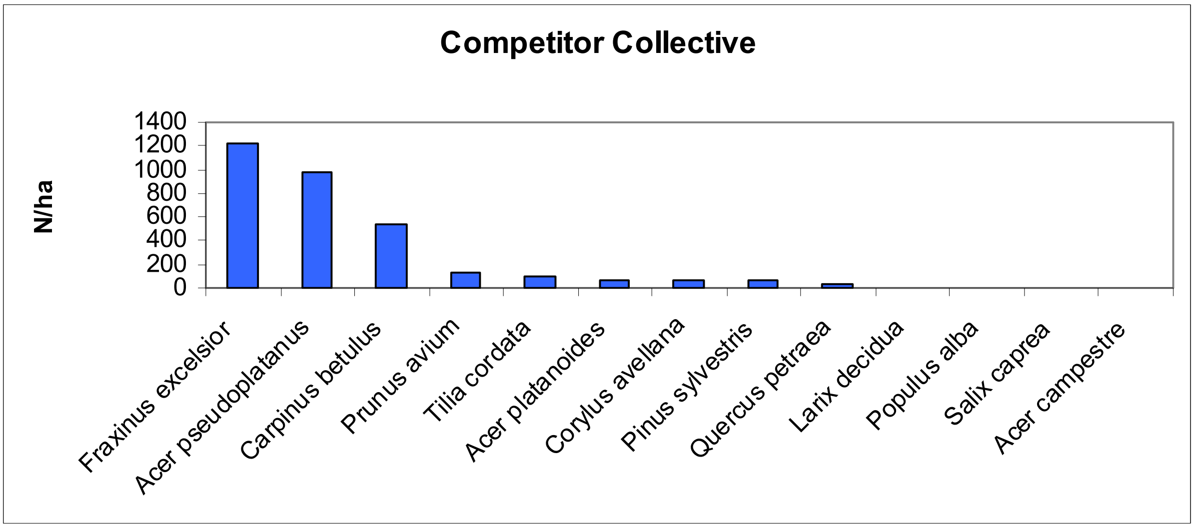

Figure 3.1-5 Stem number per hectare (n/ha) of the collective of competitors presented for the tree species

In total, 13 different species are found in the sample plots. Most frequently were found common ash, sycamore and hornbeam with stem numbers ranging from 500 to 1200 per ha. Wild cherry, lime, Norway maple, hazelnut, Scots pine, and sessile oak can be grouped together, characterised by a low frequency of 136 to 30 stem per hectare. Only singular individuals of field maple, willow, larch and poplar were found.

The 3D- diagram of Figure 3.1-6 is a summary of this diverse situation. Common ash is the most dominant species in total as well as in parcel 1, 3 and 5. Sycamore instead dominates the species distribution in parcel 8 and 10. The third important species, hornbeam, shows only in parcel 6 the highest frequency. The frequency of the remaining is scattered over the parcels and irregularly a small peak is reached. By presenting the species frequency per parcel it can be shown that the situation between the parcels is heterogeneous concerning the species distribution.

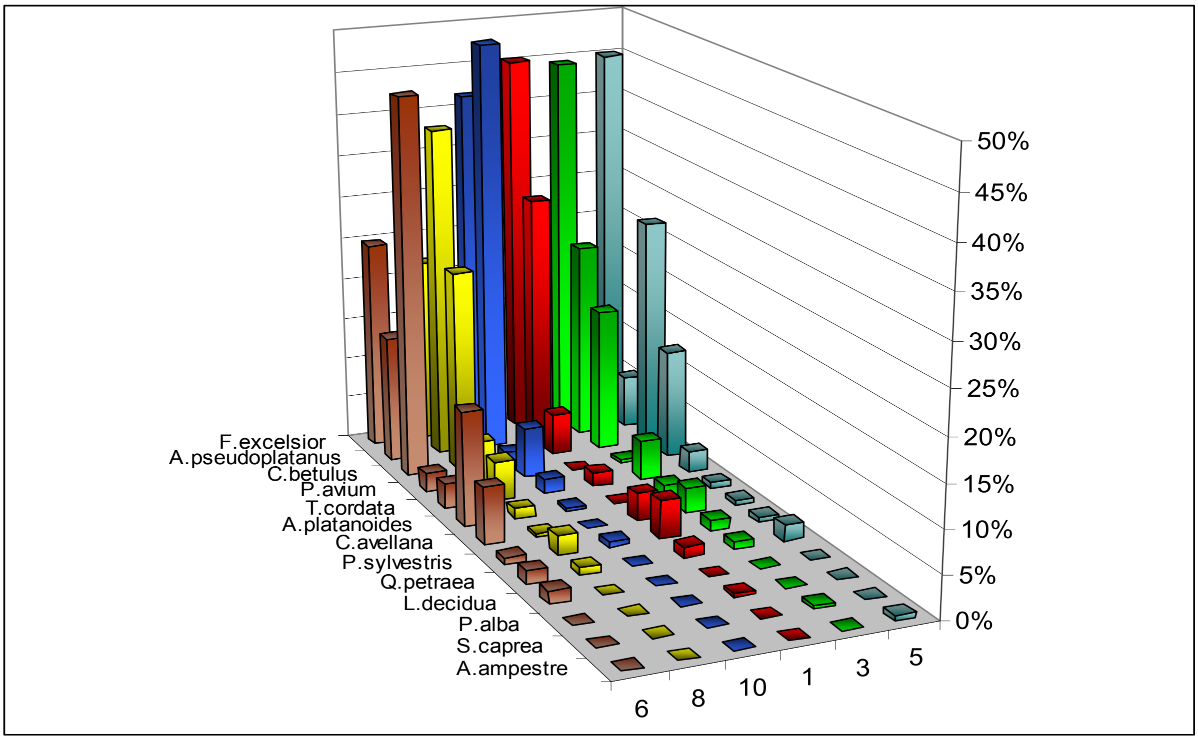

Figure 3.1-6 Tree species distribution of the collective of competitors for each parcel presented in a 3-D bar chart with the frequency in percentage on the y-axes (z-axes), the parcel on the z- axes and the tree species on the x-axes

3.1.3 Stand data per species

In order to create an overview for the collective of competitors Table 3.1-3 presents for each tree species stand variables. Larch, poplar, willow and field maple were found rarely on the sample area.

The dominant tree within the variable diameter is Scots pine with 10 cm, followed by sessile oak and wild cherry with 9 cm (rounded). The lowest dbh was found of hazelnut. The four species common ash, sycamore, Norway maple, hornbeam and lime range between 6.9 and 7.7 (trees sorted ascending).

Common ash is the highest tree in the collective of competitors with 11 m. Scots pine, and hornbeam are the second highest reaching 10.6 m, while sycamore, wild cherry, hornbeam and Norway maple range between 10.1 and 10.4 m. Lime and hazelnut reach 9.6 and 9.5 m, whereas sessile oak grows in average merely 8.5 m.

The basal area of Scots pine and Norway maple was found to be the highest around 1.70 m² per hectare whereas hazelnut is characterised by the lowest basal area of 0.52 m² per ha. The remaining species common ash, sycamore, wild cherry, hornbeam, norway maple, hornbeam, lime, and sessile oak differ in a range from 1.13 (sycamore) to 1.53 m² per hectare.

Hazelnut as a bush represents obviously the highest h/d value. The three most frequent species ash, sycamore and hornbeam are characterised by an h/d value in between 140-150 (rounded). Sessile oak and pine show h/d values of 95 and 107 and hereby, have the lowest slenderness relation of those trees with an acceptable sample size.

Table 3.1-3 Stand data of the collective of competitors for each tree species with frequency (F) and distribution percentage (%), stem number per hectare (N/ha), mean basal area per hectare (BA), slenderness (h/d), diameter at breast height (dbh) and Lorey height (h_L); low sample size for the group of *L. decidua*, *P. alba*, *S. Caprea* and *A. campestre*

Species	F	%	N/ha	BA	h/d	dbh	h_L
F. excelsior	497	38%	1224	1.24	143	7.7	11.0
A. pseudoplatanus	398	30%	981	1.13	141	7.3	10.3
C. betulus	219	17%	540	1.30	149	7.1	10.6
P. avium	55	4%	136	1.31	113	9.2	10.4
T. cordata	40	3%	99	1.10	139	6.9	9.6
A. platanoides	26	2%	64	1.68	140	7.2	10.1
C. avellana	26	2%	64	0.52	173	5.5	9.5
P. sylvestris	24	2%	59	1.72	107	9.9	10.6
Q. petraea	12	1%	30	1.53	95	8.9	8.5
L. decidua	2	.0%	5	3.97	60	14.3	8.6
P. alba	1	.0%	2	3.79	92	14.0	12.9
S. caprea	1	.0%	2	1.95	111	10.0	11.1
A. campestre	1	.0%	2	0.86	128	212	14.2

3.2 Collective of the future crop trees

3.2.1 General view

In this work, individuals of six species met the selection criteria and were marked as future crop tree. The frequency for each tree species is rather heterogeneous and presented in Table 3.2-4. The species sycamore and sessile oak fulfilled the required 7 samples so that a statistical analysis is conveyed. The remaining species common ash, wild cherry, Norway maple and larch are presented in a descriptive way. The two latter occur only in one variation and can not be compared.

