Improvement and Silviculture of Beech

Proceedings from the 7th International Beech Symposium
IUFRO Research Group 1.10.00
10-20 May 2004, Tehran, Iran

Editors: Khosro Sagheb-Talebi, Palle Madsen and Kazuhiko Terazawa

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Welcome address

Forests in Iran, Constraints and Strategies

By definition, Iran is categorized a country with low forest cover. Only 7.6% of its land is covered by forest ecosystems. Despite of this the vital role of these ecosystems can not be ignored, dependence of daily life of local population, recreational affects, soil and water conservation, and more important, its facilitation for sustaining high biodiversity of the country already have been recognized.

Unfortunately this valuable national asset faces unprecedented constraints and challenges, such as:

- Eradication of forest natural regeneration imposed by grazing of domestic animals.
- Legal and even illegal over harvesting.
- Un-proper forestry techniques or silvicultural and management strategies.
- Steady increase in demand for land use changes from agricultural, housing and industrial sectors.

In order to overcome above mentioned, damaging constraints and pressure and subsequently to approach to some how sustainable management systems, following policy and strategies have been defined, and are practiced:

- To move more closed, industrialized and intensive animal husbandry system.
- To search and establish alternative ways and sources to obtain row material needed by country's wood and paper industries.
- To increase from 5% to 10% of total area of Iran, which have been allocated to forest protected areas.
- Finally adapting and practicing the ecosystem approach in forestry management.

Adel Jalili

Chairman of the symposium, director of Research Institute of Forests and Rangelands (RIFR), Iran.

Beech Research Strategy in Iran

The total forest area of Iran is approximately 12 million hectares, which make only 7% of the total land area. Therefore, Iran is categorized under Low Forest Cover Countries (LFCC). However, it is a rich country with aspect of plant biodiversity with almost 8'000 vascular plant species. The real temperate commercial deciduous forests, with an area of almost 2 million hectares, are extended in the north of Iran, in the Caspian Region, the so-called Hyrcanian Zone. This humid region is extended in the southern coastal plain of Caspian Sea from –20 to 2500 m.a.s.l. on the northern slopes of Alborz mountains.

Beech (*Fagus orientalis* Lipsky) is the most industrial commercial tree species among more than 80 broad-leaved trees and shrubs. Beech reaches in mature stage to more than 100cm dbh and about 50 meters height. It covers almost 18% of the forest area in the Caspian region and is the dominant tree species between 700 and 1500 m.a.s.l. It forms the so-called *Fagetum hyrcanum* community in form of pure and mixed stands. The proportion of oriental beech reaches to 24% of total stem number and 30% of total volume in the Caspian forests. The mean volume of beech stands varies here between 400 and 800 m^3ha^{-1} in different sites.

The recent global trends, sustainable development and the importance of close to nature silviculture highlights the ecosystem approach as our main research strategy in the Forest Research Division (FRD) of the Research Institute of Forests and Rangelands (RIFR). Getting knowledge about the structure of the natural undisturbed beech stands, study of development stages and succession of beech forests, investigation on gap creation and natural regeneration, as well as silviculture and management of uneven-aged stands are the most important research programs. Also the genetic knowledge about oriental beech, importance of gene preservation and gene flow is taken into account in this program. These are partly under going projects and partly are planned for the next decade.

Khosro Sagheb-Talebi

Secretary of the symposium, Head of Forest Research Division (RIFR), Iran.

Contents

The Ecology and Silviculture of American Beech (*Fagus grandifolia* Ehrh.): An Overview

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Abstract

American beech, *Fagus grandifolia* Ehrh., is one of the most distinctive trees found in the forests of the eastern United States. It is distinctive because of the smooth thin light-colored grey bark that so often forms the background for lover's initials that have been carved into its trunk. It is a stately massive tree of forests and parks that attains heights in excess of 30 meters (maximum 50 meters) and diameters of 100 cm (maximum 200cm) and can be readily identified at a distance by its a wide spreading crown that casts a dense shade on the ground beneath it. It is one of the most, if not the most, shade tolerant hardwood tree species in the eastern United States.

American beech grows on a wide variety of soils ranging from sand loams to soils of alluvial origin. However, it needs a constant supply of moisture in order to grow well. Trees are rarely found on droughty soils or on sites subject to prolonged flooding. It commonly grows in association with sugar maple (*Acer saccharum*) and yellow birch (*Betula alleghaniensis*) to form an association that is described as the "northern hardwoods". Growth is slow in comparison to its associates even under the best growing conditions which occur in the Ohio and Mississippi River valleys.

American beech is usually managed using uneven-aged silvicultural systems such as individual tree selection and group selection. The goal of such a system is to create a diameter distribution that resembles a backwards J where the numbers of trees per hectare declines steeply as stand diameter increases and then eventually levels off.

The wood of American beech is very useful and is made into furniture, children's toys, novelty items (cutting boards, butcher's blocks and woodworking tables), veneer, and flooring. Beech nuts or beech mast are valued as a wildlife food. However, beech bark disease is causing serious declines in many beech stands. The disease results when bark, attacked and altered by the beech scale, *Cryptococcus fagisuga* Lind., is invaded and killed by fungi, primarily *Nectria coccinea* var. *faginata* Lohman, Watson, and Ayers, and sometimes *N. galligena* Bres.

Keywords: Eastern United States, *Fagus grandifolia* Ehrh., characteristics, distribution, uses

1 Introduction

Beeches belong to a family of plants, Fagaceae, that collectively are given the name of the beech family. American beech, *Fagus grandifolia* Ehrh., is one of 10 species of beeches (*Fagus*) found worldwide. Interestingly beeches are only located in the northern hemisphere. One species is found in North American, one is European, one is found in the Caucasus Mountains on the border between Europe and Asia, and the rest are found within the temperate regions of eastern Asia. Although the beech genus is relatively small, the European beech is a very important timber species and additionally has been used extensively for ornamental purposes. Hence many horticultural varieties exist which display a vast array of morphological characteristics such as coloration and form. Although a relative of European and other beeches of the world, American beech is does not enjoy the prominence of these other beeches. The purpose of this presentation is to provide a brief overview of the ecology and silviculture of American beech, *Fagus grandifolia* Ehrh.

2 Distinguishing Characteristics

2.1 Leaves

The elliptical to oblong-ovate simple leaves are deciduous. Size varies from 6 to 15 cm long and from 2.5 to 7.5 cm wide. Leaf margins are serrated with sharp incurved teeth. The tips of the leaves are long and tapering while the base is broadly wedge-shaped, tapering to a narrow base. Leaf surfaces are often covered with silky hairs at first then become smooth above with silky hairs below particularly in the axils of the veins. Leaves exhibit parallel venation and are connected to the twig with short petioles. Leaves are dark green above, somewhat lighter below which turn a yellowish-bronze color in the fall (Fig. 1).

Figure 1. Leaves of American beech, *Fagus grandifolia* Ehrh.

2.2 Flowers and Fruit

Flowers appear in the spring after leaves unfold. Male flowers consist of round heads with each flower containing a 4 to 8 lobed calyx and 8- to 16 stamens. Female flowers are found in spikes containing two to four flowers. Each flower consists of a 4- to 5 lobed calyx fastened to a 3-celled ovary. The fruit is an edible nut 12- to 18 mm long. The nut is triangular in cross-section and is covered by a bur that has weak unbranched spines (Fig. 2).

Figure 2. Fruit of American beech showing the “burs”.

2.3 Twigs and Buds

The pseudoterminal buds of American beech are very distinctive. They are very long and narrow and are described as being "spindle-shaped" and terminate in a sharp point. The buds are from 18 to 25 mm long. Bud scales are numerous and overlapping. Twigs are slender and zigzagged in appearance (Fig. 3).

Figure 3. Twig of American beech showing the characteristic zigzag pattern and the long spindled-shaped buds.

2.4 Bark

The bark of American beech is one of the most distinctive in the eastern hardwood forest of the United States. It is thin, smooth with a light blue-gray color which is often mottled. Interesting, the bark characteristics are retained to old age (Fig. 4).

Figure 4. Bark of American beech

3 Range

American beech is widespread in eastern North America extending from the maritime provinces of Canada south to the Gulf coast and west to east Texas. It occurs from sea level to 1,000 meters in the northern part of its range to 2000 meters in the southern Appalachians. Typical sites within this area are moist, rich uplands, and lowlands (Fig. 5).

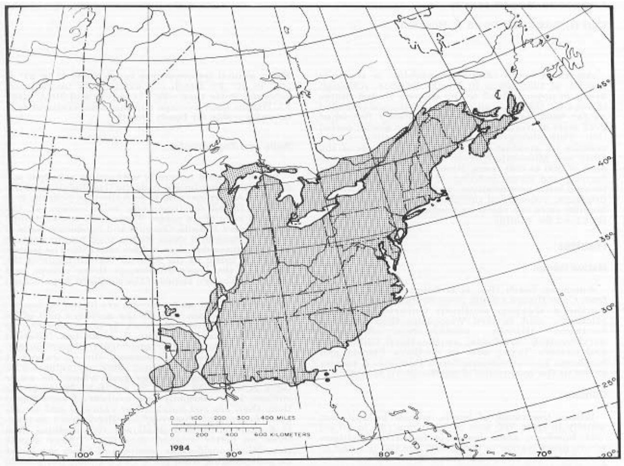

Figure 5. Range of American beech in the eastern part of the United States.

4 Ecology

4.1 Distribution

There are about 146 million hectares of forest land in the eastern part of the United States. About 14% of the forest land consists of a forest type of which American beech is an important component. The type is known as the maple-beech-birch forest type. Throughout its range in eastern United States, beech may dominate sugar maple and birch and be the most abundant species in localized areas (Fig. 6).

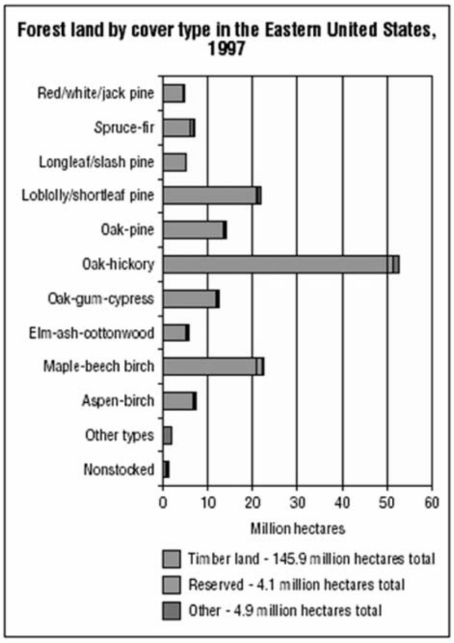

Figure 6. The maple-beech-birch forest cover type comprises about 14% of the timber land in the United States.

American beech together with sugar maple (*Acer saccharum* Marsh.) and yellow birch (*Betula alleghaniensis* Britton)) forms an extensive complex across the northern portion of eastern United States. The arrow points to the color that represents the sugar maple – American beech – yellow birch forest type. However, American beech does not continue in the mixture farther west than eastern Wisconsin. Beech becomes increasing more dispersed with other species in the southern part of its range (Fig 7).

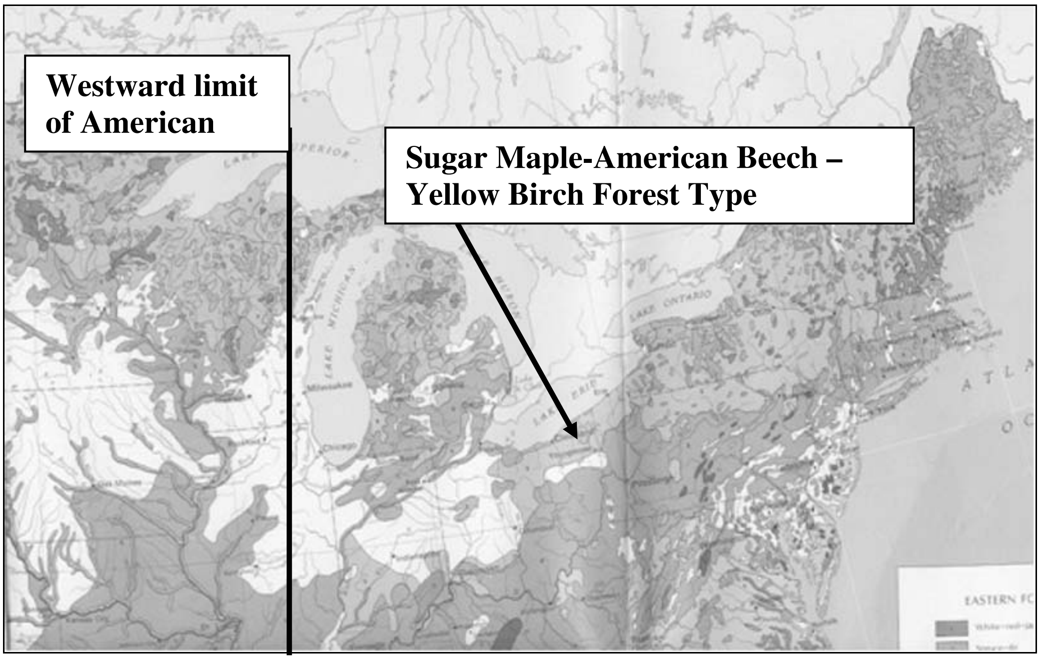

Figure 7. The arrow points to the area covered by the sugar maple-American beech-yellow birch forest cover type. The solid vertical line shows the boundary of the westward limit of the occurrence of American beech in the maple-beech-birch forest cover type.

4.2 Site Conditions

American beech is found on a wide variety of soils provided the soil has a uniform moisture regime and such that moisture is never lacking. In this regard, American beech has a higher moisture requirement than many other hardwoods that it is associated with. However, it does not tolerate flooding.

Beech grows on two principal soil groups: the grey-brown podzolic soils and the laterite. It is prevalent on the podzols. Interestingly it is not found on limestone soils – except at the western most edge of its range. It prefers soils high in humus and of loamy texture. Beech grows best on the alluvial bottom lands of the Ohio and the lower Mississippi River Valleys. Beech is found on sites where the pH ranges from 4.1 to 6.0 and rarely (with the exception above) when pH exceeds 7.0.

Beech is found at low elevations in the northern part of its range while in the south it is found it is found up to 1830 meters. Beech commonly prefers the cooler and moisture northern exposures or coves. Annual precipitation varies from 760 to 1270 mm across its range (Fig. 8).

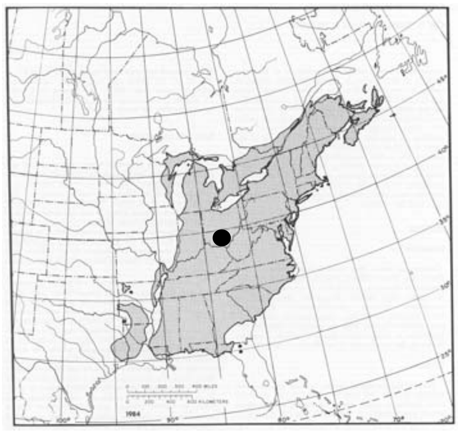

Figure 8. The circle shows the location of maximum development of American beech.

4.3 Silvics

American beech is extremely tolerant of shade, prefers moist well-drained sites, produces root sprouts as well as stump sprouts, and is long lived. These characteristics place American beech as a long-term inhabitant in the forest types in which it occurs.

Beech is classed as very tolerant of shade and in some parts of its range it is the most tolerant species. Its principal competitors are sugar maple, eastern hemlock (*Tsuga Canadensis* (L.) Carr.*)*, and balsam fir (*Abies balsamea* (L.) Mill.). Beech prefers moist well-drained sites although it can survive on drier soils. It cannot endure prolonged flooding however. Beech sprouts well from the stumps of young trees but this trait dimensions as stump diameter increases. Beech trees may develop a large number of root sprouts or suckers. In some areas this is the sole means of reproduction and there may be as many as 1700 to 2200 sprouts per hectare. This vigorous sprouting often interferes (moisture and shade) with the reproduction of other species. Beech is generally considered a slow grower and is long lived. Of 12 broad-leaved species rated according to their longevity, beech was exceeded only by white oak and sugar maple. Self pruning in beech is good in well-stocked stands but open-grown trees develop wide crowns with branches low to the ground. Epicormic branching is sometimes a problem in stands thinned too heavily.

4.4 Associated Species

Because of its wide range, beech is found with many other species including sugar maple, red maple (*Acer rubrum* L.), yellow birch, American basswood (*Tilia americana* L.), black cherry (*Prunus serotina* Ehrh.), southern magnolia (*Magnolia grandiflora* L.), eastern white pine (*Pinus strobus* L.*)*, red spruce (*Picea rubens* Sarg.) and several hickories (*Carya sp.* and oaks (*Quercus sp.)* . Beech is included in 20 forest cover types and is a major component in three: Sugar Maple-Beech-Yellow Birch (Type 25), Red Spruce-Sugar Maple-Beech (Type 31), and Beech-Sugar Maple (Figs. 9 and 10).

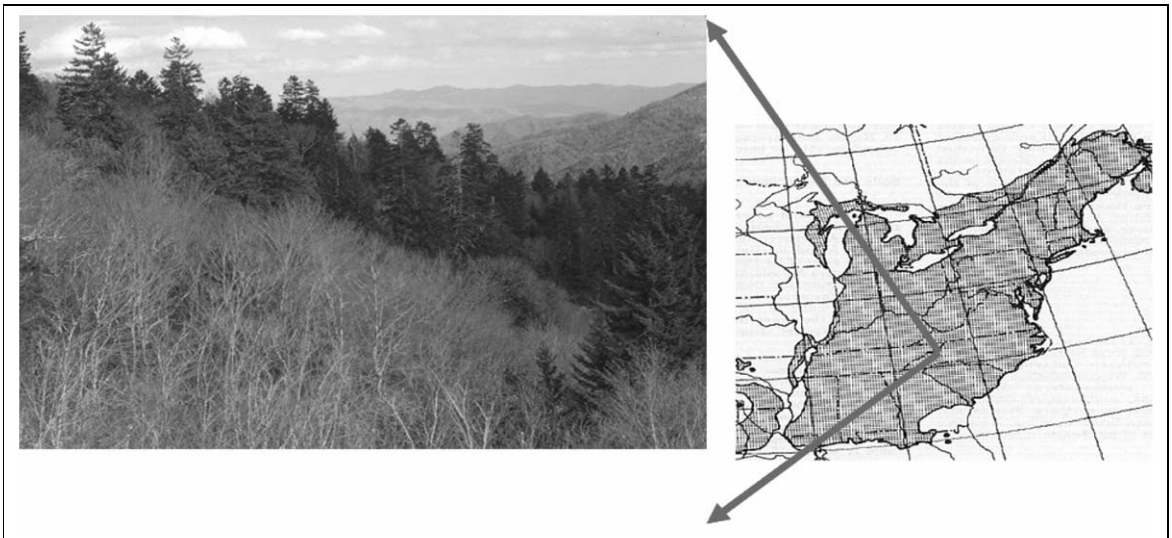

Figure 9. A beech-gap forest in the southern Appalachians mountains at about 4000 feet elevation. The conifers in the background are red spruce (*Picea rubens*). The combination of beech and spruce is unique to these areas and is part of the forest type 31 (red spruce, sugar maple, beech).