Table 3.2-4 Stem number of the collective of future crop trees per tree species and distribution in the respective variant and the unmanaged plot (V_1, V_2, U); The bold marked species sycamore and sessile oak meet the stem number requirements of at least 7 individuals for the statistical analysis

Variant	**Sycamore**	Common Ash	**Sessile Oak**	Wild Cherry	Norway Maple	Larch
N (V_1)	**16**	7	**8**	5	3	3
N (V_2)	**21**	5	**10**	4		
N (U)	**13**	10	**7**	6	4	-

3.2.2 Single tree parameters

3.2.2.1 Diameter at breast height

The mean dbh of sycamore being compared between the two variants only a low significance of 0.069 could be found. For the testing $p \leq 0.05$, statistically no significance has been proven. Though, a significant difference appears between V_2 and U which is statistically ensured. Sessile oak shows only a slight difference between the means of the two variants and therefore non-parametric test for independent samples was not significant for sessile oak. In contrast, the mean of wild cherry varies the strongest with 2.2 cm of dbh between the variants. Larch represents the highest dbh, but its sample size of only three trees is rather small.

Table 3.2-5 Mean diameter (Dbh) and the standard deviation (SD) in variant 1, 2 and unmanaged plot (V_1, V_2, U) presented per specie; significant differences of the means between variants at $p \leq 0.05$

	mean Dbh			SD			Sign. $p \leq 0.05$		
Specie	V_1	V_2	U	V_1	V_2	U	V_1&V_2	U&V_1	U&V_2
Sycamore	11.4	13.1	10.5	2.9	2.8	2.78	0.069	0.786	**0.020**
Common ash	11.3	11.7	11.1	1.5	2.6	3.1			
Sessile oak	11.2	11.3	10.4	2.4	1.5	1.86	0.069	0.456	**0.046**
Wild cherry	13.8	16	12.7	3.4	4.6	3.8			
Norway maple	13.2		9.1			3.5			
Larch	16.3								

3.2.2.2 Height

The statistical analyses were significant neither for sycamore nor for sessile oak, and also not in comparison to the unmanaged plot. A low significance was detected for sessile oak and sycamore with a *p*- value of 0.053 (0.058). It can be noted that Larch is the highest tree, followed by ash. Wild cherry has again a tendency for higher values in V_2, whereas sessile oak shows in contrast higher values in V_1 as an exception to the other species.

Table 3.2-6 Mean height (H) and the standard deviation (SD) in variant 1, 2 and unmanaged plot (V_1, V_2, U) presented per specie; significant differences of the means between variants at $p \leq 0.05$

Specie	mean H			SD			Sign. $p \leq 0.05$		
	V_1	V_2	U	V_1	V_2	U	V_1&V_2	U&V_1	U&V_2
Sycamore	12.1	12.9	13.4	1.8	2.4	1.89	0.254	0.058	0.413
Common ash	13.2	13.8	13.4	1.2	1.5	1.2			
Sessile oak	12.5	11.3	11.4	1.7	1.1	0.61	0.133	0.053	0.475
Wild cherry	11.5	12.3	12.0	1.4	1.7	2.1			
Norway maple	12.9								
Larch	13.9								

3.2.2.3 Crown Width

No statistical significant differences were detected, neither between the variations concerning the species sycamore and sessile oak nor between the variations and the unmanaged plot. Only a small difference could be detected for the mean values of sycamore between U and V_2. The small differences in the crown width of ash and oak are slightly higher in V_1. Sycamore and wild cherry instead show a higher value in V_2 with a radius of 3 m. The first shows only a slight difference while the latter has the widest crown extension with the highest difference between the two variants.

Table 3.2-7 Mean crown width (CW) and the standard deviation (SD) in variant 1, 2 and unmanaged plot (V_1, V_2, U) presented per specie; significant differences of the means between variants at $p \leq 0.05$

Specie	mean CW			SD			Sign. $p \leq 0.05$		
	V_1	V_2	U	V_1	V_2	U	V_1&V_2	U&V_1	U&V_2
Sycamore	3.3	3.7	3.2	0.7	0.9	0.5	0.158	0.683	0.087
Common ash	3.2	3.1	2.6	0.6	1.1	0.63			
Sessile oak	3.5	3.3	3.57	1.0	0.7	1.16	0.536	0.902	0.536
Wild cherry	3.8	4.5	3.3	0.7	1.3	0.8			
Norway maple	3.8		3.3			0.65			
Larch	3.7								

3.2.2.4 Slenderness (h/d)

Statistically, a difference was found for the mean slenderness of sycamore in V_2 compared to U. Further, only low significances were found between U and V_1 as well as between V_2 and V_1. The analyses did not result in any significant differences for sessile oak. Common ash shows similar to the competitor collective the highest h/d values, while wild cherry shows the lowest representing a strong vigour growth. Larch is comparable with wild cherry, while the remaining species sycamore, sessile oak and Norway maple can be grouped together representing an h/d value around 100.

Table 3.2-8 Mean slenderness (h/d) and the standard deviation (SD) in variant 1, 2 and unmanaged plot (V_1, V_2, U) presented per specie; significant differences of the means between variants at $p \le 0.05$

Specie	mean h/d			SD			Sign. $p \le 0.05$		
	V_1	V_2	U	V_1	V_2	U	V_1&V_2	U&V_1	U&V_2
Sycamore	109	100	145	16.7	13.4	90	0.064	0.080	**0.002**
Common ash	118	122	53	98	138	14			
Sessile oak	114	101	112	17.2	10.8	14	0.109	0.710	0.109
Wild cherry	86	80	50	11.8	13	11.2			
Norway maple	100		47			12			
Larch	88								

3.2.2.5 Crown length

The analyses of the mean values of the crown length were not significant for sycamore. For sessile oak instead, significant differences between the means of U and V_1 as well as U and V_2 could be proven by the non-parametrical analyses of the samples with the result that in V_1 and V_2 the crown length is higher than in the unmanaged plot.

Table 3.2-9 Mean crown length (CL) and the standard deviation (SD) in variant 1, 2 and unmanaged plot (V_1, V_2, U) presented per specie; significant differences of the means between variants at $p \le 0.05$

Specie	mean CL			SD			Sign. $p \le 0.05$		
	V_1	V_2	U	V_1	V_2	U	V_1&V_2	U&V_1	U&V_2
Sycamore	5.9	6.00	6.7	1.43	2.06	2.00	0.961	0.294	0.250
Common ash	7.1	6.6	5.9	0.94	2.31	1.6			
Sessile oak	6.3	5.9	4.61	1.67	0.64	0.61	0.270	**0.026**	**0.001**
Wild cherry	6.2	6.9	6.00	0.75	1.1	1.8			
Norway maple	6.0		6.13			1.3			
Larch	7.6								

3.2.2.6 Crown width/length ratio

The statistical analyses of the crown W/L ratio of sycamore and sessile oak result in a statistical significant difference between the variants as well as between V_2 and U. Ash shows the lowest ratio while the other species vary between 0.60 and 0.66.

Table 3.2-10 Mean crown width/length (W/L ratio) and the standard deviation (SD) in variant 1, 2 and unmanaged plot (V_1, V_2, U) presented per specie; significant differences of the means between variants at $p \leq 0.05$

	mean W/L ratio			SD			Sign. $p \leq 0.05$		
Specie	V_1	V_2	U	V_1	V_2	U	V_1&V_2	U&V_1	U&V_2
Sycamore	0.57	0.67	0.50	0.11	0.22	0.11	0.268	0.130	**0.014**
Common ash	0.46	0.51	0.42	0.08	0.17	0.12			
Sessile oak	0.63	0.57	0.77	0.37	0.13	0.20	0.128	0.740	**0.033**
Wild cherry	0.62	0.65	0.56	0.16	0.13	0.13			
Norway maple	0.66		0.09			0.52			
Larch	0.5								

3.2.2.7 Crown volume

The difference in the means of crown volume between V_1, V_2, and U was not proven to be significant for sessile oak and for sycamore. Norway maple and Larch are characterised by the biggest crown, followed by wild cherry and sycamore. Sessile oak shows a considerably lower crown.

Table 3.2-11 Mean crown volume (CV ratio) and the standard deviation (SD) in variant 1, 2 and unmanaged plot (V_1, V_2, U) presented per specie; significant differences of the means between variants at $p \leq 0.05$

	mean CV			SD			Sign. $p \leq 0.05$		
Specie	V_1	V_2	U	V_1	V_2	U	V_1&V_2	U&V_1	U&V_2
Sycamore	19.1	25	20.3	9.6	17.7	9.6	0.542	0.786	0.899
Common ash	20.7	22.3	8.7	8.6	17.8	4.5			
Sessile oak	15.6	13.0	13.3	8.0	4.2	7.9	0.669	0.620	0.887
Wild cherry	16.9	27.6	13.6	5.6	18.6	7.2			
Norway maple	24.1		13.3			6.6			
Larch	24.5								

3.3 Relation of crown parameter and diameter

3.3.1 Crown width and diameter

The tree species sessile oak, wild cherry, sycamore, Norway maple and common ash are analysed based on the correlation between their diameter and the crown width (see Figure 3.3-8). All species show a strong correlation whereas common ash and sycamore show the greatest correlation. The mean R^2 indicates that the variance of the independent variable is explained by 75 %. The crown width of wild cherry and Norway maple correlates slightly less, though signifying a strong correlation expressed by an R^2 value of 0.70 and 0.63, whereas sessile oak is characterised by a medium correlation between the two variables and by the weakest relation of the four tree species with an R^2 of 0.55. All the linear regression models were significant, and as a result the relations between crown width and diameter of all the species are statistically proved.

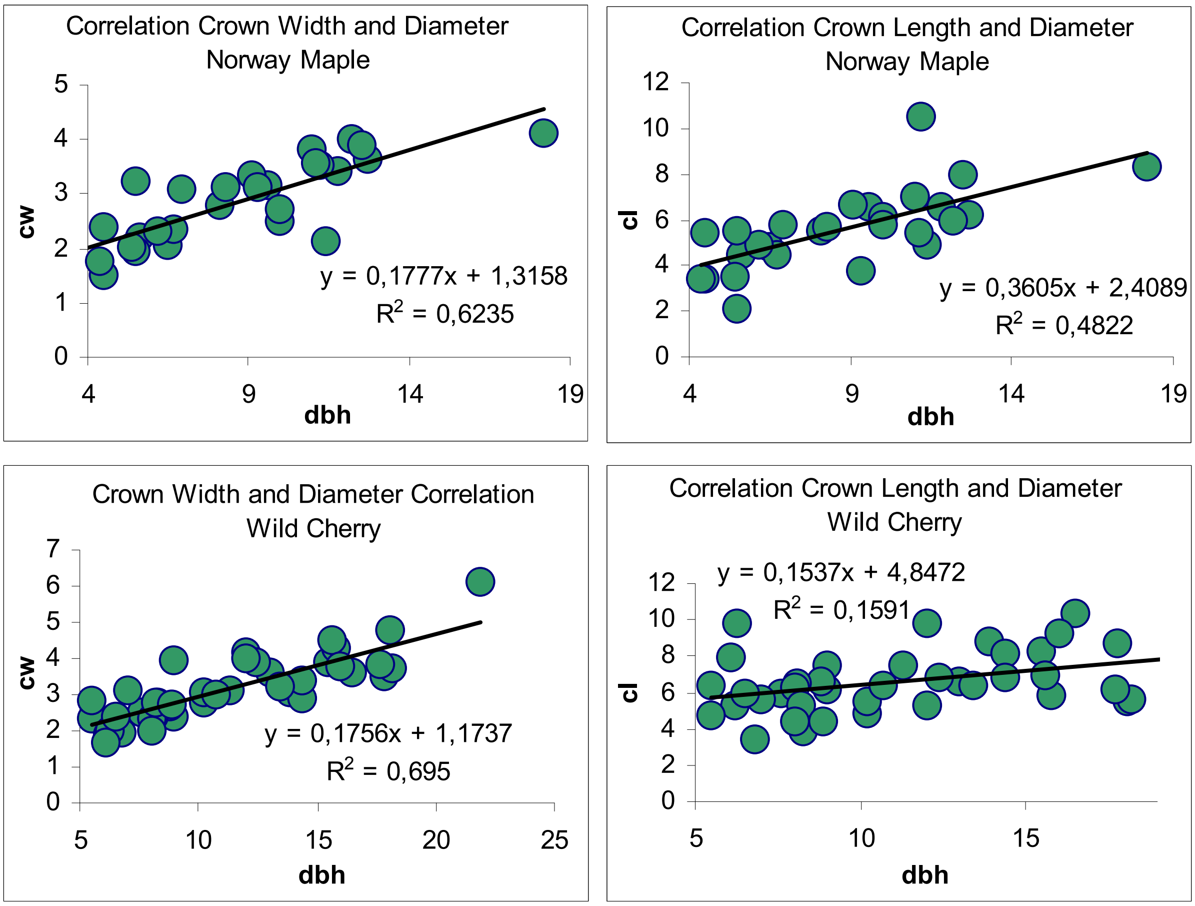

Figure 3.3-7 Correlation of crown width (cw) with diameter (dbh) on the left and crown length (cl) with dbh on the right for wild cherry and Norway maple. The R² signifies the degree of correlation with a range form 0 to 1

3.3.2 Crown length and diameter

The correlation of the above mentioned species between the variables diameter and crown length is less strong in comparison with the diameter - crown width relation as all the species are characterised by a lower R^2 (see Figure 3.3-8). Nonetheless, all the regression models were significant for all the species. Common ash shows the greatest correlation where the dependent variable crown length can be described by the diameter with a probability of 55 %. The range of the remaining species can be described within 40 to 48 %. Wild cherry is an exception characterised by the lowest R^2 of 0.16 and therefore the crown length can not be described by dbh very precisely.