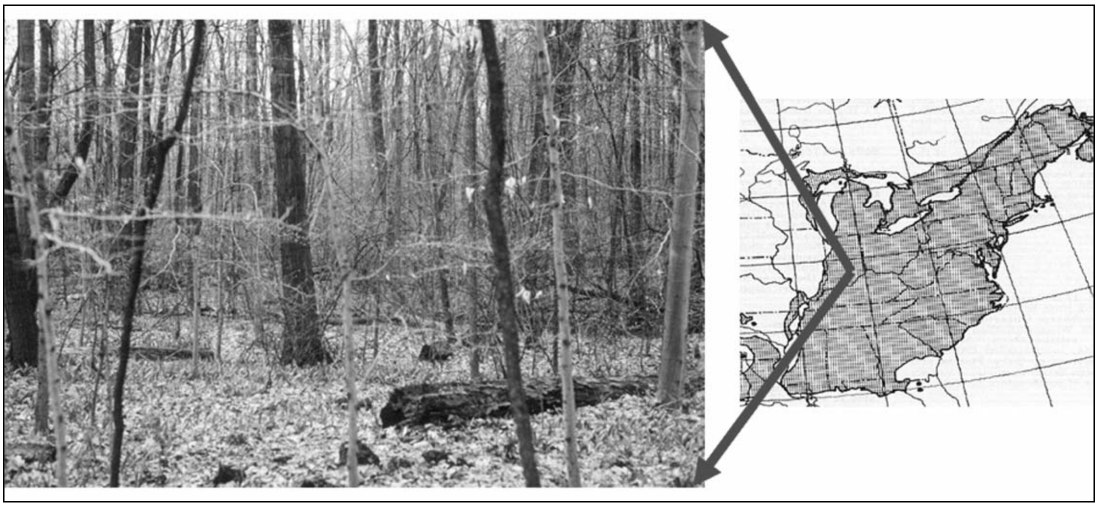

Figure 10. Beech-maple forest in Indiana.

5 Silvicultural Considerations

Uneven aged silvicultural systems are used to regenerate American beech. Beech trees are long-lived – approaching 400 years in some cases and are one of the most shade tolerant species in the eastern U.S. Forest. American beech is usually managed using individual tree selection and group selection. The goal of such a system is to create a diameter distribution that resembles a backwards J where the numbers of trees per hectare declines steeply as stand diameter increases and then eventually levels off.

Beech prune themselves in well-stocked stands but tend to form wide-spreading crowns with branches low to the ground in under-stocked stands. Epicormic branches form readily from sudden exposure to sunlight or from injuries suggesting care in reducing stand density during intermediate thinnings and in reducing mechanical damage to residual trees.

Beech seedlings develop better under a moderate canopy or in protected small openings than they do on larger open area where shallow root systems may become subject to drying out. Seedlings germinate well on either mineral soil alone or in combination with organic matter such as leaf litter. Germination and survival tend to better on mor humus than on mull humus soils.

Although it is possible to produce high valued products from American beech like flooring and furniture, American beech is frequently treated as a "weed" species: something to get rid of because other species that it associates with are often much more valuable. This would include the oaks (white and red), sugar maple, yellow birch, black cherry among others.

Growing beech to produce high valued products is further complicated by the now wide-spread occurrence of beech bark disease. The thin bark of beech makes it susceptible to sucking insects like the beech scale. The action of the scale makes beech vulnerable to the canker fungi, Nectria. The scale was introduced into Nova Scotia from Europe around 1890 and is now found as far south as Virginia and as far west as Michigan. Even though the parent tree is killed by the scale/fungi complex the roots sprout prolifically which adds to the difficulty of regenerating other species. When the insect and disease hit a stand for the first time, mortality is severe especially of large trees. Once the insect/disease is endemic, high mortality is uncommon but the number of defective trees becomes high. Since large trees are killed, mast production ceases with the result that an important source of food for many animals is now gone.

More than 70 decay fungi have been reported for beech and beech is vulnerable to injury by fire with large shallow roots being especially sensitive.

6 Summary

American beech, Fagus grandifolia Ehrh., is one of the most distinctive trees found in the forests of eastern United States. It is a stately massive tree of forest and park that attains heights in excess of 30 meters (maximum 50 meters) and diameters of 100 cm (maximum 200cm) and can be readily identified at a distance by its a wide spreading crown that casts a dense shade on the ground beneath it. It is one of the most, if not the most, shade tolerant hardwood tree species in the eastern United States. American beech grows on a wide variety of soils ranging from sand loams to soils of alluvial origin. Growth is slow in comparison to its associates even under the best growing conditions which occur in the Ohio and Mississippi River valleys. American beech is usually managed using uneven-aged silvicultural systems such as individual tree selection and group selection. The goal of such a system is to create a diameter distribution that resembles a backwards J where the numbers of trees per hectare declines steeply as stand diameter increases and then eventually levels off. The wood of American beech is very useful and is made into furniture, children's toys, novelty items (cutting boards, butcher's blocks and woodworking tables), veneer, and flooring.

Beech nuts or beech mast are valued as a wildlife food. However, beech bark disease is causing serious declines in many beech stands. Current research is focused on locating and perpetuating resistant strains of American beech

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[1]These references were used to synthesize and present the overview presented in this paper.

Silviculture of the oriental Beech (*Fagus orienalis* Lipsky); experiences made in Caspian forests, North of Iran

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Abstract

According to special ecological conditions (climatically and topographical) in North of Iran, the temperate broadleaved mixed forests (beech and oak forests) are developed in Tertiary period. Because of lack of glaciations period in the beginning of Quaternary period in the southern part of Caspian Sea these forests remain until today. The Beech (*Fagus orientalis* Lipsky) is a main species in this mixed broadleaved forests and appears stands wise in the mountainous sites of northern slopes of Elburz Mountains (700 – 2200 m.a.s.l.) north of Iran. There are many forest associations, which the beech is the dominant tree species. It appears in pure but also mixed stands; however, the mixture of tree species in the beech communities is much higher than the European beech ecosystems. The oriental beech stands are naturally mixed, uneven aged and mostly two till three storied in their vertical structure.

In Iran, it is about 40 years, which the Caspian beech forests are under management. The dominant silvicultural method, which practiced in these forests, was Shelter wood system to achieve even aged and pure beech stands. Today after 40 years experiences we can say that the shelter wood system is not suitable for the Caspian beech forests. There are many reasons; the most important one is that the Caspian beech forest naturally tends to be mixed and uneven aged. In some exceptional cases, the clear cuttings were done in mountainous oriental beech stands. The result of these experiences was catastrophic, after heavy soil erosion the pioneer succession has started on mentioned sites with *Rubus hyrcanus, Matteuccia struthiopteris and Alnus subcordata*. According to our experiences, observations and some investigations today we can say that the selection system (both, the single and the group selection system) is a suitable silvicultural system for the Caspian beech forests. Femelschlag system could be theoretically also a suitable silvicultural system in Caspian beech forests, if uneven aged forest is not the aim of management in these forests. It is obvious that ongoing and future researches will show us the appropriate silvicultural systems not only for the oriental beech forests but also for other forest communities in the Caspian region.

Introduction

There are 11 species of *Fagus* in the world and 8 of them appear in Eurasia, these are:

Fagus x moesiaca (Maly) Czeczott (F.sylvatica x F. orientalis), ***Fagus orientalis*** Lipsky (= F. macrophylla (Hohen. ex DC.) Koidz.), ***Fagus engleriana*** Seemen, ***Fagus longipetiolata*** Seemen, ***Fagus hayatae*** Palibin , ***Fagus lucida*** Rehder & E.H. Wilson, ***Fagus crenata*** Blume (F. sieboldi Endl.ex A. DC.), ***Fagus japonica*** Maxim.

Fagus orientalis has a limited disjunctive distribution area, southeastern of Europe, Caucasia and north of Iran are the main distribution area of *Fagus orientalis*. It is actually an Eurasiatic Beech species, begins in Macedonia over Crime Island in Ukraine, Caucasian Region and ends in Northeastern of Iran in Gorgan. *Fagus orientalis* is the most important tree species in Caspian forests north of Iran and vertically appears (stands wise) in from 700 m. until 2200 m.a.s.l. Also it avoids the sites with a long dry season, high temperature and heavy soils.*Fagus orientalis* is a shade tolerant species that 17% of the surface and 25% of the standing volume of Caspian forests belongs to it.

It prefers fresh brown soils, cool and foggy sites, especially in the mountainous part (1000-2000 m.) of northern slopes of Elburz Mountains. After some years suppression (Max.40 years) in the young stage it grows relatively fast and can reach big dimensions (51 meter in height and 200 cm in diameter)

The Caspian forests in north of Iran are not well known in scientific world. They belong to the north temperate broadleaved forest ecosystems and are mainly beech-oak-Hornbeam mixed forests and there are more than 85 tree species. These forests are old forest (more than 1.5 mio. years) and there are many endemic species in Caspian forests (Knapp & Marvie, 2003). Also these forests are over 40 years under regular management. The actual surface of Caspian forests is only 1.9 mio. ha (1964 exist still 3.4 mio. ha). It is important that there are still undisturbed beech forests in Caspian region and the actual annual removal in managed areas is only around 1 mio.m^3/year and the grazing with sheep and goats exist until today in Caspian forests.

Forest stands and association

There are many oriental beech associations on calcareous but also sandstone sites. According to lack of glaciations period in Caspian forest the whole beech communities (exception *Taxo-Fagetum*) are without the coniferous species like Abies or Picea. The major communities like *Rusco- Fagetum* are calcareous beech forests, but in some parts we meet Also beech communities on acid site, like *Arctostaphyllo-Fagetum* (*Vaccinium arctostaphyllos*).

There are many herbaceous species in oriental Beech communities, similarly to European forest association, like *Asperula* (*Gallium*), *Sanicula*, *Arum*, *Mercurialis*, *Luzula*, *Carex*, etc. The Beech stands are mostly uneven aged and mixed, pure beech stand exist also, but even aged beech stand in a large scale is very rare. The standing volume per ha varies between 300-700 m^3, in some part could also be till 1000 m^3 /ha.

Natural regeneration & stand dynamics

Oriental beech stands regenerates naturally group wise, spread regeneration over a large area is rare. The intensity of beech regeneration depends on gap-size in stand, in small gaps (<0.1 ha) is high and in large gaps (> 0.3 ha) decrease or disappeared beech regeneration. Also the number of beech sapling was in a study area (Ramsar) averagely 6253 in undisturbed and 9313 in managed area (Shabanian, 2000). Natural gaps in oriental beech stands varies from 0.01 – 0.40 ha and have mostly a Rhombus form (Hodjati, 2001)

The natural gap size was in average 0.14 ha, length 60 m. and width 30 meter (Hodjati, 2001). *Acer velutinum* is the most faithful accompanied tree species in beech stands and Dead trees favors beech regeneration (Shabanian, 2000).The dominant structure of oriental beech stands is uneven aged with three stories, the middle Story is underrepresented in comparison with the upper and under story and the optimal phase has the largest representative area in Caspian beech forests.

Silvicultural system

The main practiced silvicultural system in Caspian beech forest is the shelter wood system, clear cutting system were also done only in one management area. Today after about 40 years experiences we can say that the shelter wood system is not suitable for the mountainous and mixed beech stands in Caspian forests. For the choice of appropriate silvicultural system of Caspian beech forests their ecological, topographical and structural specifications must be considered as the following:

- Natural, uneven aged
- Mountainous sites
- Sensible to change of light and stand climate
- Sensible to high Temperature and soil compaction
- High standing volume (averagely 350 – 450 m^3)
- Long vegetation period and more growth
- Relatively high Mixture with other tree species

The selection system (Group and single) is a suitable silvicultural system for the natural beech stands of Caspian forests. For the silvicultural treatment of Caspian beech we recommend the following criteria must be under consideration:

- Natural regeneration GroupWise
- Favorite the elite tree species (*Acer, Fraxinus, Tilia*, etc.)
- 3 to 5 m^3 dead wood pro ha

- Soil scarification in seed year
- Beginning with the pioneer species in large gaps

Conclusion

According to our experiences made in Caspian forests, the clear cutting system and shelter wood are not the suitable silvicultural system for the management of Caspian Beech forest. the group selection system could be an appropriate silvicultural system for the forests.

The still undisturbed beech forests in Caspian forests must not harvested and must be managed for conservation. The Caspian beech forest is richer in Mixture in Comparison with European Beech forests. Tree species like *Acer velutinum* and *Alnus subcordata* are accompanied species .In some special sites appear also *Buxus hyrcanus*, *Taxus baccata* or *Lauro-cerasus officinalis* as under story elements in Beech stands.

According to introduction of exotic coniferous species, different options exist. We can say only 5% of Mixture with species like, *Abies, Larix, Picea, Pseudotsuga* and *Sequoia* could be a compromise and the experiences will show us in future. Now after forty years experiences in management and silviculture of Caspian Beech forest we believe today that we are just at the beginning of our way. We have learned a very important thing: A made recipe, does not exist for the management and silvicultural treatment of Caspian Beech forests. We must find the recipe in the entire of Caspian forest ecosystem. Not only for this reason, the undisturbed oriental Beech ecosystems have to be reserved for scientific investigations, observation and conservation of genetically diversity and the biodiversity as total. The expected scientific results could be useful not only for the Caspian regions, but also for those areas, who have the similar ecological and phylogenetical conditions.

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Analysis of untreated beech-stands (*Fagus sylvatica* L.) as a basis for new thinning concepts

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Abstract

Untreated beech-stands were analyzed in Switzerland with special reference to timber production. Results show that unmanaged stands of 60 to 90 years with dominant heights between 20 and 30 m have exhibit a sufficient number of candidate-trees *i.e.* dominant trees of good stem-quality, vitality and stability. Utilizing natural differentiation and mortality as elements of biological automation allows stand treatment with low management input. The target can be reached with fewer and later, but more effcient interventions (crop tree thinnings). Compared to the traditional, highly intensive thinning methods, costs are substantially reduced, allowing profitable timber production even in a hard business environment as in Switzerland.

Keywords: Biological automation, biological rationalisiation, *Fagus silvatica* L., untreated stands, quality timber production, Switzerland

1 Introduction

Beech is the most important broadleave species in Switzerland with 17.1 % of growing stock. In some regions, the proportion of beech is higher, like in the Mittelland region with 22.3 % and in the Jura hills, where beech is the most common species with 31.5 % (Table 1).

Table 1. Proportion of beech (growing stock) in Switzerland.

Switzerland	17.1 %
Mittelland region (lowlands)	22.3 %
Jura region (hills)	31.5 %

In Switzerland, timber harvesting costs are very high. For example, costs for harvesting stems of 30 cm diameter (DBH) are nearly 40 US$ per cubic meter (Table 2). High costs are due to numerous regulations, high machine costs, but primarily due to very high labor costs of around 40 US$ per hour.

Table 2. Timber harvesting costs in relation to mean tree diameter.

Mean diameter (DBH) [cm]	Harvesting costs [US$/m3]
20	63.1
30	38.8
40	30.4
50	23.8
60	21.2

Under these conditions, the minimum diameter for cost-covering harvesting of beech timber is around 35 to 40 cm for good harvesting conditions. Most of Swiss forest-enterprises are in the red.

On the other hand, young beech stands are still managed traditionally *i.e.* with regimes that have been developed in a time with much lower labor costs. This classical treatment includes early, intensive cleanings and thinnings with total costs of around 12’000 US$ per ha until the first cost-covering intervention, which is a high financial investment. Since classical treatment is not profitable any longer, new concepts need to be developped.

2 Materials and methods

With the analysis of untreated stands (Ammann 2004), the following questions should be answered:

- Is it possible to produce high-quality timber without thinning during a certain time?
- When and how should the first intervention be made?
- What are the risks and economic effects?

Because of the intensive tending of stands in Switzerland in the last decades, it was nearly impossible to find untreated beech stands. Finally six stands in Switzerland, primarily in the Jura hills, and one stand in Germany were selected and analyzed (Fig1).

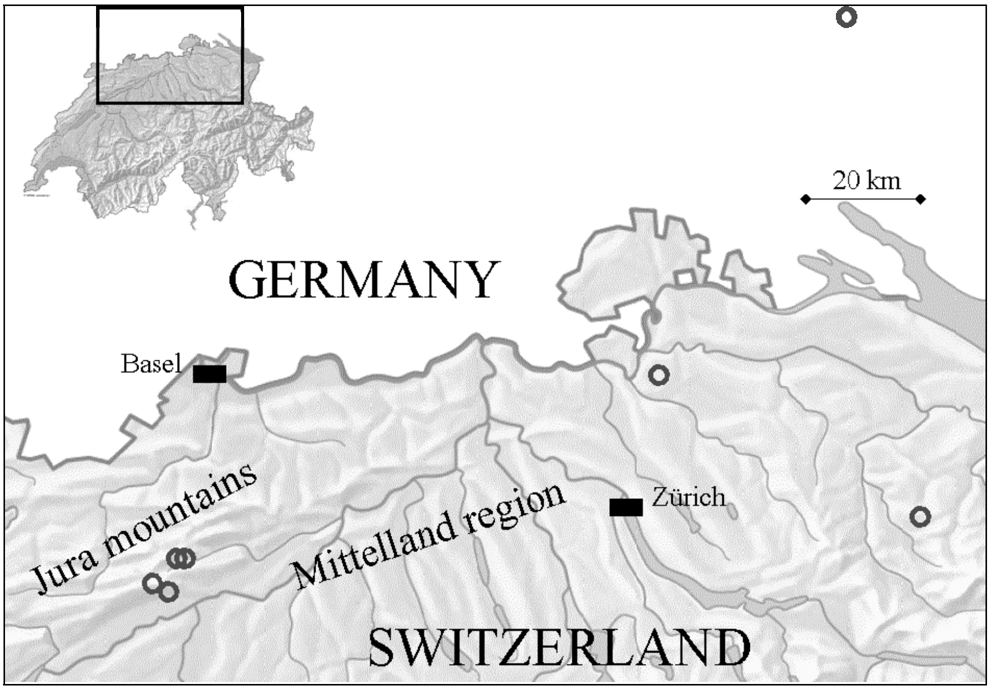

Figure 1. Map of the northern part of Switzerland with localization of the analyzed beech stands.

Table 3 provides an overview of the 7 selected, untreated stands: There were one young, 15-year-old and six older stands between 48 and 87 years with top heights of 20.7 to 31.0 m. The stands, which are all even-aged, are situated at altitudes between 680 to 1110 m. Site indices range between 17 and 25 (top height in meter at age 50). The stand with site index 17 is at the limit for producing quality timber. The stand with the best site index (25) is located in the Jura hills region, indeed. However this stand represents the excellent growing conditions of the Mittelland region and thus may serve as a typical example for this region.

Table 3. Survey of investigated, untreated beech stands, ordered by top height.

Stand	Top height [m]	Age [years]	Site index (top height at age 50)	Altitude [m asl]	Annual rainfall [mm]	Mean annual temperature [°C]	Top height [m]
Irchel	10.7	15	20	680	1050	8.0	10.7
Rüttenen1	20.7	49	21	720	1300	8.0	20.7
Dicken	22.5	48	23	880	1500	6.5	22.5
Schitterwald	23.3	80	17	1110	1500	3.5	23.3
Ringingen1	27.5	87	19	810	950	6.5	27.5
Andreslen2	27.6	64	23	710	1400	7.5	27.6
Andreslen1	31.0	68	25	710	1400	7.5	31.0

3 Results

Because the data basis for beech is small (7 stands, including one very young stand), results from analyzed ash stands and from one sycamore maple stand are presented too. These stands are also untreated.