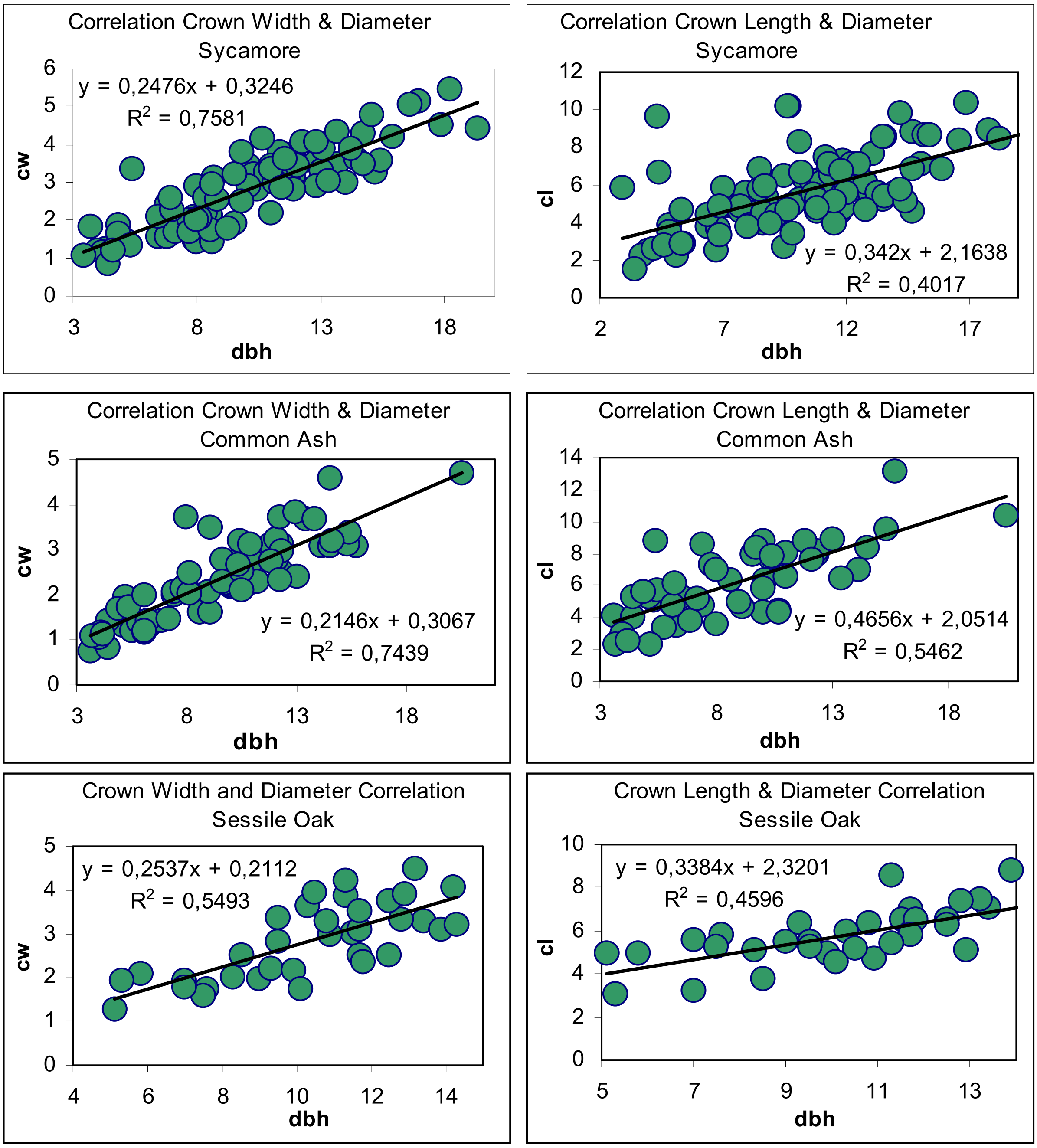

Figure 3.3-8: Correlation of crown width (cw) with diameter (dbh) on the left and crown length (cl) with dbh on the right for sycamore, common ash and sessile oak. The R² signifies the degree of correlation with a range form 0 to 1

3.4 Competitive situation

3.4.1 Distance effect on competition

The competition indices were tested in linear regression analysis whether the CI is reduced with increasing distance within the limits of the 6 m radius or not. The specific CI's perform in a different manner when distance is increased (see chapter 2.6). Martin and Ek reflect the strongest correlation between distance and CI, represented by an R^2 of 0.38.

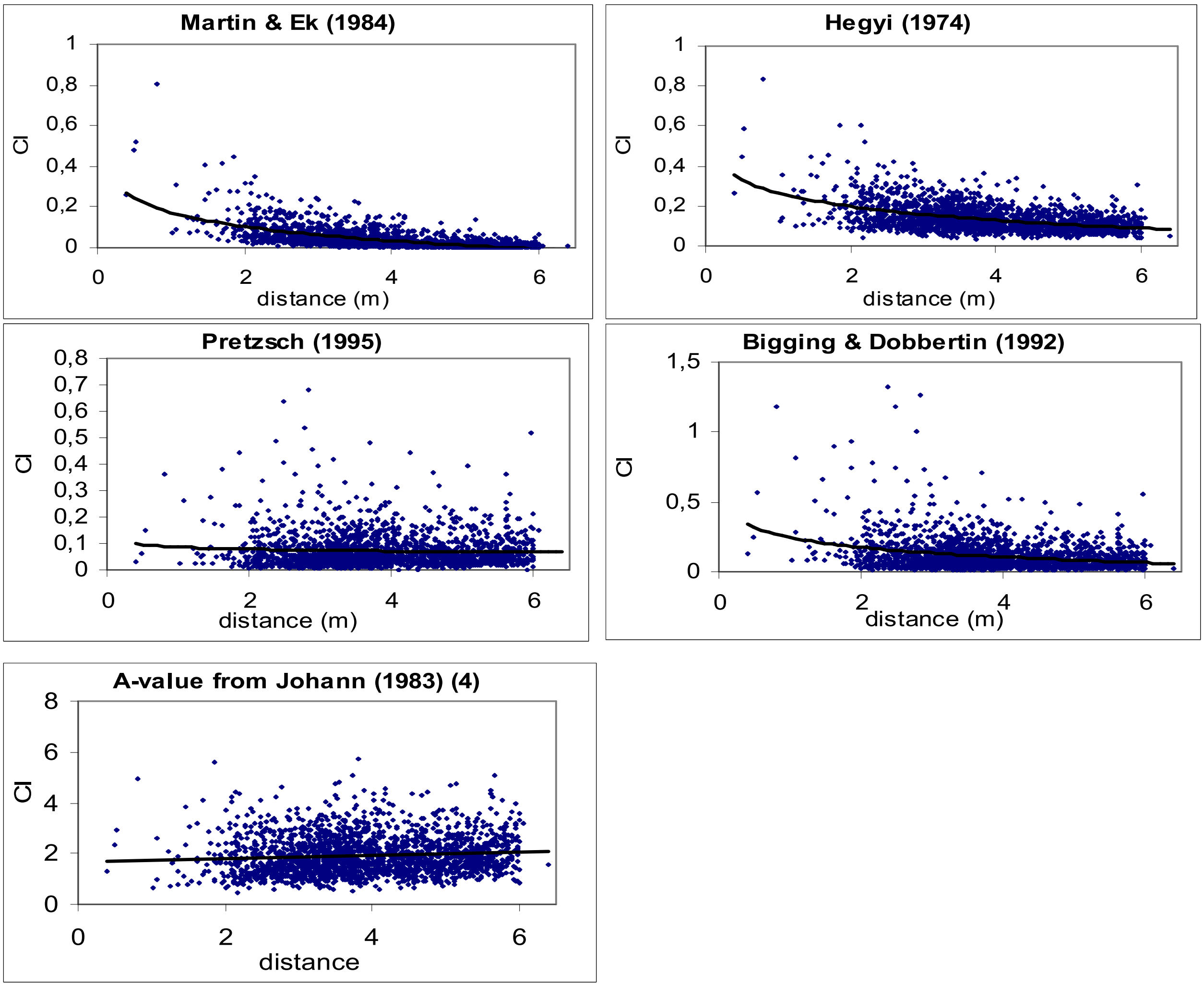

Figure 3.4-9: Competiton indices from Martin and Ek, Pretzsch, Biging and Dobbertin and the A-value from Johann and their correlation with increasing distance

Hegyi's index performs in a similar way, even though only 21 % of the variances can be explained by the independent variable compared to 38 % of Martin and Ek. In contrast, Bigging and Dobbertin's CC, Pretzsch's KKS and Johann's A-values do not show a correlation with increasing distance (R^2 values of 0.0771, 0.0028 and 0.008). The three A-values from Johann (4, 5, 6) show all nearly the same results so that only the value 4 was taken as an example.

In the range from 4 m to 6 m, the competitors still show a great effect on the subject tree expressed by the CI. Especially KKS, CC and the A-value show a lower correlation to the distance and competitors are able to reach high CI values also from farther distance depending on their single tree parameter such as height, dbh and crown variables. However, in ME and H the distance seems to be a stronger correlation factor. This fact is underlined showing the following chart in chapter 3.4.2:

3.4.2 Competitor range effect on CI

The releasing radius around the subject tree is an important variable in the CI's. In Figure 3.4-10 the specific CI of Hegyi, Martin and EK, Biging and Dobertin and Pretzsch is shown for a threshold distance of 6 m and 4 m in V_2. The bars correspond to the total value by applying a radius of 6 m around the subject tree and additionally the green part in the bars simulates the CI after using the reducing subtrahend of 2 m. In other words, the green bars signify the share of the total CI if the thinning scheme of V_1 would have been applied.

Obviously, the CI decreases by reducing the competitors in a thinning scheme as the index is always a sum of competition factors of all neighbours marked as competitor. Nonetheless, an interesting fact is that the increase of the threshold distance by two meters from 4 to 6 leads to a double competition index value in Hegyi's and in Biging and Dobbertin's approach while Pretzsch's KKS is even slightly higher indicated by the increase in percentage. Martin and Ek's index instead increases with only 36 % to a lesser extent. The A-values by Johann increase by 65 % and show a similar response on extension of competitor range than the KKS.

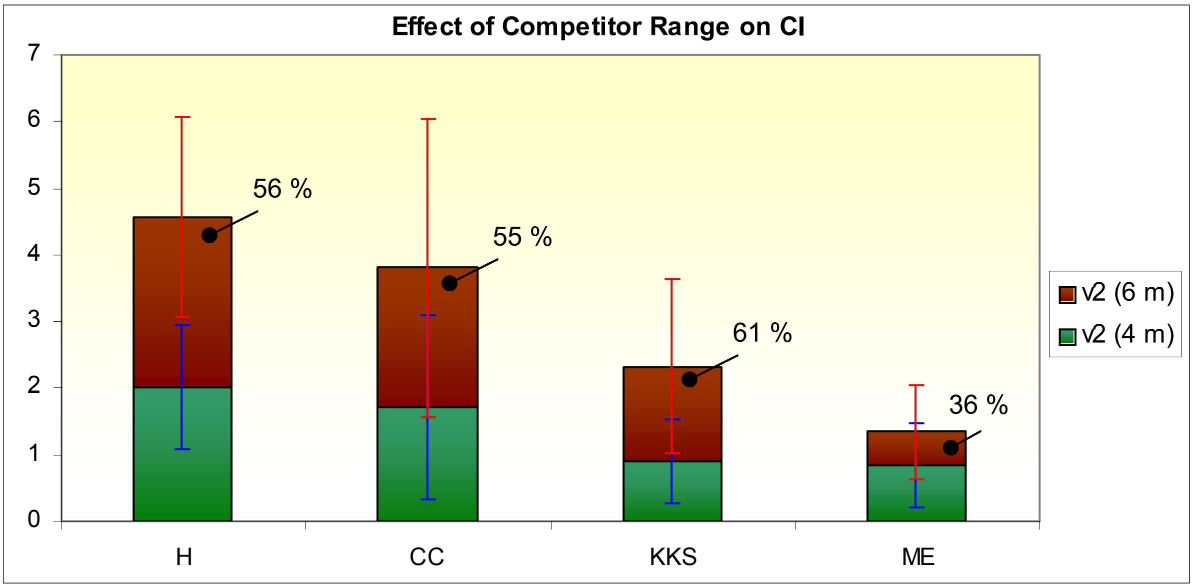

Figure 3.4-10 Competition indices (CI) of Hegyi (H), Biging & Dobbertin (CC), Pretzsch (KKS) and Martin & Ek (ME) in variant 2 (V_2) for a competitor range of the total 6 m (brown) and the reduction to 4 m (green); percentage given for increment of CI value; (errors bars red: standard deviation of V_2 (6 m), errors bars blue: standard deviation of V_2 (4 m)

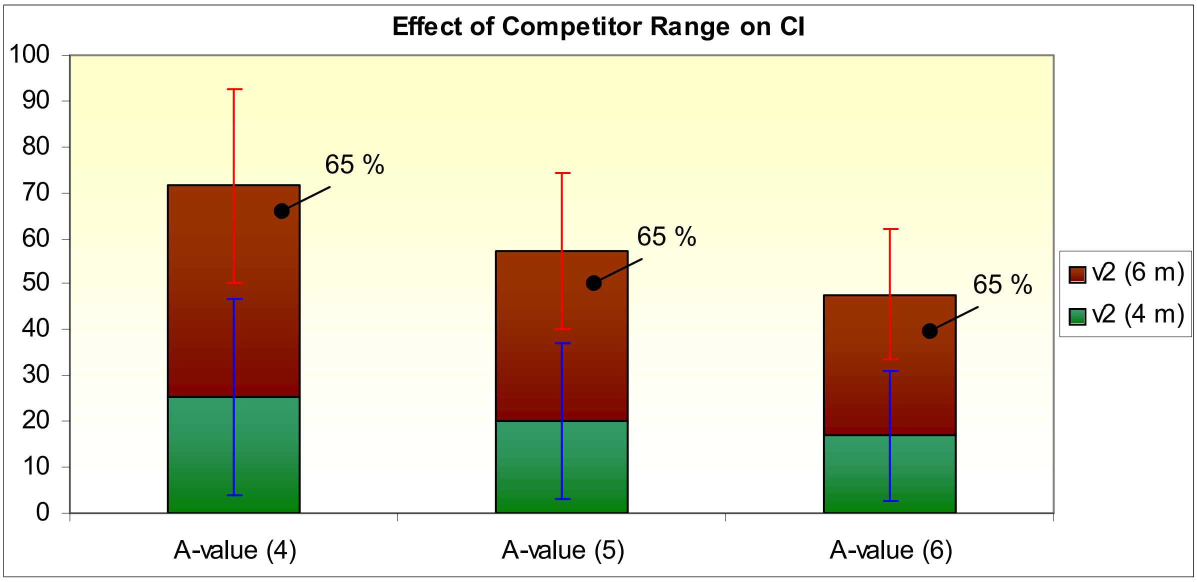

Figure 3.4-11 Competition indices (CI) of Hegyi (H), Biging & Dobbertin (CC), Pretzsch (KKS) and Martin & Ek (ME) in variant 2 (V_2) for a competitor range of the total 6 m (brown) and the reduction to 4 m (green); percentage given for increment of CI value; (errors bars red: standard deviation of V_2 (6 m), errors bars blue: standard deviation of V_2 (4 m)

3.4.3 Effect of thinning schemes (V_1 and V_2) on the CI

Shifting from the more generalised view of the distance effect of the applied CI's in the previous chapters, in this chapter the comparison between the variants are presented. In Figure 3.4-12 all single CI's are shown, so that their mean in each variant is visually described. The size rations of the CI's are not compared between each other as there are

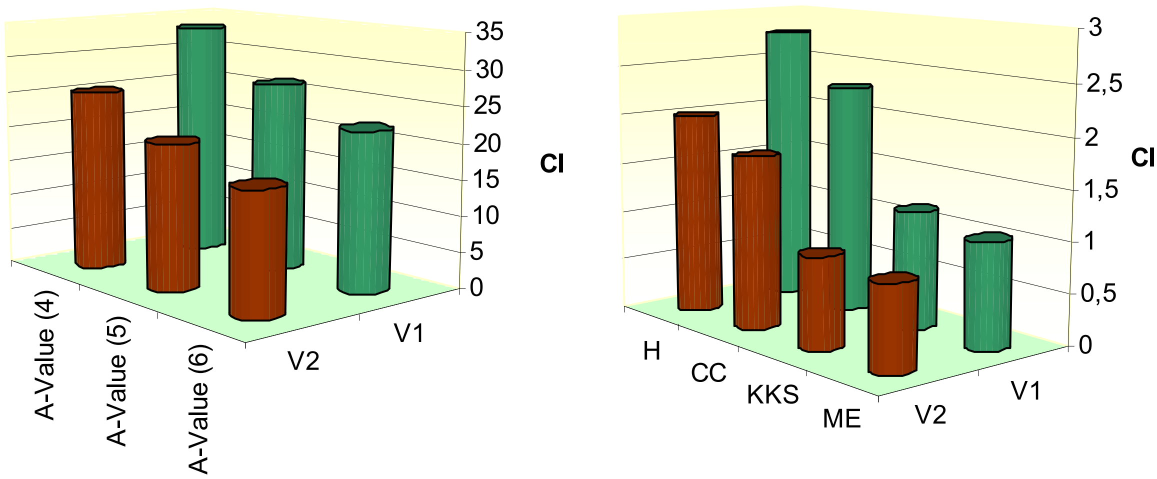

Figure 3.4-12 Competition indices (CI) in variant 1 (V_1) and variant 2 (V_2) for Hegyi (H), Biging and Dobbertin (CC), Pretzsch (KKS), Martin & Ek (ME) in the left bar chart and the A-Values (4,5,6) for Johann on the right bar chart

individual characteristics of the respective formulas. Thus, the A-value is presented in a different graph as the size ratio does not fit to the other CI's. All CI's are characterised by a higher index value in the first variant. It could be proven that this difference of the means is statistically significant for all CI's except the KKS. The Table 3.4-12 provides the descriptive statistics for the CI's. The standard deviation of all CI's except the ME is in the first variant higher. This difference is for the A-values rather small even though the total standard deviation (SD) as well as the standard error (SE) are very high. The index of ME represents the lowest SD and SE.

The tree-based competition analyses of sycamore and sessile oak are comparable with the overall results. It can be assumed that for the two species there is a statistical significant difference of H, CC and the A-Value between V_1 and V_2. Additionally, for sycamore this could be proved for the ME as well.