Unthinned stands are very dense and under maximum competition. This leads to a continuous mortality (Fig. 2). This effect of natural and cost-free thinning ("self-thinning") is basically desired.

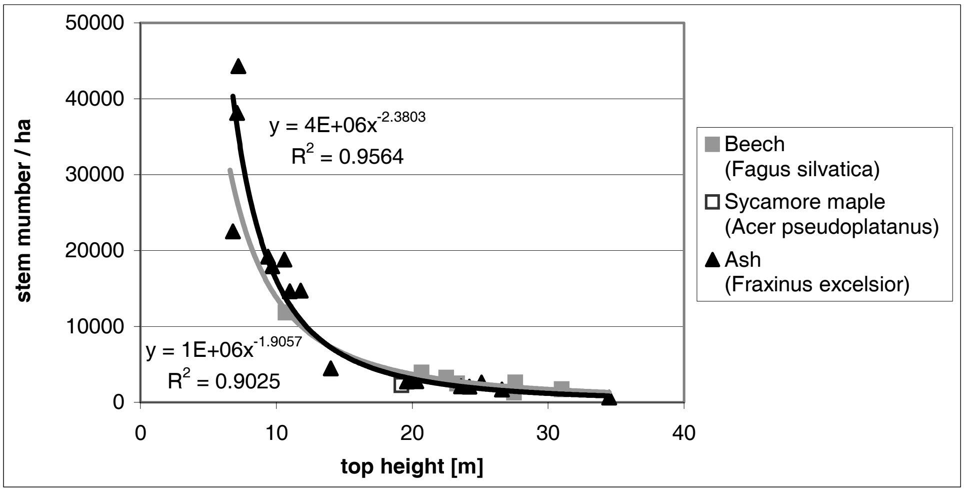

Figure 2. Development of stem number in untreated stands.

As result of the natural development and differentiation, untreated stands typically show left-asymmetrical distributions of stem diameters (Fig. 3).

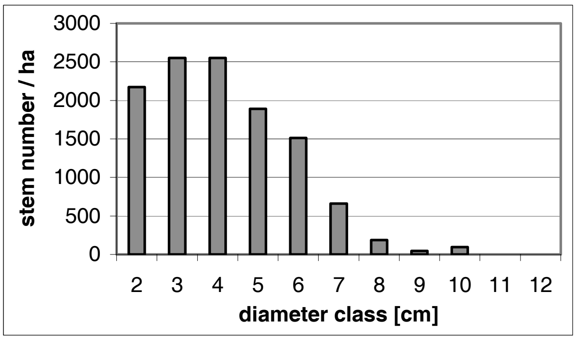

Figure 3. Distribution of stem diameters in the 15-years-old, untreated beech stand.

The same type of distribution can be observed in the 68 years old stand (Fig. 4). There still exist a lot of trees with small diameters. Most interesting and important for silvicultural success are the dominant trees, especially the potential crop trees, called candidate trees.

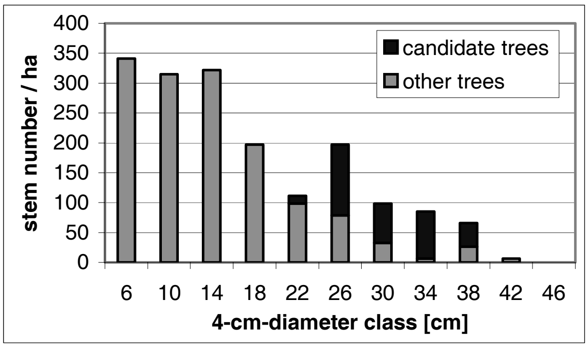

Figure 4. Distribution of stem diameters in the 68-year-old, untreated beech stand.

During stand measurement and data recording, all candidate trees were identified. A candidate tree had to be:

- dominant (high social position)
- stable (mechanical stability against snow damage)
- of good stem quality

Parallel to the decreasing stem number (Fig. 2), the number of candidate trees decreases as well (Fig. 5): At a top height of 20 m, untreated beech stands contain around 400 candidate trees per ha and at 30 m top height around 200 per ha. 200 candidate trees are just sufficient to find at least 100 crop trees in a regular distribution.

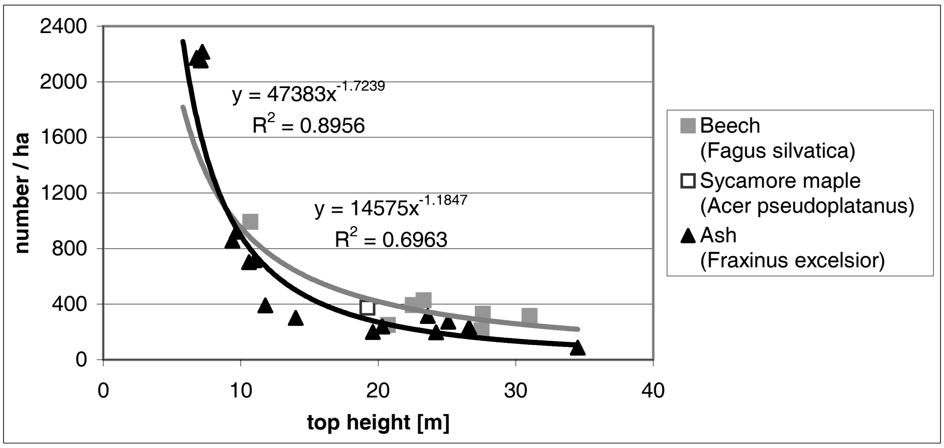

Figure 5. Number of candidate trees per ha.

The 100 to 150 best candidate trees were selected as crop trees, having regard to distance and spatial distribution.

Figure 6 gives an impression of the spatial distribution of candidate trees and crop trees in an unthinned beech stand. The total stem number was 1739 per ha. 315 candidates per ha were found, their distribution is stochastical. Nevertheless it was possible to select sufficient crop trees in a regular distribution; in this example 144 crop trees per ha were selected.

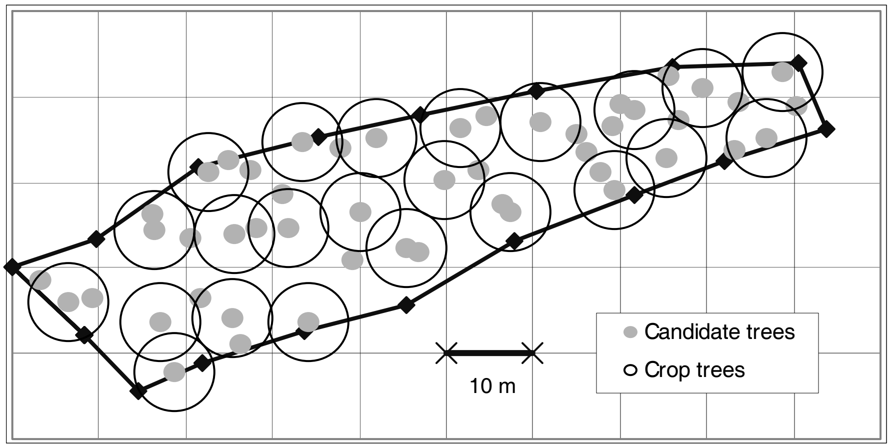

Figure 6. Spatial distribution of candidate trees (315/ha) and selected crop trees (144/ha) in a 68 years old, untreated beech stand.

Interestingly in unthinned stands, the proportion of candidate trees in percent of total stem number is increasing with age. Young stands had a proportion of around 5 %, older stands around 15 % (Fig. 7). Natural development seems to favour trees of good quality as foresters would do. A possible explication could be, that the maximum density allows for a very good education or quality-training. Density not only influences natural pruning favourably, but also reduces the formation of forked trees (Richter 1999).

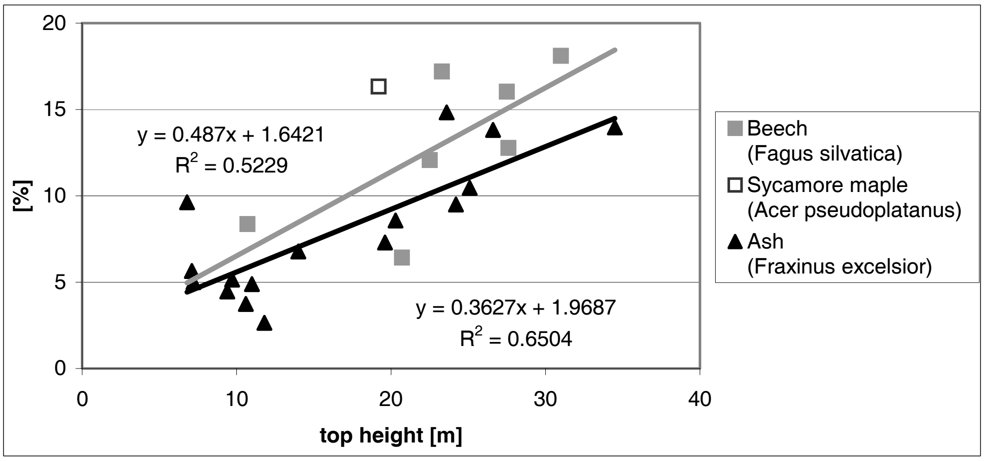

Figure 7. Proportion of candidate trees (in percent of total stem number).

Stem quality was assessed by measuring "quality-height" *i.e.* the length of the stem, which will prospectively attain at least B-quality (B is the second best of 4 quality types). Beech crop trees in the untreated stands had a mean quality-height of 8.9 m; this is a good value, taking into account the partly low site index. Another indicator of the rather good quality is the high proportion of dominant trees, which fulfilled the minimal quality conditions for candidate trees (compare Fig. 4).

The degree of slenderness of candidate-trees was used as indicator for stability. Figure 8, containing additional data from candidate trees of mixed, but also untreated stands, shows a rapid stabilization in beech stands, even without thinning. The development is substantially different from spruce stands, which remain much longer in the critical stage. For spruce, the critical value regarding the degree of slenderness is around 90, for beech, due to its higher resistance, it is much higher at a value around 140 (Kodrik 1988). In beech, this critical value is attained already at a top height of 10 m.

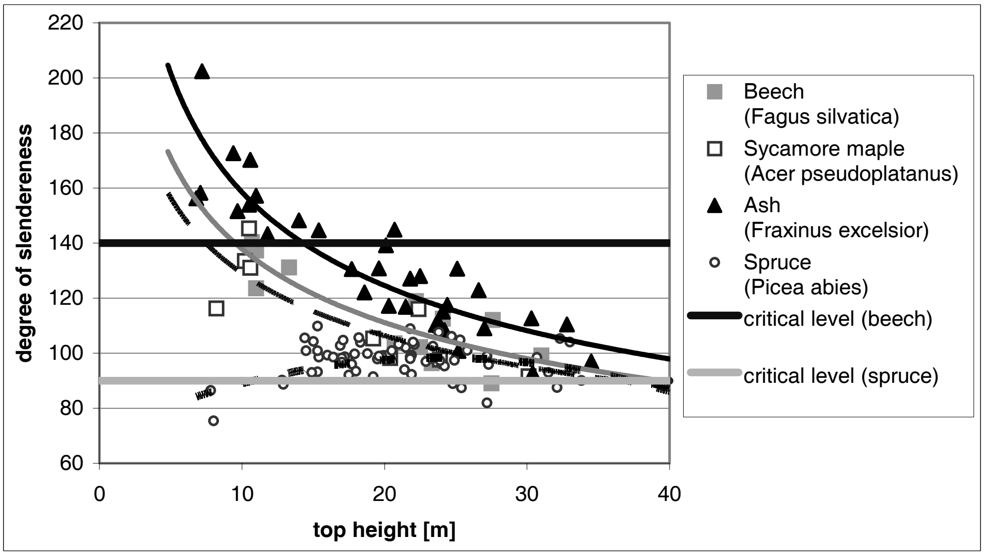

Figure 8. Degree of slenderness of the candidates in untreated stands.

Although snow damage is occurring in young beech stands, the risk is limited to a relatively short time. Because of the high density, collective stability is good. Foresters in beech-districts in Switzerland rate the risk of snow damages as small, there exists no adequate information or investigation, however.

Heavy snowfalls in young Romanian beech stands damaged in the first instance thin, suppressed and dominated trees, but also dominant, forked trees of bad quality (Nicolescu *et al.*, 2004). Hence, snow damage in beech stands may even act as a thinning with negative selection.

The mean crown-lengths of candidate trees in young stands are early on a level around 40 percent. This is desirable for natural pruning. A small decrease to around 30 percent at a dominant height of 30 m can be observed (Fig. 9). At this stage, the crown-base of candidate trees lies around a height of 20 meters. If crown-base can be kept at this height, the full grown beech crop-trees will have a crown-length of 50 percent or more, because beech will attain a final height of 40 to 45 meters on productive site conditions in Switzerland.

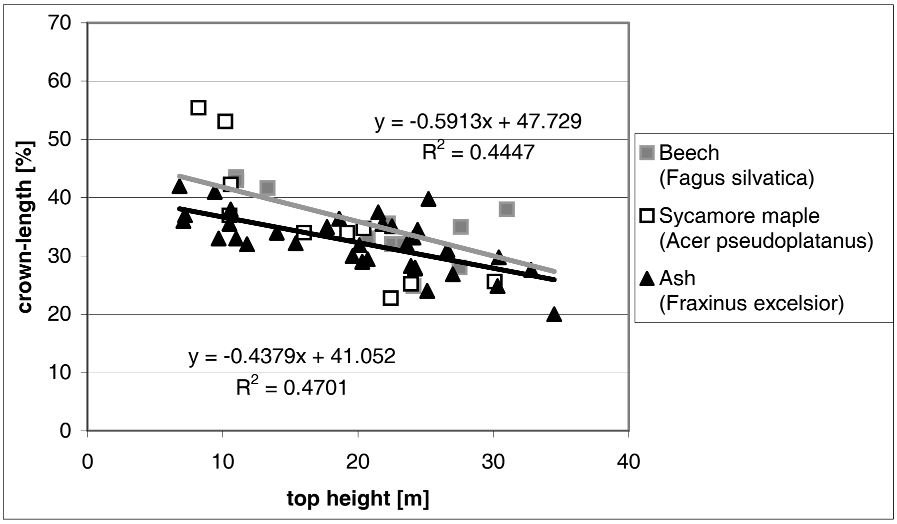

Figure 9. Crown-length of candidate trees in % of tree height.

Beech is known as a species with an extraordinary crown- and increment-reactivity even in older age. This allows at all reflecting on concepts with late interventions. Ash, for example, is very different from beech in this respect.

Diameter development is another important criteria. Due to the increasing probability of red heartwood formation with higher age (Knoke 2003), target diameter should be reached during maximal 120 years (Schütz 2003). Mean diameter of candidate trees in untreated beech stands attains 30 cm (DBH) at a top height of 30 m (Fig. 10) which corresponds to an age of 55 to 60 years on productive sites.

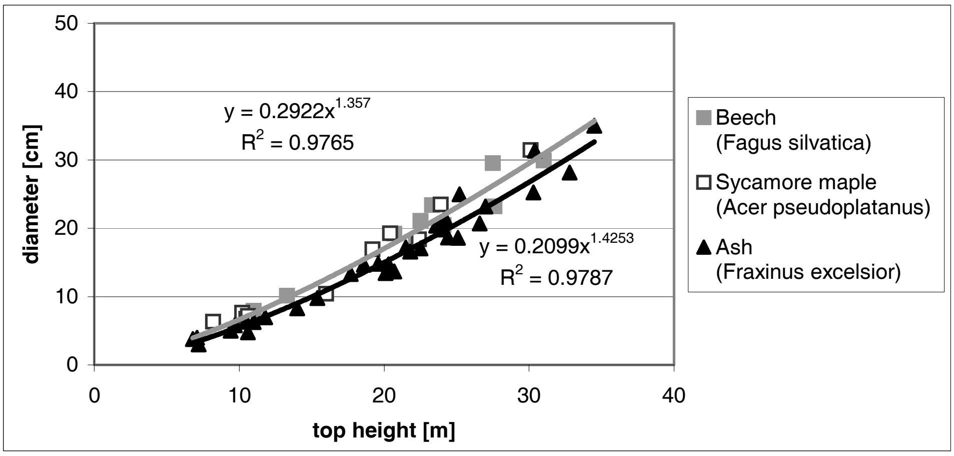

Figure 10. Mean diameter of candidate trees in untreated stands of beech, sycamore and ash.

Using the function given in figure 10, current diameter increment of beech for different site-indices may be calculated (Fig. 11). Annual diameter increment culminates at age 25. The decrease in diameter increment in older age is good reason for not delaying the first interventions too long.

Figure 11 assumes that a first intervention is performed as soon as the annual diameter increment falls below 0.4 cm (ring width of 2 mm). For stands with a site index of 28, this means that the first intervention is performed at 65, for site index 24 at 55 and for site index 20 already at an age of 40 years. Hence, the period of natural development without thinning interventions depends on the site index. Productive sites clearly allow a longer delay.

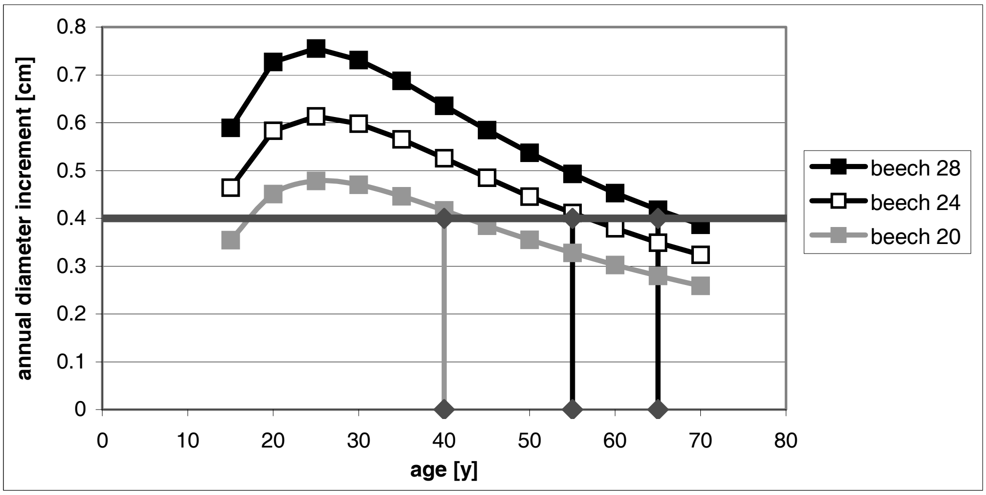

Figure 11. Annual diameter increment in relation to site index (20, 24 and 28).

Table 4 shows the calculated production period for different site indices and target diameters. For site index 28 mean diameter of crop trees is 34 cm at the first intervention (compare Fig. 10). Assuming that further diameter increment after the thinning will be 0.8 cm per year, a mean crop-tree diameter of 50, 60 or 70 cm respectively will be reached at the age of 85, 98 and 110 years respectively. The assumed diameter increment of 0.8 cm a year agrees with the findings of different authors who studied the potential of diameter increment in beech (Kahn and Pretzsch 1997; Utschig 2000; Guericke 2002). For lower site indices, lower diameter increments were assumed accordingly (Table 4).

Table 4. Estimated production period for beech according to site index and target diameter.

site index (top height [m] at age 50)		**28**	**24**	**20**
age at first intervention	[years]	65	55	40
top height at first intervention	[m]	33.3	25.7	16.6
diameter of crop-trees at first intervention	[cm]	34	24	13
further diameter increment (assumption)	[cm]	0.8	0.7	0.6
50 cm crop-tree-diameter is reached at **age**:	[years]	**85**	**92**	**102**
60 cm crop-tree-diameter is reached at **age**:	[years]	**98**	**106**	**118**
70 cm crop-tree-diameter is reached at **age**:	[years]	**110**	**121**	**135**

According to these estimates it is possible to produce beech of intended dimension in rotations of maximal 120 years and without thinning interventions for a relatively long time period. In the case of site index 20, target diameter needs to be reduced to 60 cm, however, in order to avoid rotations longer than 120 years.

The possibility to delay the first interventions in beech for a long period of time offers the chance for very efficient timber production. Marking of the first intervention in the 68 years old stand produced a harvesting quantity of 250 m3/ha (growing stock 758 m3/ha) with a mean diameter of 26.4 cm for the removed trees. Harvested as wood chips for timber-energy, this intervention would be cost-covering even in a hard business environment as in Switzerland.

4 Conclusions

Please note, that these findings should be generalized carefully, because only a limited number of stands has been found and studied.

Unthinned beech stands will grow according to our production targets for decades without a need for interventions. This offers new possibilities for production-concepts on the basis of biological rationalization with few and late starting interventions. Production of quality timber is possible with extremely low management input, compared to the traditional concepts, thanks to biological automation such as:

- natural mortality
- natural selection of best-growing trees
- differentiation in diameter and social position
- natural stabilization of trees

The new concepts do not lead to higher production risks and timber quality of a sufficient number of trees (candidates) develops as desired. They allow to economize on thinning costs; especially the first, expensive cleanings and thinnings can be avoided. The first intervention may be performed cost-covering even under difficult economic situations such as in Switzerland.

Beech is particularly suitable for concepts based on biological automation because of its excellent crown-reactivity and its constantly high diameter increment in older age. On productive sites (common in Switzerland) the use of such concepts is even more appropriate. Precondition for the desired development is a sufficient density in young-growth stands.

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Field performance of containerized beech seedlings; preliminary results

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Abstract

Beech *(Fagus sylvatica* (L.) is the most important broad-leafed species in Danish forestry. Most seedlings are planted as bare roots, but there seems to be a shift in preference towards containerised seedlings.

Two similar two-factorial experiments with stock type and planting time were established at two sites in Denmark. Seedlings in 5 different containers (3 side slit and 2 mesh containers) where planted together with 3 different types of bare root seedlings. Planting took place at 4 different times starting Dec. 2001 and ending Oct. 2002.

Preliminary results show only small differences in first year survival, but significant differences in first year height increment.

Keywords: Beech, *Fagus sylvatica*, Stock type, planting time, plug seedlings, container seedlings

1 Introduction

Containerized seedlings have been introduced to Danish forestry on several occasions. Most of them relating to major wind throw in 1966/1967 and in 1981 where a sudden demand for seedlings arose. Containerized seedlings, being grown in green houses, have a shorter production time than the traditionally used bare rooted seedlings. In the 1990's a new effort was made to introduce containerized seedlings in Danish forestry. This time the arguments where better root development and higher growth rates.

Most research comparing root development and growth of different containerized stocks has studied these phenomena in coniferous species. A general conclusion from a range of studies is that high levels of air pruning in the container increases the possibility that the seedlings will develop well distributed roots (Fraysse 1998; Lindström 1982, 1998; Lindström & Håkansson 1998). Also bare rooted stock experience root deformations during handling and transplanting (Nielsen & Sønnichsen 2002). Comparisons of the above ground part of seedling as affected by stock type show different results. Neckelmann (1979) found that ½-1 year old containerized (Paperpot) seedlings of *Picea abies* couldn't competed with 3½-4 year old bare rooted seedlings in terms of growth and survival. A later study (Neckelmann 1980) showed that 2 year old containerized (Paperpot) seedlings performed as well as 2-4 year old bare rooted ones. More recent studies on *Abies nordmanniana* finds that containerized (Jiffy7) seedlings show superior growth rates first year after planting as compared to bare rooted stock (2/1, 3/0 and 2/2) (Sønnichsen & Sørensen 2001).

Very little work has been done comparing broad leaved species grown as bare rooted or containerized seedlings, and the aim of this project is to study root growth and growth rates of beech (*Fagus sylvatica*) and oak (*Quercus robur*) as affected by stock type and container design. Results from first year height growth of beech are presented here.

2 Materials and methods

2.1 Materials

Field experiments were established at two different locations. One near the town Varde in the western part of Jutland on sandy soils, deposits from a previous ice age (Saale). Elevation is app. 25 m.a.s.l., and mean annual precipitation app. 850 mm. The other experimental site is located in the southern part of Funen, near the town Faaborg on loamy soils, moraine deposits from the last ice age (Weichsel). Elevation is app. 85 m.a.s.l., and mean annual precipitation 650-700 mm.

2.2 Methods

Each site was divided in 4 subplots representing 4 different planting times. Within each subplot each stock type was planted in a randomized block design with 4 replicates.

Subplots where planted in December 2001, March 2002, September 2002 and October 2002.

Table 1. Stock types included in the experiment

Stock type	**Container type**	**Name**	**Container volume (cm^3)**
Bare rooted seedling		1/0	-
		2/0	-
		Plug +1	-
Plug seedling	Hard walls with guiding ribs	HIKO 265	265
		Quick	200
	Side slit hard walls	HIKO 150	150
Container seedling	Root penetrable mesh	Ellegaard	180
		Jiffy7	200

3 Results

Results after 1. growing season show for bare rooted stock that age does not affect the growth rate. 1/0 og 2/0 grow at the same level (5-8 cm) at all planting times. Among the hard walled containers HIKO 150 perform well in all cases. Growth rates range from 6 to 14 cm. The other two hard walled containers show generally the same growth rates as HIKO 150 but QUICK falls through on the sandy location at the Dec. 2001 and the Sep. 2002 plantings.

The mesh container Ellegaard was only included in the first batch due to dificulties in handling. When compared to the Jiffy7 container it shows smaller growth rates in most cases.

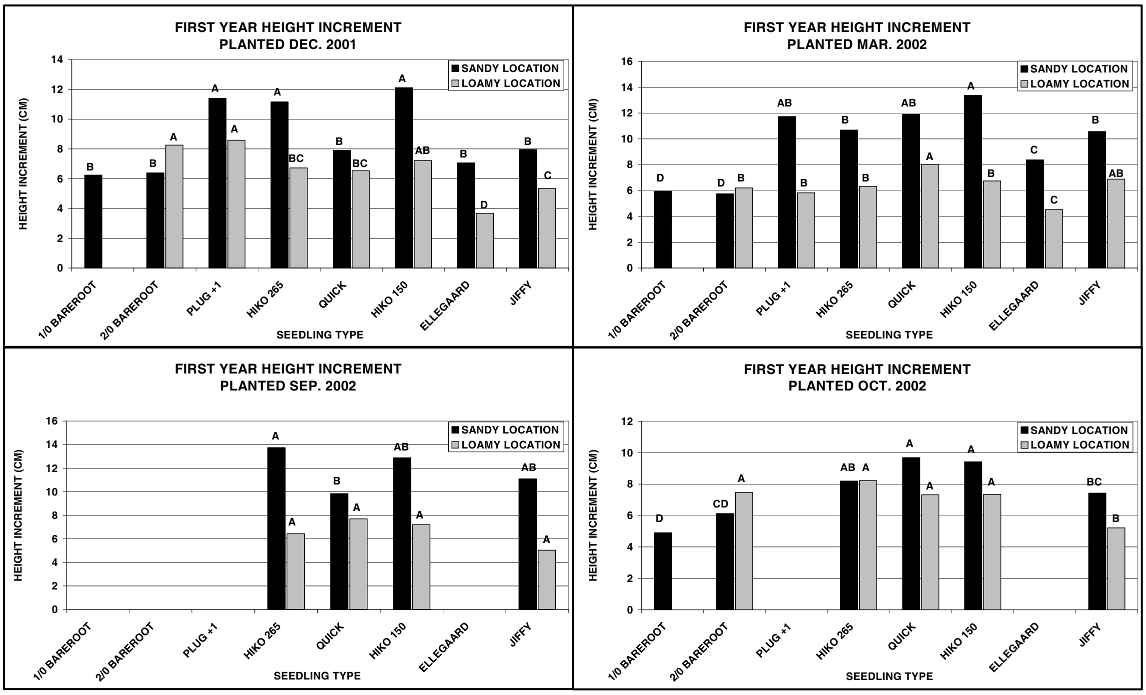

Figure 1. First year height increment of different stock type at 4 different planting times on 2 locations. Plantings in Dec. 2001 and Mar. 2002 is of the same batch and Plantings in Sep. and Oct. 2002 is of the same batch. Bars with the same letter are not different (p<0,05). Comparisons are made within locations, not between locations.

4 Discussion and Conclusion

The stock types included in this experiment cover to some extend the stock types used in Danish forestry. Traditionally 1/0 or 2/0 bare rooted seedlings are used, but containerized seedlings seem to have increased their market share over the last years and the share is still increasing. Danish forestry has in the last 5-7 years been very focused on cost minimization in the regeneration phase, and the containerized stock types included in this study is for most of them seen as too large and too expensive for a future economically sustainable forest management practice. In the coming years focus within research and practice is expected to shift towards smaller seedlings and forest practices supporting the use of smaller seedlings.

No definite conclusions can be made at this early stage, but in several cases the plug seedlings have grown more than the container seedlings and the bare rooted seedlings. Also, apparently, there is no gain in using large cavity containers as the Quick and the HIKO 265 for beech seedlings, as they do not outperform the beech seedlings grown in the HIKO 150 container.

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Growth and yield analysis on Beech (*Fagus oriantalis* Lipsky) in two ecological sites using multivariate Hotelling's T_2^2 test

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Abstract

The Caspian forests of Iran are located on the southern border of the Caspian Sea and cover an area of 1.9 million hectare. Beech (*Fagus oriantalis* Lipsky) is main endemic, valuable and economic species at higher altitudes forest area in the north of Iran. The random sample method was used in this study. Data were sampled from pure and mixed, closed canopy of *Fagus oriantalis* stands. The sampling unit was the single tree and in the total 160 ($n_1 = n_2$=80) trees were sampled in two ecological test sites. Pair-wise multivariate Hotelling's T_2^2 test was used for growth and yield analysis in this study. This statistical analysis indicated, the null hypothesis (H_0) rejected at the level of α = 0.0001. The mean vector of population 1, $\overline{X}^{(1)}$ and mean vector of population 2, $\overline{X}^{(2)}$ are highly significant different. The results of this study are indicated, growth and yield of Beech (*Fagus oriantalis* Lipsky) in two ecological forest test sites are not equal using multivariate Hotelling's T_2^2 test.

Keywords: Beech, Forest, Growth, Multivariate, Yield

1 Introduction

The Caspian forests of Iran are located on the southern border of the Caspian Sea and cover 1.9 million hectare. These forests are also called the Hyrcanian forests. Forest stands in this area are both valuable and economical. The main benefits from forests are wood production and various physical and social benefits frequently termed *forest influence*. In many instances *forest influence* is more important than forests as producers of wood. Based on *forest influence*, the Caspian forests are divided into four separate forest management areas. One of these is the Gilan influx area with 682,500 hectare. Beech (*Fagus oriantalis* Lipsky) is main endemic, valuable and economic species at higher altitudes forest area in the north of Iran. Pair-wise multivariate Hotelling's T_2^2 test was used for growth and yield analysis in this study.

Multivariate Hotelling's T_2^2, test has been applied for many years in psychological and educational research (Tatsouka, 1988). A fundamental problem facing researchers in this discipline has been the discrimination for pair-wise testing of groups, classes and populations using p dimensional datasets (Bonyad, 1995). A similar fundamental problem faces researchers in forest inventory namely the discrimination of forest parameters, which are also multivariate datasets. Therefore this study investigated the usefulness of multivariate Hotelling's T_2^2 test for inventory of forest parameters. The objectives of the research are:

Growth and yield analysis on Beech (*Fagus oriantalis* Lipsky) in two ecological forest sites in the study area.

To investigate the usefulness of statistical multivariate Hotelling's T_2^2 test using p dimensional datasets.

2 Materials and Methods

The test sites consisted of former Forest Service forests, districts number 9 and 11 which are located in the Shafurud region of Gilan province in the north Iran. The ecological variations of test sites are shown in table 1.

Table 1. Ecological variations of test sites

Test sites	Parcel	Test area (ha)	Forest types	Canopy %	Elevation (m.a.s.l.)	Slope classes %	Geographical direction
district 9	22-23-24	200	Pure and mixed Fagus stands	90-100 (Closed)	1300-1500	30 - 50	N.W.
district 11	30-31-34-35	200	Pure and mixed Fagus stands	80- 90 (Closed)	900-1200	25 - 50	N.W.

The random sample method was used in this study. Data were sampled from pure and mixed, closed canopy of *Fagus oriantalis* stands. The sampling unit was the single tree and in the total 160 ($n_1 = n_2 = 80$) trees were sampled in two ecological test sites. Measured variables are shown in table 2:

Table 2. measured variables of sample trees

Symbols	Variables	Units	No. of sample trees
x_1	Diameter at breast height	Dbh in cm	80
x_2	Total height	H in m	80
x_3	Mean annual increment of diameter	MAI in mm	80
x_4	Volume of tree	V in m^3	80

2.1 Multivarite Hotelling's T_2^2 test procedure

The Hotelling's T_2^2 test procedure (Tatsouka, 1988 and Morrison, 1990), is as follows:

1. Null hypothesis $$H_0 = \begin{bmatrix} \mu_{11} \\ . \\ . \\ \mu_{1p} \end{bmatrix} = \begin{bmatrix} \mu_{21} \\ . \\ . \\ \mu_{2p} \end{bmatrix}$$

2. Alternative null hypothesis $$H_a = \begin{bmatrix} \mu_{11} \\ . \\ . \\ \mu_{1p} \end{bmatrix} = \begin{bmatrix} \mu_{21} \\ . \\ . \\ \mu_{2p} \end{bmatrix}$$

3- $\alpha = 0.05(1)$ usually

4. Mean vector of popul.1 $\overline{X}^{(1)} = \begin{bmatrix} \overline{X}_{11} \\ \overline{X}_{12} \\ \cdot \\ \cdot \\ \overline{X}_{1j} \end{bmatrix}$, Mean vector of popul.2 $\overline{X}^{(2)} = \begin{bmatrix} \overline{X}_{21} \\ \overline{X}_{22} \\ \cdot \\ \cdot \\ \overline{X}_{2j} \end{bmatrix}$

Within-group SSCP matrix (W_k).

W_k = SSCP$_1$ + SSCP$_2$ $W_k = \begin{bmatrix} x_{11} & x_{12} & \cdot & \cdot & x_{1p} \\ x_{21} & x_{22} & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ x_{p1} & \cdot & \cdot & \cdot & x_{pp} \end{bmatrix}$

6. The vector of centroid difference $\overline{X}^{(1)} - \overline{X}^{(2)} = \begin{bmatrix} \overline{X}_{11} \\ \overline{X}_{12} \\ \cdot \\ \cdot \\ \overline{X}_{1j} \end{bmatrix} - \begin{bmatrix} \overline{X}_{21} \\ \overline{X}_{22} \\ \cdot \\ \cdot \\ \overline{X}_{2j} \end{bmatrix}$

7.
$$T_2^2 = (\overline{X}^{(1)} - \overline{X}^{(2)})'\left(\frac{W}{n_1+n_2-2}\frac{n_1+n_2}{n_1n_2}\right)^{-1}(\overline{X}^{(1)} - \overline{X}^{(2)})$$
$$= \frac{n_1n_2(n_1+n_2-2)}{n_1+n_2}(\overline{X}^{(1)} - \overline{X}^{(2)})'W^{-1}(\overline{X}^{(1)} - \overline{X}^{(2)})$$

Where:

W^{-1} is the inverse matrix of the within-group SSCP matrix.

8. The corresponding T_2^2 statistic is distributed as a F variate with p and n_1+n_2-p-1 d.f.

$$\frac{(n_1+n_2-p-1)}{(n_1+n_2-2)p}T_2^2 = F^{p}_{n_1+n_2-p-1}$$

where:

p = No. of variable in each group

n_1 = sample size for group 1

n_2 = sample size for group 2

N = n_1+ n_2 (Total sample)

k = (No. of Groups)

9. Computed: $$F = \frac{(n_1 + n_2 - p - 1)}{(n_1 + n_2 - 2)p} T_2^2$$

10. Tabulated: $$F = F_{\alpha(1),p,n_1+n_2-p-1}$$

11. Compare the two F values.

12. Interpret the result.

2.2 Multivarite Bartlett's test procedure

Multivariate Hotelling's T^2 test is based on the assumption of equality of population co variance-covariance matrices. This assumption is evaluated using Bartlett's test. The Bartlett's test procedure is as follows:

1. $H_0 = \Sigma_1 = \Sigma_2$
2. $H_a = \Sigma_1 \neq \Sigma_2$
3. $\Sigma_k = S_k /(n_k - 1)$

Where:

Σ_k is var-covariance matrix

S_k is SSCP matrix.

n_k is sample size from the kth population.

4. $$\Sigma_W = \frac{SSCP_1 + SSCP2}{N - k} = \frac{\sum_{k=1}^{2} SSCP_k}{N - k}$$

where:

Σ_W = The pooled within-groups variance covariance matrix.

$|\Sigma|$ is determinant of Σ_W matrix

$N = n_1 + n_2 + \cdots + n_k$ (total sample size).

5. The hypothesis is tested by a modified log-likelihood-ratio statistic

$$M = (N - k)\ln|C| - \sum_{k=1}^{k}(n_k - 1)\ln|C_k|$$

6. h is scale factor $$h = 1 - \frac{2p^2 + 3p - 1}{6(p+1)(k-1)}\left(\sum \frac{1}{n_k} - \frac{1}{N-k}\right)$$

where:

p = number of variables in each group.

7. Mh is distributed as a chi-square (χ^2) with p(p+l)*(K-l)/2 d.f.

8. Tabulated chi-square is $\chi^2_{\alpha=0.05(1),\, p(p+1)*(k-1)/2}$

9. Compare two chi-square.

10. Interpret the result.

3 Results

3.1 Bartlett’s test for equality of population var-covariance matrices

Equality of population covariance matrices is a basic assumption for Hotelling's T_2^2 test. Bartlett's test of equality of k=2 population (groups) covariance matrices were carried out in association with all Hotelling's T_2^2 significance tests. A numerical example was carried out between variance-covariance matrix of district 9 and district 11. Bartlett's hypothesis was tested by the modified log-likelihood-ratio statistic M defined below:

$$M = (N-k)\ln\left|\sum_{W}\right| - \sum_{i=1}^{k}(n_k - 1)\ln\left|\sum_{k}\right| = 187.48$$

$$h = 1 - \frac{2p^2+3p-1}{6(p+1)(k-1)}\left(\sum\frac{1}{n_k} - \frac{1}{N-k}\right) = 0.95$$

Computed $\chi^2 = \mathrm{Mh} = 178.106$

Tabulated $\chi^2_{\alpha = 0.001(1),\ p(p+1)*(k-1)/2} = 29.588$

Since 187.48 > 29.588

Reject the null hypothesis with probability of at least 0.001.