Table 3.4-12 Descriptive statistics of the competition indices (CI) in the two variants for Hegyi (H), Biging and Dobbertin (CC), Pretzsch (KKS), Martin & Ek (ME) and the A-Values (4,5,6) for Johann with the variables stem number, mean CI, standard deviation, standard error, and the *p*-value for significance

CI	Variant	N	Mean	SD	SE	$p \leq 0.05$
ME	1	39	1.1	0.34	0.05	**0.001**
	2	38	1.34	0.69	0.10	
H	1	39	2.78	1.12	0.18	**0.002**
	2	38	2.01	0.94	0.15	
CC	1	39	2.29	1.81	0.29	**0.021**
	2	38	1.72	1.39	0.23	
KKS	1	39	1.18	1.07	0.17	0.101
	2	38	0.91	0.64	0.10	
A-Value 4	1	39	33.30	10.60	1.70	**0.002**
	2	38	25.33	10.42	1.69	
A-Value 5	1	39	26.64	8.48	1.36	**0.002**
	2	38	20.26	8.33	1.35	
A-Value 6	1	39	22.20	7.07	1.13	**0.002**
	2	38	16.88	6.95	1.13	

4 DISCUSSION

Establishment of mixed deciduous forest stands

In natural forest communities homogeneity concerning the tree species is not very likely to happen, and only on extreme and rare sites one single species would form pure stands (Mitscherlich 1969). In central Europe, a mixture of species and especially deciduous forests of beech but also oak, hornbeam and a range of valuable broadleaved species were much more common during medieval times until the transition to modern times (Duchiron 2000, Schmidt 2004). From an ecological point of view broadleaved tree species fulfill many functions of diversity and are also important for the soil and mineralisation processes (Leibundgut 1983, Kahle 2007, Duchiron 2000). For instance in the 1920/30's, huge areas of pure coniferous stands in Germany were degraded by the accumulation of the upper duff layer, the moderately decomposed organic matter, thus resulting in acidification of the soil (Mitscherlich 1969). In contrast, mixed deciduous forests are more stable against unfavourable biotic and abiotic disturbances such as storm events or extended pests devastating vast areas due to single species plantation character (Leibundgut 1983, 1988; Mitscherlich 1969). It should be noted that the cultivation of broadleaved tree species just as a matter of fact in order to replace conifers can lead to unsuccessful and costly experiences as well. This can be studied at the same example in Germany when after 1920/30 and as a response to soil degradation and pests many broadleaved tree species were planted on a wide range without considering the respective demands on the site conditions. Hence, huge amounts of invested money were lost due to the failure of the establishment (Mitscherlich 1969). In contrast, if smarter initial reflections on the cultivation of mixed deciduous forests are applied, the potential of net revenue of those stands is very attractive (Spiecker 2009). There is a wide range of mixture combinations whereas in German classic forestry literature such as Assmann (1961), Mitscherlich (1969) and Kramer (1988) is mainly putting the focus on a few tree species above all Norway spruce, silver fir, beech and oak. The management of mixed even aged forests is a togetherness of light demanding and shade tolerant species e.g. oak and beech (Mitscherlich 1969). As an example given by Mitscherlich (1969), the dominant upper layer is formed by the light demanding oak and the second shade tolerant beech serves as protection against sleeping buds in a co-dominant social position being thinned when growing into the oak layer. The current research trial in Karnabrunn is comparatively innovative in two kinds that first natural regeneration was the initial starting point providing a diverse range of more than 13 tree species leading to the selection of 6 future crop tree species. And second, the initial thinning was conveyed intensively and to an early timepoint in comparison to traditional management (Assmann 1961, Mitscherlich 1969, Kramer 1988). Light demanding species which are dealt with in this study are sensitive concerning shade and shelter. Even late interventions in order to release light demanding trees in their mature phase are responded by an immediately increasing diameter growth (Eflein et al. 2008). This was shown in 80-100 year old wild service tree (*Sorbus torminalis* [L.] Crantz) stands by Eflein et al. (2008) and he recommends therefore early and repeated thinnings in favour of vital trees as a response to this growth potential. However, the sensitivity of shade is reported for a wide range of light demanding species and prescribed silvicultural techniques as described by Eflein et al. (2008) are necessary for instance for common ash, wild cherry, sycamore etc. (Milnar 2004; Hochbichler 2008; Roman-Amat 2009; Spiecker 1994; Reeg et al. 2009; Duchiron 2000; Kahle 2007; Hein 2004; Dong 2009; Brix 2009; Ammer 1997; Pelleri et al 2007).

Results

Oaks in Hungary occupy a large area of totally 35 % of the forest area producing a large amount of valuable timber which is merchantable internationally as the production exceeds the demands (Solymos 1993). Based on long tradition and experience, several indigenous oak species are established by natural regeneration and managed in a two storied mixtures with hornbeam and beech (Solymos 1993). In South Germany (Baden-Württemberg), the importance of oak was re-discovered lately and the promotion of oak cultivation is increasing since the last two decades which was initiated mainly by research of Spiecker (1991). In Austria and also in France has remained a greater share of coppice with standards forests from the past in contrast to Germany which are to a great extent a mixture of oak and other species (Hochbichler 1993; Giulietti 2007; Duchiron 2000).

Even though sycamore is far from being comparable with oak concerning total area, standing volume and annual cut in Germany and also in Austria, it has an excellent reputation as valuable hardwood in Central Europe due to aesthetic and mechanical properties as well as tooling abilities being widely used especially for indoor construction (Becker and Klädtke 2009; Austrian Forest Report 2008; Dobrowolsk et al. 2008). In the following the situation of sessile oak and sycamore is discussed for our experimental plot in Karnabrunn.

The collective of competitors are analysed in a descriptive way. However, the information derived of the stand data is of minor importance for the elite trees which are released geometrically by a threshold distance, rather than selectively by stem number reductions of the competitors. Though, the slenderness signifies the stability and vitality and is therefore a response variable for the entire stand and important for the future crop trees as well (Kramer and Akça 1982). The shown values of the collective of competitors such as slenderness (139) and the basal area (1.2 m²), the mean height (10.5 m) and the mean diameter (7.5 cm) as well as the relatively high tree number in average of 3240 per hectare represent rather well the juvenile stage of the stand. The analyses were merely conducted for the future crop tree species sessile oak and sycamore due to a lower sample size in comparison with the remaining future crop tree species.

In the study area, sessile oak is only present on a small range but due to the above described awareness of its value it was positioned on the first place in the tree hierarchy ranking for selection of the elite trees. Sessile oaks occur rarely with a low stem number per hectare on our experimental plot. In the collective of the competitors sessile oak is characterised by a good h/d relation being explained by a high dbh and low height which results in a lower slenderness value. This implies that sessile oak has a good performance in stability and vigour (Weaver and Spiecker 1993, Hochbichler and Krapfenbauer1988). While Spiecker (1991) puts the main emphasis of his widely recognised work about the diameter growth of oak on the ages of 40 to 60 years, stating that this period is the most essential one in growing space, in this study the juvenile growth was focused. For an optimal growth in this phase a suddenly intensive release after a period of high competition pressure should take place in order to stimulate the secondary shoot development (Nutto 1999, Mosandl 1991, Hochbichler 1993, Roman-Amat 2009).

Sycamore instead is dominantly distributed in the study area and in comparison to sessile oak it shows a far lower dbh, it is taller and therefore has a lower basal area. The value of the slenderness is higher than sessile oak, but still is meeting the recommendations at this age of 90-100 (Hochbichler 2008). This less vigorous standing changes when shifting the focus to the target trees. Sycamore in the future crop tree collective is far more vigorous than sessile oak, showing higher dbh as well as height and therefore a slenderness value lower than sessile oak and finally also a bigger crown. The crowns of sycamore are able to react promptly to thinnings, and especially thicket-pole and young pole stages is the best timing for first thinnings (Pellerie 2007, Hein and Spiecker 2008). Further, Hein and Spiecker (2008) and Hasenauer (1997) investigated on the basis of the dimensional relationships of open grown trees that sycamore invests especially in the young stage in vertical height increment whereas significantly late in the mature phase the lateral growth catches up. Concluding the above said, the co-dominant position of sycamore easily changes when enough growing space is available. This is also relevant for sessile oak, when heavy thinnings are suddenly releasing under competitor pressure growing trees even though for the latter generally a stronger reaction was found in the lower releasing intensity.