It may be concluded that the within class covariance matrix of district 9 and district 11 are significantly different. However, it should be noted that Hotelling's multivariate technique is robust with respect to departure from the assumption of equality of covariance matrices.

3.2 Multivarite Hotelling's T_2^2 test

The basic statistics of measured variability in district 9 and 11 were computed as follows respectively.

Simple Statistics on Beech trees (district 9)

Variable	N	Mean	Std. Dev.	Sum	Minimum	Maximum
X11	80	50.0750	25.1259	4006	14.0000	102.0000
X12	80	27.6000	7.0829	2208	13.0000	39.0000
X13	80	3.0450	0.6884	243.6000	1.6000	5.0000
X14	80	3.1155	3.2319	249.2420	0.1300	11.2800

Simple Statistics on Beech trees (district 11)

Variable	N	Mean	Std. Dev	Sum	Minimum	Maximum
X21	80	47.5625	21.2185	3805	13.0000	100.0000
X22	80	24.3688	4.9954	1950	12.0000	36.0000
X23	80	3.7075	0.9716	296.6000	2.0000	6.0000
X24	80	2.5565	2.4976	204.5210	0.1300	9.9980

From the above analysis, it should be noted that dbh and total height of sample trees have the largest variance in two test sites. The mean vector of four measured variables (p=4) in district 9 denoted by 1 and in district 11 denoted by 2, as follows:

$$\overline{X}^{(1)} = \begin{bmatrix} \overline{X}_{11} \\ \overline{X}_{12} \\ \overline{X}_{13} \\ \overline{X}_{14} \end{bmatrix} = \begin{bmatrix} 50.0750 \\ 27.6000 \\ 3.0450 \\ 3.1155 \end{bmatrix} \qquad \overline{X}^{(2)} = \begin{bmatrix} \overline{X}_{21} \\ \overline{X}_{22} \\ \overline{X}_{23} \\ \overline{X}_{24} \end{bmatrix} = \begin{bmatrix} 47.5625 \\ 24.3688 \\ 3.7075 \\ 2.5565 \end{bmatrix}$$

The difference between the mean vectors is:

$$\overline{X}^{(1)} - \overline{X}^{(2)} = \begin{bmatrix} 3.5125 \\ 3.2312 \\ -0.6625 \\ 0.5590 \end{bmatrix}$$

Within and pooled, W, sum of squares and cross product (SSCP) matrices for SS (SSCP1) and LP (SSCP2) are computed as follows:

SSCP1 matrix for district 9

	X11	X12	X13	X14
X11	250474.0000	122674.0000	12055.2000	18667.6020
X12	122674.0000	64904.0000	6723.2000	8263.9930
X13	12055.2000	6723.2000	779.2000	725.0113
X14	18667.6020	8263.9930	725.0113	1601.7036

SSCP2 matrix for district 11

	X1	X2	X3	X4
X1	216543.0000	100073.0000	14437.9000	13749.0030
X2	100073.0000	49478.2500	7324.1000	5757.1080
X3	14437.9000	7324.1000	1174.2200	782.2609
X4	13749.0030	5757.1080	782.2609	1015.6541

Pooled within sum of square cross product matrix W

W=SSCP1+SSCP2 matrix

	X1	X2	X3	X4
X1	467017.0000	222747.0000	26493.1000	32416.6050
X2	222747.0000	114382.2500	14047.3000	14021.1010
X3	26493.1000	14047.3000	1953.4200	1507.2722
X4	32416.6050	14021.1010	1507.2722	2617.3578

The inverse (W^{-1}) of pooled within sum of square cross product matrix W is as follow:

W^{-1} matrix.

	X1	X1	X1	X1
X1	0.0003	-0.0003	-0.0006	-0.0018
X1	-0.0003	0.0004	-0.0003	0.0014
X1	-0.0006	-0.0003	0.0068	0.0050
X1	-0.0018	0.0014	0.0050	0.0125

Computed $$\mathrm{T}_2^2 = \frac{n_1 n_2 (n_1 + n_2 - 2)}{n_1 + n_2} (\overline{\lambda}^{(1)} - \overline{\lambda}^{(2)})' W^{-1} (\overline{\lambda}^{(1)} - \overline{\lambda}^{(2)})$$

$$\mathrm{T}_2^2 = \frac{80*80(80+80-2)}{80+80} \begin{pmatrix} 3.5125 & 3.2312 & -0.6625 & 0.5590 \end{pmatrix}' \begin{bmatrix} 0.0003 & -0.0003 & -0.0006 & -0.0018 \\ -0.0003 & 0.0004 & -0.0003 & 0.00014 \\ -0.0006 & -0.0003 & 0.0068 & 0.0050 \\ -0.0018 & 0.0014 & 0.0050 & 0.0125 \end{bmatrix} \begin{bmatrix} 3.5125 \\ 3.2312 \\ -0.6625 \\ 0.5590 \end{bmatrix}$$

$T_2^2 = 42.976$

Computed $$F = \frac{(n_1 + n_2 - p - 1)}{(n_1 + n_2 - 2) p} \mathrm{T}_2^2$$

Where:

α=0.05

$n_1 = 80$ sample size district 9

$n_2 = 80$ sample size district 11

N= $n_1 + n_2$ = 80 +80 = 160 (Total sample)

p = 4 Number of variables

k = 2 Number of test sites (district 9 and 11)

$$F = \frac{(80+80-4-1)}{(80+80-2)4} * 42.976 = 10.54$$

Tabulated $F^{p}_{\alpha = 0.001(1),\ n_1 + n_2 - p - 1} = 3.74$

Since 10.54 > 3.74

This statistical analysis indicated, the null hypothesis (H_0) rejected at the level of α = 0.0001. The mean vector of population 1, $\overline{X}^{(1)}$ and mean vector of population 2, $\overline{X}^{(2)}$ are highly significant different. The results of this study are indicated, growth and yield of Beech (*Fagus oriantalis* Lipsky) in two ecological forest test sites are not equal using multivariate Hotelling's T_2^2 test.

4 Discussion and conclusions

The multivariate Hotelling's T_2^2 test is a very powerful mathematical technique for pair-wise discrimination of n dimensional datasets. Multivariate Hotelling's T_2^2 test provides an objective criterion for deciding whether or not to pool two n dimensional datasets (mean vector data). The test may be used anytime one must decide whether of not two mean vectors data are the same. Hotelling's T_2^2 test may be used in many different contexts in forest inventory. The results of the multivariate Hotelling's T_2^2 tests have shown that it is possible to discriminate and differentiate forest species (pair-wise) using n dimensional data.

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Quantitative description of forest structure in a virgin beech forest and a comparison with managed beech forests

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Abstract

The aim of the research is to provide an objective description of stand structure in a virgin forest such that it facilitates a comparison with managed forests. Structural indices were tested to determine whether they allow reliable and meaningful statements to be made about the extent to which a stand approximates a close to nature structure.

Consequently 24 systematically distributed sample plots of 0.4 ha were established in a virgin beech forest in Havešová, situated in East Slovakia. Twenty-four tree location maps were obtained and the DBH of the trees measured. In the same stand 70 forest gaps along a transect line were also recorded. For each tree location map the diameter differentiation and mark correlation functions as well as a Structural Complexity Index were determined. These Indices were then compared to those from selected managed beech forests. The parameters of groups of neighboring trees with similar dimensions were also recorded in the sample plots in the virgin forest. In the inventory of gaps all interruptions observed in the forest canopy within the upper 1/3 of the upper stand height were recorded. The number of dead trees per gap was used to standardize the size of gaps. Further the frequency of death was determined from neighboring trees that had died in the same year.

The diameter differentiation in uneven-aged managed forests and in an 80, and a 120 year old stand did not differ from the areas sampled in the virgin forest. In contrast the diameter differentiation in two stands over 140 years old was clearly lower. The mark correlation functions in the virgin forest revealed a slight reduction in the product of the DBH for tree pairs about 6-7 m apart, but changes in this value as the distance decreased were less than in managed forests. Reliable values were obtained from the Structural Complexity Index for uneven-aged stands. However, the reliability decreased markedly in even-aged stands with greater distances between trees. In the virgin forest grouping neighboring trees of a similar size showed that by increasing the number of trees per tree group, the number of tree groups decreased exponentially. The number of forest gaps also decreased exponentially with increasing gap size. 57 % of the gaps were one tree gaps and 39 % were 2 to 10 tree gaps. The largest gap was formed by the death of 56 trees, and comprised 0.28 % of the total gap area. All Indices produced plausible results. The diameter differentiation, mark correlation functions and the Structural Complexity Index were developed for relative specific purposes, for example for the comparison of stands before and after thinning treatments, or for the identification of particularly heterogeneous or homogenous areas within a forest. These Indices are less suited to assisting decisions about how to convert the structure of a managed forest to that of a virgin forest. In this case gap research or the grouping of similar sized trees can be recommended.

Keywords: Forest structure, Structural heterogeneity, Spatial pattern, *Fagus sylvatica*, Close to nature

1 Introduction

The forest structure has always played a central roll in forest descriptions. In more recent times this broadly used term has gained importance in discussions about close to nature forest structure. This study is confined to the consideration of the horizontal distribution and the diameter at breast height (DBH) of living trees and has ignored many other important elements of forest structure (see Projektgruppe Naturwaldreservate, 1993 or Winter *et al*., 2003). However, setting this limit may simplify the discussion, which is otherwise complex by virtue of the diversity of structural elements. Silvicultural and forest ecological experience has shown that the forest texture of other structural elements can resemble a "scaffolding" (Meyer *et al*., 2001).

The aim of this research is to obtain reproducible results in the analysis of the distribution of different sized trees to describe forest structure, which then allow objective comparisons to be made with other stands studied. Given the differences in forest structure found in close to nature forests, the reliability of the indices used should also be tested and their meaningfulness assessed.

2 Materials and Methods

The research was undertaken in the virgin beech forest reserve in Havešová, in Slovakia, and comprised a beech forest with a relatively poor herbaceous layer. Other tree species present comprised only 0.5 %. A well-developed mesotrophic brown earth soil has developed over sedimentary deposits of sandstone occasionally interspersed with shale. The upper canopy height is approximately 45 m. Additional stand information is available in Korpel (1995). In the Reserve 24 square plots with an area of 0.390625 ha (62.5 m x 62.5 m) were systematically located. In each plot all trees with DBH above 4 cm were measured and the tree coordinates determined. Structural indices were calculated for the distribution of trees in the plots. In addition a 6 m long line transect was laid, along which all gaps in the crown layer above 30 m stand height were recorded. The sampling method recommended by Runkle (1992) was used. In a gap all dead trees with a DBH ¸ 30 cm found within the plot between the bases of the gap boundary trees were measured and the year of death estimated. Due to the presence of scars between the annual shoots of young trees, which had either been freed up or damaged, the age of the trees that had died within the last 20 years could be estimated relatively accurately. To determine the age of trees that had died earlier core samples were taken from neighboring trees that had clearly been freed up and were responsive. On average dead trees were almost completely replaced after 45 years. In such cases one must assume a maximum error of 10 years in the estimation of age. Plots and gaps on sites with more than a 30° slope were excluded from the study. The average slope was estimated to be 10°. A more detailed description of the gap inventory is available in Drößler und Lüpke (2004).

The managed forests are moderately to well supply with water and nutrients and at located in Central Germany in hilly to submontane elevations in subatlantic to subcontinental climatic areas. Tabaku (1999), Drößler (2001) and Albert (1999) have provided more detailed descriptions of Stands A, E and F, Stand B, and Stand C respectively. Stand D comprises a typical single-layered beech forest resulting from a shelterwood cut. The Stand was lightly thinned about 30 years ago and later heavily thinned. It will be managed under a target diameter cutting regime in future. The site is comparable to Stand A, but the soil has a somewhat deeper layer of loam derived from loess. The trees in the managed stands with DBH ¸ 7 were recorded. Comparisons between the virgin and managed forests are thus based on the distribution of trees with diameters of than 7 cm or more.

The derived distributions of trees with know DBH provided the basis for calculating the diameter differentiation (Füldner, 1995) suggested by Pommerening (2002) and the mark correlation functions (Stoyan, 1992). A Structural Complexity Index (SCI) from Zenner und Hibbs (2000) was also calculated. A Delauney-Triangulation was then conducted on the basis of tree distribution from which a network of non-overlapping triangles with endpoints at the tree stem coordinates was derived. The triangles were raised at their endpoints by an amount corresponding to the height of the trees (the tree heights were derived from height curves constructed for each stand from 30 trees with known diameter and height that were evenly distributed across the diameter spectrum). The area of a constructed three-dimensional triangle was divided by the area of a planar triangle, and the SCI was calculated from the average of the values of the individual triangle pairs produced (in detail in Zenner und Hibbs, 2000). In this way higher SCI values are obtained when greater height differences occur between neighboring trees. The value 1, for example, corresponds to a stand with no height difference between the trees. In addition to known indices published in the literature additional neighboring trees of a similar size were selected. Classes were then developed, which approximated the classes used in Germany for the description of the dimension of trees in stands.

Table 1. Description of the stands investigated

	A	B	C	D	E	F	virgin forests
base rock	limestone	limestone	limestone	limestone	sandstone	sandstone	sedimentary sandstone
soil type					brown earth	brown earth	brown earth
Tree species	*Fagus sylv.*	*Fagus sylv.* *Acer pseud.* *Acer platan.* *Tilia cordata*	*Fagus sylv.* *Acer pseud.* *Fraxinus ex.*	*Fagus sylv.*	*Fagus sylv.*	*Fagus sylv.*	*Fagus sylv.*
Age	uneven	uneven	80 years	120 years	166 years	148 years	uneven
Upper height	33.5 m	31.0 m	31.2 m	35.9 m	38.4	35.6	app. 45 m
Type of Management	selection method	selection method	heavy thinning	heavy thinning target diameter - cutting	target diameter cuttimg	Unused for 25 years	unused
Plot size	6.25	1.5	0.4	0.4	6.25	8.75	24 x 0.4 ha

Table 2. Classes of similar sized trees defined in consideration of those used in forest management in Germany.

DBH	Description	Typical characteristics
4-6 cm	Young growth	Natural self pruning to 7 cm DBH
7-15 cm	sapling	Average DBH of the majority of the dominant trees less than 15 cm
16-20 cm	Pole wood	Average DBH of the majority of the dominant trees 15-20 cm
21-34 cm	Low timber stand	Average DBH of the majority of the dominant trees 20-35 cm
35-49 cm	Middle timber stand	Average DBH of the majority of the dominant trees 35-50 cm
50-64 cm	High timber stand	Average DBH of the majority of the dominant trees > 50 cm
65-79 cm	Very high timber stand	
at least 80 cm	Old trees	

The crowns of 60 trees evenly distributed across the spectrum in all dimensions were measured in 8 directions. The 8 radii were averaged and a regression analysis between the average crown radius and the

DBH was calculated. The correlation between both parameters was good ($R^2 > 0.8$). Thus every tree with known DBH could be allocated a circular crown. If the modeled crowns of the trees in a certain DBH class (as shown in Table 2) touched they were identified as neighboring trees and the number of trees in the group determined. For the individual groups of neighboring trees the average distance between the bases of the trees was also determined.

The sampled gaps were categorized according to the number of the dead trees per gap and the unrepresentative occurrence of large and small gaps recorded was corrected. Drößler und Lüpke (2004) describe the correction method applied. From the estimated time of death of the trees, the distinction between trees that had created the gap and trees that had increased the size of the gap was made.

3 Results

Füldner's (1995) index of the diameter differentiation described size differences in relation to the next neighbor. T1(0.7-1) gives the percentage of tree pairs where the difference between the two diameters is more than 70 %. The percentage of the T1 class in relation to the next neighbor does not differ greatly if one calculates the index for the second or third closest neighbor.

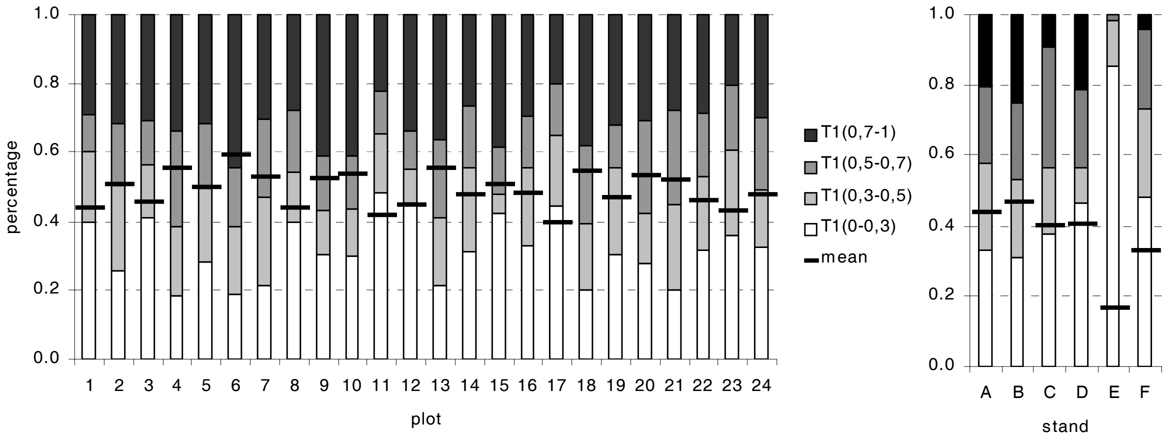

Figure 1. Füldner's (1995) diameter differentiation between next neighbors on 24 sample plots in virgin forest and in 6 managed forests.

The extent of diameter differentiation in the 0.4 ha plots in the virgin forest has also been observed in Stands A and B, where selection methods are applied, and in the 80 and 120 year old Stands C and D. Stands E and F, both more than 140 years old, exhibited a smaller diameter differentiation than in the virgin forest.

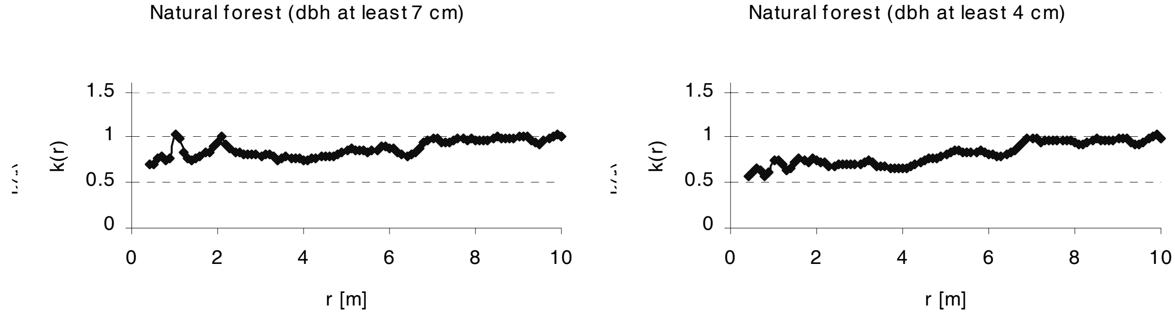

Figure 2. Mark correlation functions for trees in the virgin forest with DBH ≥ 7 cm compared to trees with DBH ≥ 4 cm. This function presents a relationship between tree pairs a certain distance apart and the relative, averaged value derived from the product of the DBH of both trees and the distance.

Both mark correlation functions in the virgin forest suggest, independent of the minimum diameter, that tree pairs separated by less than 6 m are somewhat smaller. While the functions revealed no significant differences between Stand B managed by selection method and the virgin forest, trees in pairs less than 2 m apart in Stand A were smaller. This trend was also observed in Stands C, D and E. In Stand F the size of tree pairs with DBH between 5 m and 2 m decreased. At distances below 2 m the product of the DBH of a tree pair clearly increased again.

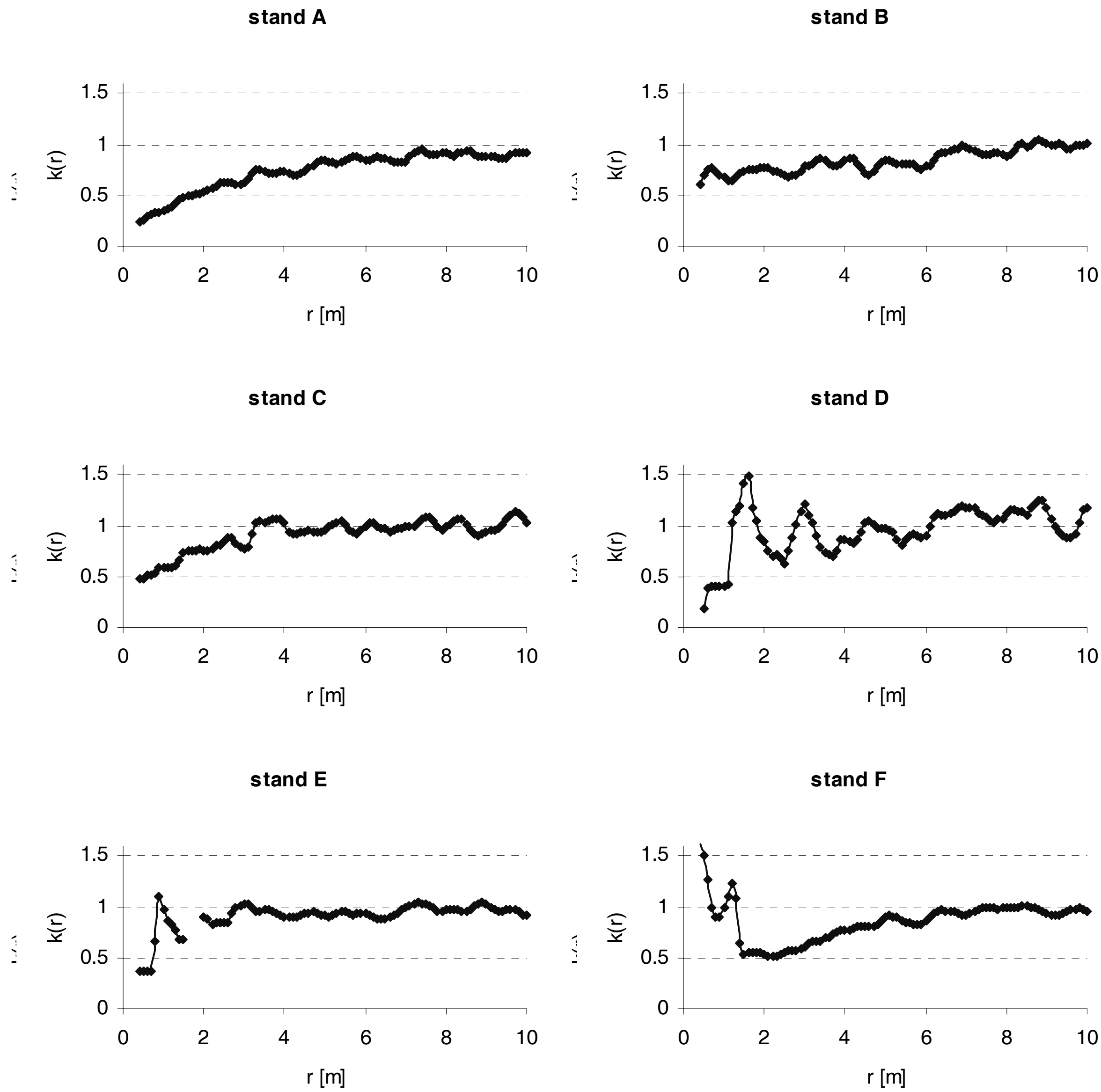

Figure 3. Mark correlation functions of trees in managed forests with DBH 7 cm or more.

The SCI revealed a high heterogeneity for the virgin forest stand structure and a very low heterogeneity in stand structure for the two oldest Stands E and F. The SCI yielded values in between for Stands A and B, both managed using selection methods, and for the 80 year old Stand C and 120 year old Stand D. However greater values were derived for Stands C and D than for the stands under selection regimes. The calculation of SCI for trees with DBH of at least 4 cm resulted in significantly higher index values than for those with DBH of 7 cm or more.

Table 3. Structural Complexity Index (SCI) from Zenner und Hibbs (2000) summarised for 24 virgin forest plots for trees with DBH of at least 7 cm, and 4 cm, and for 6 managed stands.

		SCI 7	SCI 4
	max	4.96	5.69
virgin forest	mean	**3.89**	**4.73**
	s	0.43	0.49
	min	3.06	3.86
Stand A		**2.11**	
Stand B		**2.56**	
Stand C		**3.01**	
Stand D		**3.09**	
Stand E		**1.40**	
Stand F		**1.03**	

Table 4 shows that 207 of 1417 trees in the class DBH 4-6 cm stood in isolation. The largest group of neighboring trees in this class consisted of 98 trees. In the DBH class 16-20 cm a trend towards single group classes with a maximum of 4 neighboring trees was evident. Old trees with a DBH of 80 cm or more can still occur in groups of 10 neighboring trees of similar size. Table 4 and Figures 6 and 7 relate to the virgin forest only.

Table 4. Virgin Forest Havešová: Frequency of trees in a DBH class listed according to the number of trees per group. The criterion for grouping trees is crown contact. First number in brackets: cases where a neighboring tree of similar size occurring outside the sample area could not be excluded. Second number in brackets: cases where a larger tree was present in the tree group. Last and second last lines: total number of trees and the average distance between trees for each DBH class.

	dbh classes (cm)							
number of trees per group	4-6 cm	7-15	16-20	21-34	35-49	50-64	65-79	min 80 cm
single	207 (83)	236 (104)	187 (81)	156 (87)	114 (72)	80 (58)	66 (53)	32 (26)
2	76 (30/15)	89 (45/9)	23 (12/2)	58 (33/6)	30 (21/5)	29 (27/2)	14 (10/0)	13 (11/0)
3	23 (12/8)	36 (20/6)	7 (5/1)	17 (11/3)	14 (11/4)	14 (11/2)	8 (6/0)	15 (15/0)
4	19 (10/10)	22 (12/4)	3 (2/0)	9 (6/2)	5 (5/3)	4 (3/2)	6 (6/1)	4 (4/0)
5	12 (6/9)	17 (8/3)		3 (1/0)	2 (0/0)	3 (3/0)	4 (4/0)	5 (5/0)
6	9 (8/6)	11 (4/3)			2 (2/0)			
7	5 (4/3)	7 (5/3)		1 (0/1)	1 (0/1)	2 (1/0)		1 (1/0)
8	7 (4/7)	7 (5/3)						1 (1/0)
9	2 (0/1)	2 (2/1)				1 (1/0)		1 (1/0)
10	2 (1/1)	1 (0/1)			1 (1/0)	2 (2/0)		
11	3 (0/2)	4 (4/3)						1 (1/0)
12	1 (1/11)	1 (1/1)						
13	1 (0/1)	1 (1/1)						

14	4 (3/4)							
15	1 (1/1)	1 (1/1)						
16								
17	3 (3/3)	3 (3/2)						
18	1 (1/1)							
19	2 (2/2)							
20	2 (2/2)	1 (1/1)						
21		1 (0/1)						
22	1 (1/1)	1 (1/1)						
23	1 (1/1)	1 (1/0)						
24	1 (1/1)							
25		1 (1/0)						
26								
27		1 (1/1)						
28								
29		1 (0/1)						
30								
31	1 (1/1)	1 (1/1)						
38		1 (1/1)						
44	1 (1/1)							
63	1 (1/1)							
89	1 (1/1)							
98	1 (1/1)							
total tree number	1417	1265	266	381	275	254	162	179
Average distance of groups in a DBH class	2.74	3.72	4.35	5.67	6.73	7.75	9.15	11.79

Fifty seven percent of gaps are created due to the death of a single tree. Fourteen percent of gaps are formed following the death of 2 or 3 trees. Gaps caused by the death of 4 to 10 trees comprised 15 % of gaps. Gaps with more than 20 gap creating trees were also found. They were rare however. In this research the maximum number of dead trees found to create a gap was 56.

Figure 5 shows that new gaps were formed due primarily to the death of a single tree or a maximum of 3 trees. Large disturbances only occurred if a gap already existed. After one dead tree had created a gap, at least 6.5 additional dead trees contributed to the expansion of a gap.

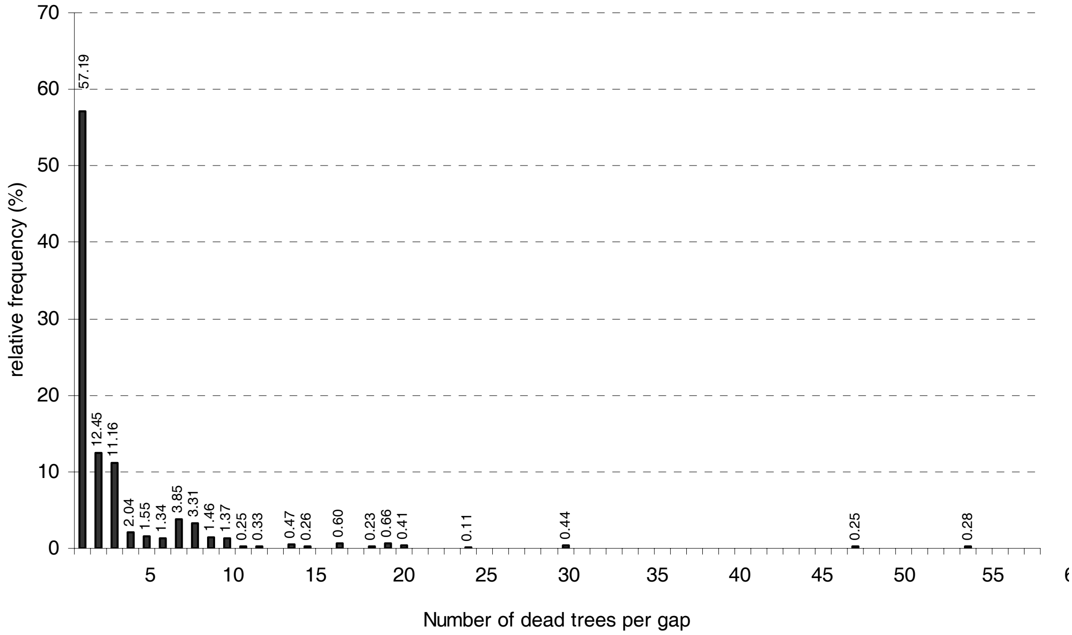

Figure 4. Virgin Forest Havešová: Relative frequencies of gaps according to the number of dead trees per gap.

Figure 5. Virgin Forest Havešová: percentage frequencies of the number of dead trees that died in the same year. Gap creating trees that extended an already existing gap were distinguished from those that formed a new gap. Where the death of trees occurred more than 30 years ago a clear distinction was no longer possible since trees that may have died earlier would be completely decomposed.

4 Discussion

Many structural indices have been developed. However a uniform definition of forest structure has not been applied and can be used very broadly in general scientific discussions. The definition used in this investigation focuses on the location and the DBH of the trees in the determination of possible analyses from tree location maps. Here other important forest stand elements are referred to Winter *et al*. (2003).

The diameter differentiation was conceived to describe structural changes resulting from forest practices (Albert, 1999). If one defines structure as the difference in size between neighboring trees then changes to structural diversity following forest practices can be shown. However one should not assume that attempts to obtain as heterogeneous a structure as possible result in the best approximation of a close to nature structure. This approach is insufficient for the reproduction of a natural forest structure. In a virgin forest values found for the diameter differentiation can also be achieved in managed forests. Mark correlation functions can indicate the distance between trees within which the product of the diameter of two trees a certain distance apart tends to be lower. This is relevant in the consideration of competition. In contrast to diameter differentiation however, if a low value is obtained using this index the nature of tree pair is still unclear. For example the tree pair under consideration may include one tree with a particularly small DBH and one tree with a large DBH, or both trees with relatively small DBH. For both indices the examination of tree distribution in diameter classes may assist the analysis.

The Structural Complexity Index facilitates the quantification of differences between different heterogeneous areas in the forest. However the index is of limited assistance in the comparison of forest structure in managed forests. The index is useful when the distances between trees in the stands to be compared are similar since greater distances between trees result in values that are too low. In an even-aged stand where isolated over-topped beech trees have survived for long periods the index produces relatively high values. Differences in the maximum height of the stands also need to be considered when interpreting the index. The index is probably suitable for ranking the structural diversity between uneven-aged forests. Although the SCI quantified Stands E and F as having low structural heterogeneity, observations suggested otherwise.

All three structural indices are suited to different purposes and relate to the total stand. None serve the purpose of developing management recommendations to attain a best approximation of a close to nature forest structure.

The grouping of trees in a diameter class is relatively easy and achievable. If the frequency of tree groups in a diameter class is known then work to achieve such an arrangement of trees in the forest can be undertaken (if that type of natural growth is the aim). The disadvantages may be the somewhat arbitrary establishment of diameter classes and class width. Here preference was given to classes relating to the classification of different growth stages in even-aged managed forests in Germany. A division into classes with diameter width of 10 cm is thus possible. Grassi *et al.* (2003) defines the forest development phases in uneven-aged forests using the division of the single trees into height classes. The definition of neighborhood using a circular crown model can also be replaced by using set tree distances, or by identifying which tree crowns actually touch when the sampling is being conducted in the forest. In this way the forester gains an impression of the virgin forest that he can check in the managed forest. In addition to the number of trees per group the proportional area of the group or the average distance between trees within a group can also be determined. The disadvantages are the time consuming counting of the groups or the additional distance measurements between the trees. This type of structural analysis could be advanced through a program with the capacity to calculate the class divisions and the limits to the extent of the neighborhood.

The gap investigation provided an understanding of the natural processes of death, which can be copied using forestry harvesting practices. The definition of the boundary between gap and stand is very important in the interpretation of research results. For example consideration must be given to whether a tree with 10 or 20 cm DBH belongs in the gap or represents the gap boundary. Further the number of dead trees in a gap is limited due to the decomposition of these trees. Despite these uncertainties the disturbance regime can usually be estimated quite easily. The results of this study show that single tree gaps formed the majority of gaps, but that the greatest number of trees fell in the expansion of gaps. From this example one may conclude that single tree harvesting followed by an expansion of the gap later or, in some cases, group selection of about 10 trees may present opportunities to implement close to nature management in a beech forest.

Overall the results of the gap research and the grouping of trees of a similar size appear easier to understand and clearer than the other structural indices presented. In addition the analytical method can be mathematically described. However one needs to be aware that the continuous distribution functions are broken up into classes with arbitrary limits. Structural indices that depict the range of natural structures by a single value are clearly unsuited for directing silvicultural practices to obtain a close to nature forest stand structure in beech forest.

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Mechanical qualities of wood of *Fagus orientalis* and comparison of its sites with respect of these characteristics*

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Abstract

By a national Project, it has been proposed to measure major engineering properties of wood grown in Iran. Part of this research Project is to compare the Forest sites in their Potentiality and influence on wood quality grown in them as well. This article presents results of Laboratory Statistical data collected through conducting tests on Specimens of clear wood of Beech from three of its regional subdivision sites and comparison of the sampled sites in terms of clear wood qualities.
The results have shown that there exist no drastic commercially difference anomy wood of three sites which were sampled in Asalem, Golband and Sangdeh. But considering design Values for engineering Purposes, selected grade of Beech wood from Sangdeh will be prior to that of Golband and the latter prior to that of Asalem.

Keywords: Beech, Properties, Comparison, sites, measuring

1 Introduction

The development of safe and efficient working stresses for Beech Products (i.e. lumber, laminated timber, plywood, round timbers and other solid wood products) each with special requirements has a starting point, the need for an authorative compilation of its clear wood strength values.
To accomplish this task, an experimental project has been prepared for collecting test materials and conducting test in accordance to a known standard specification. D 5536-89 Specification of ASTM Standard was adopted for forest sampling and D143-89 specification of the same standard for testing small clear specimens out of collected test materials.
Beech (*Fagus oreintalis* Lipsky) grows naturally in hardwood Forests of Caspian Region. Its site extends from North – west to south – East of northern aspect of Albourz Range and from 500m up to 1300 m above sea level. Beech grooves are found in their sites at mid-elevation.
Variations in Beech growing sites in terms of ecological factors such as amount of precipitation, temperature, type of Soil and annual growth period as well (table 1) may not look so drastic, but worthy to be assumed so, as history of some field observations indicate. These factors affect the morphology of Beech trees which has been studied (Marvie Mohadjer, 1975). Accordingly wood of such differentiable tree trunks are expected to show variations in their properties more than relevant natural ranges. So sampling plan had to be arranged to include all variation sources and provide valid results for comparing Beech sites from each other with respect to wood qualities grown in them, if considerable discrepancies exist.
Based on this goal, Beech growing sites for sampling purposes were designated as Asalem (in west), Golband (in mid-section), Sangdeh (site toward east) and Gorgan area (eastern part).
Statistical population for sampling in each site included all trees with diameter feasible for harvesting within next ten-year period, depending upon silvicultural preference.

* This work is part of national project on measuring major engineering properties of wood grown in Iran. This project is sponcered by The Forest service of Iran.

Table 1. The history of Beech sampling sites condition

Item of factors	Asalem	Golvand	Sangdeh	Gorgan
Mean Temp. (°C)	14.8	18	11	NA**
Growth period *	NA	NA	NA	NA
Elevation, m	1200	1760	1600	NA
Precipitation annual (mm)	1024	1500	960	NA
Type of Soil & pH level	Clay-acidic	Clay-alkaly	Clay-alkaly	NA
Type of Forests	High-Uneven	High – Uneven	High- Uneven	NA
Ave. age of stand	100-115	65-90	85-97	NA
Ave. growth ring width (mm)	3	2	2	NA

* Some results of Phonological studies on Beech Seeds (Etemad, 2003) are available, but seem uncertain to be generalized for mature trees as well. Spring migrates from east side of Caspian region toward west. Therefore growth period in eastern parts should comparably be longer. ** NA-not available yet.

2 Material and Method

As mentioned earlier, D5536-89 specification of ASTM standard (Forest sampling for clear wood properties) was adopted to sample Beech in its regional subdivision sites, namely Asalem, Golband, Sangdeh and Gorgan Sample trees in each site was randomly chosen and the geographical directions of each tree was marked, then cut down. The age of sample tree and its growth ring width of mature wood were determined on its stump. From the harvested sample trees, log pieces were cut off and sawn for collecting designated test materials, according to corresponding standard. Test materials were ripped for two set of matched clear specimens. One set of specimens were tested in green condition and the other set were tested after being air-dried.