In our experimental plot, it could be not proven that the difference of one meter between the releasing radii of 3 m in V_2 and of 2 m in V_1 has a significant effect on the tree growth namely diameter and height of sycamore and sessile oak after five years. As a result the null-hypothesis H_0 (1) could not be rejected and had to be accepted. However, it should be noted that the R^2 for dbh and height for sycamore show low significance at α =5%. This is important considering the fact that a significance was proven for height and diameter of sycamore between V_2 and the unmanaged variant. As mentioned before, an ability of strong growth as a reaction to increasing the growing space is stated in the literature. However, whether or not the different reduction of competition in a range of one meter matters for the diameter and height growth is thereafter justifiably answered negatively. But, pointing on the *p*-value which indeed rejects our null-hypothesis and if we look at the significant differences which were found between the greater releasing intensity of V_2 and the unmanaged variant, then we can assume though, that there is a stronger positive influence on the diameter and height growth on sycamore. This statement is underlined by the fact that the statistical analyses proved a significantly higher crown width/length ratio in V_2 compared to V_1 and the unmanaged variant. It might be that the trees in V_2 are provided with a greater potential to enter the dimensioning phase faster due to a larger crown. Hein and Spiecker (2008) show similar results in their work for common ash and sycamore stating that open grown trees show a larger crown compared to trees from closed forests when tree diameter being equal. The above discussed results are restricted to sycamore whereas for sessile oak the tendencies found are rather unspecific: No significant differences resulted between the two variants. By merely looking at the mean values, most frequently the V_1 was showing higher values, even though this variant represents a lower releasing intensity. However, the crown volume was highest in the unmanaged stand and lowest in the V_2. This difference was even significant. In contrast, the width/length ratio of sessile oak shows also a significant different between V_2 and the unmanaged stand even though in the coherence of those two variables the mean in V_2 was higher. The interpretation of the just described outcome of the analyses of sessile oak is difficult, so that they can not support or reject the findings of recent research (Dong et al. 2007; Hein and Spiecker 2008).

Wild cherry is characterised by a great vigour reflected by a strong diameter and height and therefore a good h/d relation and the latter meeting recommend values in this stage

(Hochbichler 2008). This could be also shown by recent findings of Dong (2009) and Spiecker (1994, 1988) stating that wild cherry is characterised especially in the juvenile wood by a fast height increment, which reached fast its culmination in the age of 16 years and thereafter decreased rapidly. Large differences in diameter were found in this study between the thinning variants represented by a high standard deviation (Dong 2009). The vigour of wild cherry in this study could be also proven in a study of a mixed stand of dominant beech and co-dominant wild cherry and wild service trees in eastern France. A silvicultural prescription was applied in order to promote the neglected valuable trees in an age of 19 years by a strong release of the co-dominant trees. As a response strong growth reaction of diameter and crown width were shown (Roman-Amat 2009). The described differences in our experimental plot were not statistically analysed as the sample size was too low.

In most of the parcels common ash was found to be the most dominating species concerning its distribution. However, despite a higher frequency, the selected individuals of common ash represents merely one third of the number of sycamore, the latter leading the future crop tree collective distribution. To define sound objectives is one of the crucial factors in shifting from traditional to a single tree oriented management. Therefore, common ash was positioned in the hierarchical selection process at the 5th place which explains the low share in the future crop tree collective despite a high total distribution in the stand. Considering the collected data, ash is characterised by a great height in comparison with the other future crop tree species. When heavy tending operations around common ash lead to optimal light conditions, the tree is able to respond strongly with height increment (Dobrowolska et al. 2008; Hein and Spiecker 2008). Though, the variables dbh, basal area and volume, attest the species ash in total a less vigorous growth and especially the slenderness undermines the recommended value of 100-110 in this stage (Hochbichler 2008). As a conclusion, the potential growth capacity of sycamore seems to surpass common ash on the study area (Schmidt and Roloff 2009). This coherence could also be found in the North German plane even though this ability of sycamore was neglected in the past (Nagel 1985 in Schmidt and Roloff 2009).

Relationship between crown parameters and diameter

A strong correlation between crown width and diameter at breast height for sycamore, sessile oak, wild cherry, Norway maple, common ash could be recognised. A correlation was also found for the variables crown length and diameter even though the variances can be described by the independent variable inferior. These results are underlined by the fact that heavy thinnings enlarge the tree crowns resulting in a higher productivity as the essential photosynthetic surface for growth processes is increased (Assmann 1961). Newer findings confirm this relationship (Hochbichler 2008; Hochbichler and Krapfenbauer 1988; Spiecker 1994; Hein 2004). Hein (2009) found strong correlations in the development of diameter growth and crown width for the species sycamore, common ash and wild cherry. Analysing the relationship of crown width and the diameter provides important information used for modelling and controlling diameter growth and defining production goals (Hein 2009). Open growth conditions lead to the maximum potential dimension assuming that the tree has never experienced any competition (Hasenauer 1997). The newly appearing strong thinning scenarios remind strongly at conditions which can be found traditionally in coppice with standard forest (Hochbichler 2008). Dimensional relationships of crown parameters and diameter are important for silvicultural prescription of thinning processes or in tree growth simulators.

Critical analyses of the sampling design and validity of the results

In praxis, sample plots to derive stand data are usually in form of a circle, square or rectangle, of a size between 0.05 and 0.1 hectare and randomly or systematically arranged (Kramer and Akça 1982). In this study, the stand data was derived from the sample plots around the future crop trees which were selected neither randomly nor systematically. Therefore, these data are only used to give a general view for stand situation. For this study, only current data were used and no incremental growth was described. Growth trends are yet an important tool in silviculture to estimate the success of a management strategy (Kramer and Akça 1982, Mitscherlich 1969). The sample size of the future crop trees was rather low. This is the result of the more practical oriented research trial where future crop trees were selected according to a tree hierarchy and quality criteria rather than to their sample size. Finally, only for sycamore and sessile oak sound statistical analyses could be conveyed. The latter showed rather high standard deviations for several variables, which can be explained by a lower sample size than for example sycamore.

The thinning method does not consider species characteristics even though their importance is propagated in many literatures (Dong 2009; Duchiron 2000; Leibundgut 1978; Gadow 2003). The information which can be derived can rather be used for species specific potential to use growing space. Therefore, every tree species must go through the same liberation modus in the two variants. The results have therefore to be considered as valid only for the specific conditions and only for the respective tree species in these conditions.

Competitive situation

'The effect of intertree competition on individual growth is a very difficult concept to quantify' (Holmes and Reed 1991; in Ammer and Dingel 1997). The quality of the single tree develops not merely according to the mean stem number per ha, but rather according to the individual competitive situation of this tree (Mlinar 2004). Much research was done to predict tree growth as precisely as possible by the examination of the competition effect on growth of individual trees (Tomé and Burkhart 1989, Bella 1971 Martin and Ek 1984, Biging and Dobbertin 1995, Ledermann and Stage 2001, Radke 2002, Mugasha 1989, Pretzsch 2001). An ongoing discussion is held whether distance dependent or distance independent indices show a higher accuracy (Tomé and Burkhart 1989, Ledermann and Stage 2001, Biging and Dobbertin 1995). In this work distance dependent competition indices were used assuming an improvement in precision. Distance seems to be in mixed structured stands the better alternative while in pure even aged stands no improvement by distance is stated (Martin and Ek 1984). Though, the variable distance is given different importance within each CI formula. By presenting the overall effect on competition in dependence of distance for the entire stand without distinguishing the two variants, it became obvious that the CI of Martin and Ek (1984) was decreasing most significantly with increasing distance due to an exponential weighting factor of the distance in the formula (Sperlich 2008). Pretzsch's index (1995), and the A-Values from Johann (1985) in contrast, were the least affected concerning the distance. The KKS of Pretzsch uses crown geometry and vertical angles to calculate the index. This is a trend in more recently proposed distance dependent indices. The shape of the function representing effects of increasing distance is not immediately obvious for these more complex indices (Ledermann and Stage 2001; Hasenauer 2006; Pretzsch 2001). Further, the threshold distance varied from 4 m to 6 m which represents a low range of competition. It can be assumed that with a greater threshold distance, the effect of the distance becomes more obvious.

The mean index value for each computed CI except the KKS was in the variant with the lower thinning intensity significantly higher than in the heavier released variant. This is an interesting fact, considering that the analyses of the single tree parameters in general did not show significant differences in height and diameter growth. Hence, it can be concluded that the index from KKS fits best to our findings, supposing that as there are no obvious effects in tree growth between the variants indicated, thus the CI should also not show a difference in competition.

Recommendations

Hochbichler (2008) concluded from his single tree investigations of oak, wild cherry, sycamore, Norway maple, etc. in their pole wood stage (contender) that initial silvicultural tending intensity is crucial for the development of the branch free stem and for the crown development (crown length, crown width/length ratio). In this work, it could be statistically proven for sycamore and sessile oak and descriptively described for wild cherry and common ash that the crown development responded stronger in the heavier released stands and is therefore for an optimal future growth recommended. The selection of future crop trees can be implemented to an early stage when the second pruning operation takes places or oriented at the height, when vigour trees reach a height of 3-5 m. This was shown by earlier research on this study area for the crown development of common ash, wild cherry, sycamore, and oak (Mlinar 2004) as well as on other sites (Spiecker and Spiecker 1988).