Tests on both set of matched small clear Beech wood specimens were made to measure their strength in static bending, compression parallel to grain, compression perpendicular to grain, shear parallel to grain, tension perpendicular to grain, toughness, cleavage, hardness and nail withdrawal resistance as well. Among the physical properties of specimens, specific gravity based on dry volume, radial and tangential and volumetric shrinkages were measured also.

2.1 Method for establishing clear wood strength values

Observed data were first normalized by SPSS software, and then mean, standard deviation and coefficient of variations of measured properties on each geographical side of every sample trees were calculated. Table 2 contains results of these calculations for green specimens and table 3 summarizes these results for dry wood tested.

The results of these calculations were used to make comparison between segments of every individual sample trees from butt log to end commercial diameter.

These comparisons included 4-side of any trees sampled and among trees in each sampling station. The same data reduction was applied to data of measured physical properties, too (table 4).

Mean Values of clear Beech wood strength, both in dry and green conditions were calculated out of relevant data coming from the trees sampled regional sites. Results of these calculations are included in the left sections of tables 2 and 3.

Table 5 was established for the ratios of dry clear wood properties to that of unseasoned ones. These ratios would indicate affection of moisture content of wood on its mechanical properties (table 5).

Mean Values of Beech wood strengths out of the sampled sites were determined and considered overall mean for the species. The overall mean values were referenced to compare Beech of three sites. These comparisons are presented in tables 6 and 7 for dry and green conditions, respectively.

Effort was made to compare varieties of Beech species in terms of their mechanical and physical properties. Measured and values available in existing references were incomplete and limited too (table 8).

3 Results

Static bending, (for MOR, MOE & E), compression parallel to grain and shear parallel to grain of clear Beech wood from its groove in Sangdeh owns higher quality by 18.3, 15.9 and 9% respectively above overall mean values of the species in these properties. Wood of this species from its site in Golband in static bending stays 4.7% above its mean value, but from site in Asalem 15.3% below mean. In compression parallel to grain, clear Beech wood from Golband and Asalem are inferior as compared with average of the species by 1.5% and 6.6% in the same order.

In compression perpendicular to grain, Beech wood from Asalem and Sangdeh would fall slightly above reference mean, by 5% and 3.5% respectively. But Beech of Golband is inferior by 12% as compared with mean of species.

In tension perpendicular to grain, wood of Golband indicates 5.5% inferior value, in comparison with relevant reference mean.

For nail withdrawal resistance in Side grain, Clear Beech wood of Sangdeh is prior than mean of the Species by 11.15 and that of Golband locates below reference mean by 4.8% and from Asalem is about the mean.

Regarding determined physical properties, specific gravity of clear Beech wood of Sangdeh is 3.6% higher than the referenced average. But clear wood of the species from Asalem has lower specific gravity by 0.85% and that of Golband is less than mean by 1.2%.

with respect to shrinkage, clear Beech wood of Sangdeh Shrinks less than mean of the species, 1.5% tangentially and that of Asalem by 1.1% and Beech of Golband is inferior in this regard by 2.9% above mean in same direction.

In radial direction, Beech of Asalem shrinks 5.7% less than average, but those of Golband and Sangdeh would shrink more than referenced mean by 1.7% and 6.6% respectively.

Beech wood of site in Asalem does have 1.1% Volumetric Shrinkage less than average and from Sangdeh, above mean by 1.3%. Beech of Golband has mean value of this property.

4 Conclusion

The properties of clear Beech wood sampled from trees of its growing sites which have been measured through this study, would show no drastic discrepancies among sites, but some of these properties which are relatively important in terms of their potentiality for engineering designs, conclusion could be drawn as: clear Beech wood from Sangdeh is somewhat superior than wood of this species from Golband and Asalem. In descending order, clear Beech wood from Golband could be preferred to that of Asalem.

Table 2. Clear Beech Woods Strength Values Unadjusted for end Use and Measures of Viriation in Green Condition

Test	Properties	Regional Subdivision: Asalem			Golband			Sangdeh			Properties of *F.orientalis* in Iran		
		Mean	Std. Dev.	C.V %	Mean	Std. Dev.	C.V %	Mean	Std. dev.	C.V %	Mean	Std. dev.	C.V %
Static Bending	Stress at Proportional limit kg/cm^2	348	53	15	384	61	16	342	63	18	358	61	17
	Modulus of Rupture kg/cm^2	502	78	15	513	83	16	506	82	16	507	80	16
	MOE, kg/cm^2	58517	144501	25	57295	13264	23	69024	15009	22	60965	15069	25
	Modulus of Elasticity, E kg/cm^2	77000	16348	21	73000	15037	21	78000	17542	23	76000	16390	22
	Work to Proportional limit, KJ/m^3	8	2	29	11	3	24	7.5	3	35	9	3	33
	Work to Ultimate load KJ/m^3	33	2	29	36	11	31	36	11	31	35	10	29
Compression Parallel to grain.	Stress at Proportional Limit, kg/cm^2	179	32	18	189	33	18	185	34	18.	183	33	18
	Crushing Strength, kg/cm^2	208	36	17	212	34	16	216	37	17	211	36	17
	Modulus of Elasticity, E, kg/cm^2	18000	6948	38	19000	6665	36	24000	6483	27	20000	7155	36
	Work to proportional Limit, KJ	7678	2325	30	7591	2227	29	6139	1177	19	7331	2188	30
	Work to Ultimate load KJ	14783	5935	40	14833	6170	41	12694	5611	44	14189	5984	42
Compression perpen. To grain	Stress at Proportional limit kg/cm^2	49	12	24	42	9	21	48	11	23	47	11	23
	Work to Proportional Limit, KJ	6774	2734	40	4925	1373	28	6711	2080	31	6207	2364	38
Shear paral. To grain	Ultimate stress, kg/cm^2	61	12	20	62	10	16	68	11	16	63	12	19
	Work to ultimate Load, KJ	12094	4605	38	12558	5798	46	6051	2864	47	10537	5327	51
Tention perpen to gr.	Ultimate stress, kg/cm^2	35	13	37	42	12	29	35	14	40	37	14	38
Clearage	Kg/cm	58	15	26	72	19	26	53	13	25	60	17	28
Hardness	Tangential Surface kg	266	39	15	268	36	13	278	43	16	271	40	15
	Radial Surface, kg	259	35	14	266	39	15	262	38	15	262	38	15
	Cross-Section, kg	333	36	11	321	42	13	350	48	14	335	44	13
Nail withdrawal resistance	Tangential direc., kg/cm. pen.	26	6	23	26	6	23	28	6	21	27	6	22
	Radial direc., kg/cm pen.	30	7	23	30	6	20	32	6	18	31	6	19
	Grain direc. Kg/cm pen.	14	4	29	14	5	36	19	4	21	16	5	31

Table 3. Clear Beech wood Strength Values Unadjusted for end Use and Measures of Variation in dry condition.

Test	Properties	Regional Subdivision: Asalem Mean	Asalem Std. Dev.	Asalem C.V %	Golband Mean	Golband Std. Dev.	Golband C.V %	Sangdeh Mean	Sangdeh Std. dev.	Sangdeh C.V %	Properties of *F.orientalis* in Iran Mean	Std. dev.	C.V %
Static Bending	Sterss at Proportional limit, kg/cm^2	573	120	21	657	106	16	540	113	21	588	123	21
	Modulus of Rupture, kg/cm^2	534	157	29	910	120	13	885	147	17	871	147	17
	MOE, kg/cm^2	76258	15865	21	85000	22	25	104619	14693	14	86810	20842	24
	Work to Proportional limit, KJ/m^3	18.90	7	37	22	7	32	13.17	5	38	18	7	39
	Work to Proportional ultimate load, KJ/cm^3	64	18	28	66.5	19	28	57	20	35	63	19	30
Compression Parallel to grain.	Stress at Proportional limit,kg/cm^2	339	51	15	350	46	13	359	50	14	348	49	14
	Crushing strength, kg/cm^2	397	58	15	427	53	12	471	58	12	426	62	15
	Modulus of Elasticity, E, kg/cm^2	34000	9643	28	36000	10781	30	51000	10966	22	38000	12190	32
	Work to Proportional limit ,kJ	17580	2590	15	18238	3669	20	17935	3492	20	17937	3227	18
	Work to Ultimate load, KJ	27173	6533	24	29807	8437	28	31642	7750	25	29356	7848	27
Compression perp. To grain	Stress at proportional limit, kg/cm^2	105	24	23	88	21	24	103.5	19	19	1100	23	23
	Work to proportional limit, KJ	25013	8093	32	9549	4248	44	11356	3041	37	16867	9516	56
Shear Para. To grain	Ultimate Stress, Kg/cm^2	116	22	19	118	22	19	132	20	15	121	23	19
	Work to ultimate Stress, kg/cm^2	19117	6180	32	14039	5572	40	12007	4454	37	15536	6227	41
Tension para. To grain	Ultimate Stress kg/cm^2	52	19	37	58	20	34	57	21	37	35	20	36
Toughness	J	42	9.81	25	40	9.81	25	40	9.81	25	41	9.81	24
Jeavage	Kg/cm	101	23	23	90	27	30	69	19	28	90	26	29
Hand ness	Tang ,Surface, kg	416	65	16	378	82	22	433	50	12	408	71	17
	Radial Surface, kg	387	65	17	365	80	22	426	55	13	391	72	18
	Cross-Section kg	577	70	12	558	127	23	619	66	11	583	96	16
Nail with Resistang	Tang. Direc. Kg/cm pen.	31	8	26	29	8	28	35	7	20	31	8	26
	Radial direc. Kg/cm pen	32	8	25	31	9	29	35	8	23	32	8	25
	Grain dirc. Kg/cm pen	20	7	35	21	7	33	25	6	24	22	6	27

Table 4. Major physical properties of clear Beech wood and measures of variation

Properties		Regional Subdivision: Asalem			Golband			Sangdeh			Properties of *F.orientalis* in Iran		
		Mean	Std. Dev.	C.V %	Mean	Std. Dev.	C.V %	Mean	Std. dev.	C.V %	Mean	Std. dev.	C.V %
Specific gravity		0.582	0.030	5	0.582	0.030	6	0.61	0.031	5	0.589	0.03	5
Shrinkage % of wet Dimension	Tang.	9.32	20	23	9.69	2	20	9.28	2	17	9.42	2	20
	Radial.	4.29	1	19	4.63	1	23	4.85	1	18	4.55	1	20
	Volum.	13.95	1	10	14.10	1	13	14.28	1	10	13.10	2	11

Table 5. Major physical properties of clear Beech wood and measures of variation

Regional Subdivision:	MOR	E	Crush. Stren.	Sher Para. To grain	Comp. Per. To grain	Tension Per. To grain	Cleav.	Hardness, surface: Tang.	Rad.	Cross-.	Nail withdrawal Resis. Direction: Tang.	Rad.	grain
Asalem	1.06	1.89	1.91	1.90	2.14	1.48	1.74	1.56	1.49	1.73	1.19	1.07	1.43
Golband	1.77	1.89	2.01	1.90	2.11	1.38	1.25	1.41	1.37	1.74	1.11	1.03	1.50
Sangdeh	1.75	2.12	2.18	1.94	2.15	1.63	1.30	1.55	1.62	1.77	1.25	1.09	1.31
Species of F. *oreintalis* in Iran	1.72	1.90	2.02	1.92	2.13	1.48	1.50	1.51	1.49	1.74	1.14	1.03	1.37

Table 6. Comparison of clear Beech wood properties in dry condition from three sampled regional subdivisions, with respect to overall mean values of corresponding properties of species.

Measured properties.		Descrepancies, % Regional subdivision: Asalem	Golband	Sangdeh
Static Bending	Stress at proportional	-2.55	11.74	-8.2
	Modulus of Rupture, MOR	-38.7	4.5	50.5
	Apparent value of Modulus of Elasticity, MOE	-12.2	-2	20.5
	Modulus of Elasticity, E	-7.8	-	9.8
	Work to proportional limit	5	22	-26.8
	Work to ultimate Load	1.6	5.5	-9.5
	Stress at proportional limit	-2.6	0.57	3.2
Compression parallel to grain	Crushing strength	-6.8	0.2	10.5
	Modulus of Elasticity, E	-10.5	-5.3	34
	Work to proportional limit	-2	1.7	-
	Work to ultimate load	-7.4	1.5	7.2
Compression perpendicular to grain	Stress at proportional limit	5	-12	3.5
	Work to proportional limit	48	-43.4	-32.7
Shear parallel to grain	Ultimate stress	-4	-2.5	9
	Work to ultimate load	23	-9.6	-22.7
Tension perp. To grain	Ultimate stress	-5.5	5.5	3.6
	Toughness	2.4	-2.4	-2.4
	Cleavage	12	-	-23
Hardness	Tang.sur.	2	-7.4	6
	Rad.sur.	-1	-6.6	9
	Cross-Section sur.	-1	-4.3	6
Nail with drawal Resis tance	Tang. Dirc.	-	-6.5	12.9
	Rad. Direc.	-	-3	9.4
	Grain direc.	-9	-4.5	13.6
	Specific gravity	-0.85	-1.2	3.6
Shrinkage	Tang.	-1.1	2.9	-1.5
	Rad.	-5.7	1.7	6.6
	Volum.	-1.1	-	1.3

Table 7. Comparison of clear Beech wood properties in green condition, from three regional subdivision, with respect to overall mean values of corresponding properties of the species.

Measured properties		Descrepancies, % Regional subdivision: Asalem	Golband	Sangdeh
Static Bending	Stress at proportional	-2.8	7.2	-4.5
	Modulus of Rupture, MOR	-1	1.2	-20
	Apparent value of Modulus of Elasticity, MOE	-4	-6	13.2
	Modulus of Elasticity,E	1.3	-4	2.6
	Work to proportional limit	-11	22	-17
	Work to ultimate Load	-5.7	2.8	2.8
	Stress at proportional limit	-2.2	3.3	1.1
Compression parallel to grain	Crushing strength	-1.4	0.5	2.4
	Modulus of Elasticity, E	-10	-5	20
	Work to proportional limit	4.7	3.5	-16.3
	Work to ultimate load	4.2	4.5	-10.5
Compression perpendicular to grain	Stress at proportional limit	4.2	-10.6	2
	Work to proportional limit	9	-20.6	8
Shear parallel to grain	Ultimate stress	-3.2	-1.6	7.9
	Work to ultimate load	14.8	19.2	-42.5
Tension perp. To grain	Ultimate stress	-5.4	13.5	-5.4
	Cleavage	-1.8	20	-11.7
Hardness	Tang.sur.	-1.2	-1.1	2.6
	Rad.sur.	-0.6	1.5	-
	Cross-Section sur.	-3.7	-4.2	4.5
Nail with drawal Resis tance	Tang. Dirc.	-3.2	-3.7	3.7
	Rad. Direc.	-3.2	-3.2	3.2
	Grain direc.	-12.5	-12.5	18.8

Table 8. Comparison of some Physical and mechanical properties of Beech Varieties based on existing sources

Properties	Country													
	France	Belgium	Germany	Greece	Romania	Poland	Bulgaria	Yugoslavia	Italy	Yugoslavia	North America	Bulgaria	Iran	Turkey
	Fagus silvatica									*F.moesiaca*	*F.grandifolia*	*F.orientalis*		
(1)Specific grav.	NA	NA	0.59	0.70	NA	0.70	0.67	0.65	0.67	0.61	0.64	0.73	0.59	NA
(2) Shrinkage:														
Long. %	0.1-1.1	NA	NA	NA	0.1-0.3	NA	NA	NA	NA	NA	NA	NA	NA	NA
Rad. %	3-4.4	NA	NA	NA	5.5	NA	NA	5.3-6.1	5.3	5.8	5.5	NA	4.55	NA
Tangen. %	12-18	NA	NA	NA	10-11	NA	NA	11-12	13	12	11.9	NA	9.42	NA
Volum. %	16-17	NA	NA	18-19	17	20-21	NA	17-18	18	15-18	17.2	NA	14.1	NA
Compresion Parallel to gr. Kg/cm^2	380-490	NA	460-700	NA	475	500-550	520	580-800	580	550-650	514	560	426	NA
Modulus of Rupture, kg/cm^2	1000-1600	950-1450	NA	NA	1050	900-1100	1100	1200-1300	1100	1000-1600	1050	NA	871	NA
Modulus of elasticity $X10^3$ Kg/cm^2	105-180	NA	NA	NA	130	120-160	NA	120-140	NA	NA	121	NA	102	125

(1) Based on oven – dried weight and volume

(2) Percent of wet dimension down to air-dried moisture content

NA – Not Available

* Source – Le Hetre, Wood handbook wood as an Engineering Material, (USDA).

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Investigation on Quality and Quantity of Seed Production of beech (*Fagus oientalis* Lipsky) in Mazandaran Forests

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Abstract

Nine stations over 3 regions were selected at western (Ramsar), central (Noshahr), and eastern (Neka) area of Mazandaran province and in each region 3 elevation of 750, 1500 and 2200 meters above sea level (m.a.s.l). In each plot beech seeds were collected and divided into 5 separate classes: 1) sound seeds, 2) Empty, 3) Eaten by mouse, 4) Eaten by insects and 5) eaten by other animals and birds. The number of germinated and remaining seeds in the corresponding plots was counted. On the basis of International Seed Testing Association (ISTA), seed viability vitality, weight and dimension of 1000 pellets were measured.

The mean of each measurement was compared in different elevation and region. The highest percentage and germination level on the forest floor belonged to Ramsar in 1500 meter above sea level. The highest viability vitality of the seeds was related to elevation of 1500 m.a.s.l in the Ramsar and Noshahr regions. The largest amount of empty and eaten seeds by insect was found out in Noshahr region over 2200 m.a.s.l. the highest amount of seed production was in Neka with 750 m.a.s.l .

The Size of seed and weight of 1000 seed were larger in Ramsar region with 750 and 1500 m.a.s.l than those from other stations. The seeds from Ramsar and 1500 m.a.s.l. elevation have the highest germination capacity and speed.

Keywords: *Fagus orientalis*, Seed production, Pure beech stand, ISTA, Germination, Iran

1 Introduction

The basic element of Natural regeneration is seed production. Seed makes relationship between the regeneration and genetic inheritance. Transforming of heredity is done by seeds. Propagation by seed is much more complete and progressed rather than other ways of propagation. One of the most important principals of silviculture is sustainable biologic production and this would be done by natural regeneration, having completed and enough information about quality and quantity seed production is necessary for every forest manager.

The oriental beech is an indigenous species in Hyrcanian forest that makes different societies from 700 meter above sea level (m.a.s.l.) to 2600 and has great economical value. The goal of this study is gathering information about seed production rates, seed germination capacity, determining the biotic and abiotic harmful factors for seeds, weight of 1000 pellets, size of seeds, seed germination percent in nature, established seedling and introducing the bests area for seed production.