5 CONCLUSION

Following clearing, a former pine stand in the southern Weinviertel, East Austria, was left for natural succession to take place. The resulting rich diversity of tree species that was recruited was subsequently used in this project, investigating how stand tending can be optimised to achieve both high quality and dimensions and rapid growth rates. The selected future crop tree species were chosen according to a tree hierarchy including the following tree species (in hierarchical order): Sessile oak, sycamore and cherry, Norway maple, larch, common ash and lime. The silvicultural prescription was developed in a way that the trees benefit from a free crown development by heavy thinnings at an early stage. The result should be reflected in a higher dimensioning and earlier incremental growth while at the same time the desired quality has to be ensured by intensive tending. In order to investigate such research questions in a juvenile stand, a sample design was created where in one thinning variant a releasing radius of 2 m was set around the future crop tree and in a second variant the same procedure was done with a 3 m radius. Thereby, all trees were considered as competitor, i) which were located within the threshold distance, and ii) which were growing into the second third of the subject tree's crown. This study was investigating any differences in several single tree parameters as well as differences in applied competition indices between the variants of the last five years. Furthermore, crown width as well as crown length and diameter relationships were tested for correlation.

Only sycamore and sessile oak were meeting the required sample size for a statistical analysis. The results showed no significant differences of the variables between the variants except some crown parameters. In contrast, the CI indicated significant differences between the variants apart from the CI of Pretzsch (KKS). As only the KKS did not show any statistical significance between the compared means of variant one and two, this index seems to illustrate the reality in the best manner.

The crown width and diameter relationships showed significant correlation of sycamore and sessile oak. The crown length and diameter correlation was also significant but less obvious due to a lower R^2.

Summarizing the results, the applied thinning scenarios were statistically not significantly different but:

1) Diameter and height of sycamore showed higher values in variant two, though being insignificant at α =5%.

2) The individuals of variant two with the 3 m thinning radius showed significantly higher differences in comparison to the unmanaged variant. This was not the case for the first variant of the 2 m radius.
3) Crown parameters such as crown volume and crown width/length ratio were significantly higher in the heavier released stands of 3 m for sycamore and sessile oak.

The results show that the examined trees of sycamore and sessile oak responded significantly to heavy liberations at an early timepoint in an age of 12 to 18 years concerning their crown development. Yet, in comparison between the two thinning variants, the effect of the heavier thinning variant did not show a strong difference in height and diameter of sycamore and sessile oak. However, the crown parameters seem to react more promptly than diameter and height.

The specific competitive situation is the main driving factor for the future growth responses in the variants. By doubling the releasing radii for the next growth period of 5 to 10 years, almost open grown tree conditions are created, in particular in V_2. In the course of ongoing research the effect of those heavy liberation scenarios promise an interesting research subject.

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APPENDICES

Varibles for the crown shape model in chapter 2.5:

Table 13 Crown shape models for fort the sunlight and shaded crown for main tree species relevant in this study. The shape of the sunlit crown is calculated by the parabolic equation r_o = adist^b, the shape of the shaded crown by the linear equation r_u = c+ dist x d. The derivation of parameters a, b, c, and d are given in the table: a description of variables is given in figure 2.5-4.

Tree Species	Upper crown			Lower crown		
	a	l_o	b	c	d	r_{cb}
Pinus sylvestris	$r_{max}/(l_o)$	l x 0.68	0.50	For all species		r_{max} x 0.63
Larix decidua	$r_{max}/(l_o)$	l x 0.66	0.50	c = r_{max} –d x (l_o)		r_{max} x 0.50
Fagus sylvatica	$r_{max}/(l_o)^{0.33}$	l x 0.40	0.33			r_{max} x 0.33
Quercus petraea	$r_{max}/(l_o)^{0.33}$	l x 0.39	0.33		For all species	r_{max} x 0.36
Acer pseudoplatanus	$r_{max}/(l_o)^{0.33}$	l x 0.35	0.52		d= (r_{cb} - r_{max})/(l- l_o)	r_{max}
Alnus glutinosa	$r_{max}/(l_o)^{0.5}$	l x 0.56	0.50			r_{max}

Variables for the collective of future crop trees in total. Variants are not separated:

Table 14 Mean of the crown width/length ratio of the species in the collective of future crop trees; the stem number (N), the minimum (min), the maximum (max) and the standard deviation (SD) of the sample is presented

Species	mean	N	min	max	SD
Sycamore	0.62	37	0.4	1.2	0.18
Common ash	0.48	12	0.28	0.72	0.12
Sessile oak	0.60	18	0.34	1.43	0.25
Wild cherry	0.64	9	0.47	0.86	0.14
Norway maple	0.66	3			
Larch	0.5	3			

Table 15 Mean of the crown volume of the species in the collective of future crop trees; the stem number (N), the minimum (min), the maximum (max) and the standard deviation (SD) of the sample is presented

Species	mean	N	min	max	SD
Sycamore	22.5	37	5.3	66.3	14.9
Common ash	21.4	12	4.9	51.9	12.5
Sessile oak	14.1	18	5.2	27.3	6
Wild cherry	22.3	9	10.3	54.2	14
Norway maple	24.1	3			

Larch	24.5	3

Table 16 Mean of the timber volume of the species in the collective of future crop trees; the stem number (N), the minimum (min), the maximum (max) and the standard deviation (SD) of the sample is presented

Species	mean	N	min	max	SD
Sycamore	7.7	37	1.7	19.2	4.7
Common ash	6.6	12	3.3	12.1	2.4
Sessile oak	6.4	18	2.1	11.1	2.2
Wild cherry	10.2	9	3.5	23.4	6.4
Norway maple	9.5	3			
Larch	11.8	3			

Table 17 Mean of the slenderness of the species in the collective of future crop trees; the stem number (N), the minimum (min), the maximum (max) and the standard deviation (SD) of the sample is presented

Species	mean	N	min	max	SD
Sycamore	104	37	77	151	15.4
Common ash	120	12	92	162	19.2
Sessile oak	106	18	85.2	132.9	15.0
Wild cherry	83	9	66	97	12.0
Norway maple	100	3			
Larch	88	3			

Table 18 Mean of the crown width of the species in the collective of future crop trees; the stem number (N), the minimum (min), the maximum (max) and the standard deviation (SD) of the sample is presented

Species	mean	N	min	max	SD
Sycamore	3.5	37	2.0	4.6	0.8
Common ash	3.2	12	2.0	4.6	0.8
Sessile oak	3.4	18	2.2	4.6	0.8
Wild cherry	4.1	9	3.0	6.1	1.0
Norway maple	3.8	3			
Larch	3.7	3			

Table 19 Mean of the timber volume of the species in the collective of future crop trees; the stem number (N), the minimum (min), the maximum (max) and the standard deviation (SD) of the sample is presented

Species	mean	N	min	max	SD
Sycamore	12.5	37	7.4	17.5	2.1
Common ash	13.5	12	11.7	16.3	1.3
Sessile oak	11.8	18	9.3	14.6	1.5
Wild cherry	11.9	9	9.6	14.4	1.53
Norway maple	12.9	3			
Larch	13.9	3			

Table 20 Mean of the timber volume of the species in the collective of future crop trees; the stem number (N), the minimum (min), the maximum (max) and the standard deviation (SD) of the sample is presented

Species	mean	N	min	max	SD
Sycamore	12.4	37	6.9	19.3	2.9
Common ash	11.5	12	8.1	14.5	1.89
Sessile oak	11.3	18	7.0	14.6	1.84
Wild cherry	14.9	9	10.2	21.9	3.9
Norway maple	13.2	3			
Larch	16.3	3			

Available space and area around future crop trees in the thinnings variants one and two:

Table 21 Variables listed for variant 1, thinning radius 4 m ($V_{1\,(4\,m)}$), and variant 2, thinning radius 6 m ($V_{2\,(6\,m)}$): Individual sample area of a single subject tree (A_{sample}), mean stem number of competitors per sample area and subject tree (N_{comp}), total stem number of subject trees (N_{subj}), total sample area of all subject trees (A_{total}), total stem number of competitors in A_{total}; increment from V_1 to V_2 in percent shown for N_{comp} and A_{sample}

	A_{sample} (m²)	N_{comp} (mean)	N_{subj} (total)	A_{total} (m²)	N_{comp} (total)
$V_{1\,(4\,m)}$	50.2	17	42	1908	522
$V_{2\,(6\,m)}$	113.1	37	38	4298	1428
% increment	56 %	54%			

Hereby I assure that I wrote independently this present Master Thesis

”Investigatoin of Single Tree Parameters in Deciduous Forests”

and did not use other than indicated sources and aids.

…….. of September 2010,

Vienna,

Dominik Sperlich