2 Materials and methods

2.1 Materials

This research was carried out in mixed forest of beech in the Caspian region of northern in Iran. The studied stand is located in Mazandaran province at 36° 58′ north and 54° 8′ East, extending between 750 and 2200 m.a.s.l. the mean annual precipitation and mean annual temperature of the Mazandaran province reach to 1124 mm and 11°C respectively. The soil type is forest brown soil with 3-4 cm layer of humus. Soil texture is loam and clay – loam with pH of 5.5

2.2 Methods

In west, east and centre of the Mazandaran forests were chosen in three regions. In each region three stations were selected in 750, 1500 and 2200 m.a.s.l.. in every station 30 trees with diameter higher than 40 cm were marked on a horizontal line.

The distance between the selected trees was 50 meters. Totally 270 trees studied in this research and all quantitative characteristics as diameter at breast height (D.B.H.), Tree height, crown diameter, were measured and the ground slope for each tree were written. Eight cluster sampling plots, each with one meter width and the length of largest crown diameter of each tree in four main directions and in each direction two plots were designed for seed collection, studying the germinated seeds and remained ones. After seed collection, in the spring of the next year, germinated seeds and remained ones in the plot were counted two times.

Also the herbaceous plants, density and variety in each plot were studied to find out the rate of seed germination. Total gathered cupules of oriental beech was 63 2884 that were counted 4Times. After studying all the cupules, they were separated in five classes

1) Sound seeds 2) Empty 3) Eaten by mouse 4) Eaten by insects and 5) Eaten by other animals and birds (Okada *et al.*, 1995).

3 Results

- Only in three stations there was a correlation between seed production and tree diameter.

- The comparison between different characteristics such as seed production rate, seed size and etc was done by multi-variable variance analysis.

- The tables (tables 1 to 4) show that the most of seed production happens in 750 meters above sea level, and according to elevation in Neka region in the east of Mazandaran forests according to stations.

Table 1. Analysis of variance for comparison of mean couple production in beech trees

SOV	DF	SS	MS	F
Model	35	3885094.9	111002.7	17.4
Region	2	1113129.0	556564.5	88.18*
Station	2	1962466.6	981233.3	55.91*
Direction	3	38064.9	12688.3	2.09*
Region-Station	4	662517.9	165629.5	26.2
Region-Direction	6	47648.6	7941.433	1.3
Station-Direction	6	3470.8	578.4667	0.1
Region-Station-Direction	12	57797.2	4816.433	0.8
Error	1044	6588662.6	6310.98	

* indicates 0.05 significant level

Table 2 . Duncans test for comparison of mean cupules production in different elevations

Station	Number of sample	mean		
		1	2	3
2200m	360	39.08		
1500m	360		79.99	
750m	360			142.74

Table 3. Duncans test for comparison of mean cupules production in different regions

Region	Number of sample	mean	
		1	2
Ramsar	360	64.24	
Noshahr	360	64.91	
Neka	360		132.67

Table 4. Duncans test for comparison of mean cupules production in different directions

Direction	Number of sample	mean	
		1	2
West	270	82.63	
South	270	83.98	83.98
East	270	85.03	85.03
North	270		97.45

-The highest number of collected seeds is related to the north direction of all studied trees.

- According to the weight of 1000 pellets and the size of them, the size of seeds collected in Ramsar region is the most. The size of the seeds decreases as the elevation increases.

- The number of sound seeds in Ramsar region was the most and in Noshahr region was the least. The average number of sound seeds in 750 and 2200 (m.a.s.l) was more than 1500 (m.a.s.l).The average number of eaten seeds by mouse (*Glis glis*) was the most in Noshahr region and according to elevation, in 1500 m.a.s.l, it was the highest.

- The average number of eaten seeds by insects was the most in Noshahr region and according to elevation, in 2200 meters above sea, it was the highest. The average number of eaten seeds by mammals and birds was the most in Neka region and according to the elevation, in 750m.a.s.l. it was the highest. The average number of total damaged seeds such as eaten by mouse, insects, mammals and birds was the most in Noshahr region and according to elevation, in 2200 m, it was the highest.

- The highest seed germination capacity is related to 1500 m.a.s.l and in Ramsar region it was the highest among other stations. The average number of germinated seeds in 1 square meter plots was the most in 1500 m. and in Ramsar region. The average number of remained seedlings was the most in 1500 m among the elevations and it was the most in Ramsar among the stations. The highest percent of seed germination happened in 5-25% herbaceous covering. Seed germination decreases when the herbaceous covering increases.

- A hypothesis test of adequacy of the produced seeds was done for a successful regeneration. In seven stations we studied, the number of Seeds (sound and empty seeds) in 1 square meter was more than 100. The highest number of remained seedlings in 1 m^2 was related to Ramsar region among all regions and was related to 1500 m. above sea level among all elevations (Le Tacon, 1974).

- Biotic and abiotic factors that use the seeds are mammals, birds, insect and fungi.

4 Discussion and Conclusion

Oriental beech flowers from more than 40cm diameter at breast height (DBH) in Hyrcania Forests, but seed production rate is very low in the beginning of flowering. The individual beech trees that absorb more light can flower in lower ages. The youngest beech tree that flowered in this research had 14 cm DBH. It seems that sunlight is the most important factor in flowering of individual trees. According to the trees in the stands flowering and fructification starts at first in the East than toward the west of Mazandaran forests with 5 days interval. This is because of heat in the East. Protogeny happens in oriental beech forests and female flowers appear 4 to5 days earlier than male flowers (Nielson *et al.*, 1954). Generally each cupule has 2 to 3 seeds but in one case it was seen that only one tree had 5 seeds in one cupule.

Seed dormancy in oriental beech was 30 to 90 days. The lower station seeds (750m) germinate earlier than the higher ones (1500 m & 2200 cm). It seems that temperature and seed growing in cold situation causes more dormancy. Seed germination decreases as herbaceous cover increases because of competition between seeds and herbaceous cover.

There is a correlation between DBH and seed production rate in some stations. The reason of greater amount of seeds in the Northern direction is the slope. The most seed production happens in Neka region but the most amounts of sound seed is in Ramsar in both 750m and 1500 m. the reasons are: good conditions of the site, the lack of biotic and abiotic destructive factors (Weissen, 1978).

The rate of empty seeds was more in the mountainous stations because of late cold, the lack of fecundation and the great population insects. In Noshahr the rate of seeds eaten by mouse (*Glis glis*) was the most among other stations because the population of this mouse was more because of good environmental conditions and enough food supply and the lack of natural predators such as eagle. The rate of seeds eaten by animals and birds was the most in 750 m above sea level in Neka station. In general, total destruction in Noshar region was the most according to other regions. And this destruction happens more in higher elevations (2200m) (LeTacon *et al*., 1976) .The great destruction rate of seeds is because the lack of bio equilibrium and the great population of harmful factors. One of the most important reasons in natural regeneration failure is the low rate of sound seeds. Ramsar region with more sound seed had more germinated seeds.

The remained seedlings in autumn were more in Ramsar region, in 1500m because the moisture was more, But in 2200 m the soil moisture was low so the remained seedling were less. Many scientists believe that 10 to 20 seedlings are enough for a successful natural regeneration, but in this research it was achieved that in the best sites the rate of remained seedlings was less because of high seed destruction rate. The number of seeds in one square meter in Hyrcanian forests wasn't enough so we should be careful in choosing the silivicultral methods.

As the elevation increases the size and the 1000 pellets weight decreases. Germination capacity test showed that in Ramsar region the rate was the most. Also the seeds produced in 1500m had the most germination capacity according to other stations. As Marvi Mohadger and other studies have shown, Oriental beech sites in 1500 meters above sea level have more growing power (Oganyan, 1981) .Also according to the results of this research we can say that these sites are the best sites according to seed production. The 1500 meter station of Ramsar region was the best site in this study.

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The influence of light, lime, and NPK-fertilizer on photosynthesis, respiration, transpiration and water use efficiency of different beech provenances (*Fagus sylvatica* L.)

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Abstract

The study aims to improve the fundamental understanding of the effects of light and soil chemical status of gas-exchange in beech seedlings, and further how these effects are influenced by provenance selection.

Beech seedlings of 5 different provenances (two from northern Germany, one from Romania, and two from Calabria in southern Italy) were grown under four different light regimes (6%, 14%, 36 %, and 100% respectively) and in an acid brown earth varied in four different ways (control, application of 3 g dolomite per liter, application of 1 g NPK-fertilizer per liter, and both limed and fertilized respectively.

Gas exchange was measured with the CO_2-H_2O porometer (H. Walz, Effeltrich, Germany). The measurements were carried out at 21°C and a relative humidity of 60 per cent. The light regime heavily affected photosynthesis, respiration, photosynthetic economy, light saturation, compensation point, transpiration as well as water use economy. The chemical status of the soil affected only photosynthetic economy, transpiration and water use efficiency. All measured parameters except compensation point shoved provenance variation. Interactions between light and soil properties were found for photosynthetic economy, transpiration and water use efficiency.

The results are discussed in relation to silvicultural practices i.e. controlling the natural regeneration of beech by means of canopy thinning, liming and fertilizing. Further possible implications for provenance selection are outlined.

Keywords: *Fagus sylvatica, fertilizer, lime, gas exchange*

1 Introduction

In order to improve the natural regeneration of beech (*Fagus sylvatica* L.) numerous field experiments have been carried out. These experiments have mainly analysed the effect of soil manipulation such as liming and fertilizing and of the manipulation of light through canopy opening upon early seedling development and growth (Burschel and Huss 1964; Burschel and Schmaltz 1965; Burschel 1966; Suner and Röhrig 1980; Koss 1989, Madsen 1994 a & b, Madsen and Larsen 1995). These experiments demonstrate the predominance of light as growth factor for early development of beech seedlings. Further, the improvement of the soil conditions by fertilizing and liming often show positive effects, especially on nutrient poor and acid soils.

Such field experiments, however, give only general indications of within which limits of light and nutrient supply beech seedlings will develop satisfactorily. A deeper insight in how the variation in the primary growth factors influence the basic eco-physiological reaction of the beech seedlings such as energy exchange (photosynthesis, respiration) and water relations are not available.

The aim of the present investigation was to analyse the influence of light and nutrients on basic energetics and water relations of beech. The reaction of liming and fertilizing on gas-exchange were investigated by Schulte *et al*. (1989) and Stickhan (1989). These investigations were, however, all made on old beech trees (80 - 100 years).

2 Materials and methods

2.1 Materials

Beechnuts of 5 different seed sources were sown in containers (250 cm^3 volume), one seedling in each container. The Basic soil (control) consisted of the upper 10 cm of the mineral soil from old beech stand in northern Germany (FoA. Brake, compartment 329F, an acid brown earth described by KOSS 1989). The soil was mixed in with i) 3 g dolomite per litre (Ca), ii) 1 g NPK fertilizer per litre (NPK), and iii) both 3 g dolomite and 1 g NPK per litre (CaNPK). Table 1 shows the composition of the 4 soil treatments as well as the results of the analysis of exchangeable cat-ions. The provenances included in the study are listed in table 2. Provenance C1 and C3 represent beech populations from the southernmost part of the natural range, the Romanian provenance (RO) represents a typical Southeast European provenance used to quite a large extent during the last 30 years in Denmark due to insufficient fructification of the local beech. The two German provenances (HA and LE) come from the northern part of Germany (Niedersachsen and Schleswig-Holstein) and represent typical beech stands from North-western Europe. The aim was to include the full genetic variation in European beech with the selected provenances. With the selected provenances more or less the whole genetic variation in beech should be included in the study.

Table 1. Soil treatments and exchangeable cat-ions ($\mu mol*g^{-1}$)

Treatment	**Soil composition**
Control	Mixture of the upper 10 cm soil from a mature beech stand
Ca	Control + 3 g dolomite[1)]/l (3000 kg/ha)
NPK	Control + 1 g NPK[2)]/l (1000 kg/ha)
CaNPK	Control + 3 g dolomite[1)] /l and 1 g NPK[2)] /l

Treatment	**Exchangeable cations ($\mu mol*g^{-1}$)**								
	H^+	**Na^+**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**Fe^{3+}**	**Mn^{2+}**	**Al^{3+}**	**CEC**
Control	6.2	1.2	0.9	11.0	2.1	2.9	0.3	81.7	106
Ca	0.0	1.3	0.8	59.9	18.2	1.1	0.1	24.5	106
NPK	7.0	1.2	3.2	12.6	2.8	3.3	0.3	79.4	110
CaNPK	0.1	1.4	3.3	57.0	16.9	1.4	0.2	28.1	108

1) Dolomite lime: (75% $CaCO_3$, 25% $MgCO_3$)

2) Blaukorn/Höchst: (5.5% N-NO_3, 6.5% N-NH_4, 12% P_2O_5, 17% K_2O)

Table 2. Beech provenaces included .

Name	**Provenance, region, country**
C1	Aspromonte, Calabria, Italy
C2	Fossiata-Arnocampo, Calabria, Italy
HA	FoA Hasbruch, Niedersachsen, Germany
LE	FoA Lensahn, Schleswig-Holstein, Germany
RO	Strimbu Bauit, Maramures, Romania

2.2 Methods

The light conditions during the growing season were varied in 4 different levels: full light (100 per cent), 36 per cent of full light, 14 per cent, and 6 per cent of full light respectively.

The experiment was laid out in a complete block design with 5 replications. Hence the plant material consisted of 400 seedlings (5 provenances, 4 light levels, 4 soil treatments, and 5 replications). The experiment was established in the beginning of April. The gas-exchange measurements were carried out during the growing season at the end of July and in the beginning of August. Further, morphological measurements were carried out during and after the growing season (Larsen and Buch 1995).

Gas exchange was measured with the CO_2-H_2O porometer (H. Walz, Effeltrich, Germany). The measurements were carried out at 21°C and a relative humidity of 60 per cent. Each plant was measured at dark as well as at 75, 217 as well as 715 $\mu E/m^2/s$. By means of the four measurements of CO_2 exchange a light saturation curve was computed by the formula:

$$y = a + b \times c^{0.01x}$$

Where

y	=	net photosynthesis
x	=	light intensity
a	=	photosynthetic maximum
a+b	=	respiration

During the measurements CO_2 and H_2O air humidity as well as cuvette temperature and leaf temperature were measured. After measurement, leaf area was determined with a LiCor Leaf-area-meter.

The data were computed by means of analyses of variance (3-way). Differences between treatments were analysed with the Duncan-range test. In the tables significant differences between treatments are shown by different characters. The relative differences between the treatments are shown in per cent, where 100 per cent is represented by the treatment full light, the control soil, and mean value of the five provenances, respectively.

3 Results

The net-photosynthesis, computed as the maximum net-photosynthesis from the light saturation equation, is presented in table 3 according to treatment as well as the results from the statistical analyses. A highly significant effect of light and of provenance was observed, whereas no effects of soil manipulations upon photosynthesis were obtained. The highest photosynthetic rates were measured at full light (100 per cent) as well as by plants grown under deep shade (6 per cent of full light). Correspondingly, the highest rate of photosynthesis was obtained at 14 per cent light.

In terms of photosynthetic rates the provenance material is divided into three different groups. Thereby the provenances from the southernmost part of the natural range (Southern Italy, Calabria) exhibits the highest photosynthetic rates, the provenance from the eastern part of the natural distribution of beech (Romania) was characterized by the lowest values, whereas the two Northwest European provenances (Northern Germany) were characterized by intermediate rates. No interactions between light and provenance or between soil and provenance were demonstrated.

High, respectively, highly significant differences in respiration rates were obtained between provenances as well as in relation to light conditions, whereas no effect of soil treatment was obtained. A continuous decrease in respiratory rates with decreasing light was measured (table 3). The respiration of the seedlings grown under 6 per cent light was only 30 per cent of the respiration of the seedlings grown under full light conditions.

Tabel 3: Net photosynthesis, respiration and photosynthetic economy (photosynthesis/respiration-ratio).

Treatment	**Photosynthesis** $\mu mol\ CO_2 m^{-2}s^{-1}$	%	**Respiration** $\mu mol\ CO_2 m^{-2}s^{-1}$	%	**Photos.-economy** $(ph+re)re^{-1}$	%
Light						
100%	6.22 c	100	0.44 a	100	19.1 c	100
36%	6.79 b	109	0.36 a	83	25.8 b	135
14%	7.70 a	124	0.18 b	40	53.4 a	279
6%	6.25 c	100	0.13 c	30	59.4 a	311
Soil						
Control	6.95 a	100	0.26 a	100	42.5 a	100
Ca	6.59 a	95	0.27 a	106	41.8 ab	98
NPK	6.95 a	100	0.28 a	110	37.9 ab	89
CaNPK	6.46 a	93	0.30 a	117	35.5 b	84
Provenance						
C1 (Italy)	7.86 a	117	0.34 a	120	39.3 a	100
C3 (Italy)	7.80 a	116	0.28 b	99	44.0 a	111
HA (Germany)	6.32 b	94	0.24 b	86	42.5 a	108
LE (Germany)	6.29 b	93	0.26 b	92	41.9 a	106
RO (Romania)	5.43 c	81	0.29 ab	104	29.1 b	74
Mean	6.74		0.28		39.4	
F-statistics						
Light	13.33 ***		83.57 ***		85.69 ***	
Soil	1.60		1.28		2.29	
Provenance	25.02 ***		3.57 **		6.16 ***	
Light*Soil	1.16		1.35		0.85	
Light*Prov.	0.32		0.91		2.07 *	
Soil*Prov.	0.57		0.69		0.70	

Different characters (a, b, c, d) indicate that there are significant differences between treatments on the 5 % level according to the DUNCAN-test.

The significant differences between provenances in respect of respiration rates can be attributed to the fact that one of the Calabrian provenances (C 1) showed significantly higher respiration rates than the two German and the other Calabrian provenances.

The photosynthetic economy is computed as the ratio between gross photosynthesis (photosynthesis + respiration) and respiration. Significant effects of light and provenance as well as a significant interaction between light and provenance were computed (Table 3). The photosynthetic economy increases dramatically by decreasing light condition, the plants grown under 6 per cent light have thereby a more than 3 times higher photosynthetic economy than the seedlings grown under full light. The differences in photosynthetic economy between provenances are explained by the significantly lower photosynthetic economy of the Romanian provenances compared with the other provenances.

Although the analyses of variance could not detect any significant effects of soil treatments the Duncan-test divide the four soil treatments into two different groups, so that the CaNPK-treatment was significantly different from the control treatment. The general effects of soil manipulations on the photosynthetic economy seem to be a decreasing economy with increasing nutritional status in the soil.

Light saturation is computed by means of the light saturation equation as the light intensity in $\mu E/m^2/s$ at 90 per cent of maximum photosynthesis. Highly significant differences in light saturation were obtained in relation to light treatment and between provenances, whereas soil manipulation had no effect (Table 4). Light saturation at the seedlings grown under full light was obtained at 407 µE, whereas the seedlings grown under 6 per cent of full light were light saturated already at 299 µE. The provenance material was divided into three different groups. A group of Calabrian provenances with the highest light saturation points (400 and 386 µE respectively) an intermediate group of North European provenances, and the Rumanian provenance with the lowest light saturation point (313 µE).

The compensation point is computed by means of the light saturation equation as the light intensity in µE sufficient to create a balance between CO_2-uptake and CO_2-release. Light treatment showed a highly significant effect upon compensation point, whereas neither soil manipulation nor the different provenances provided significant effect (Table 4). The compensation point was dramatically lowered by decreasing light condition during growth (table 4). Whereas the compensation point by the plants grown under full light was reached at 16.6 µE, the plants growing under deep shade (6 per cent) were able to lower their compensation point down to 2.7 µE or only 20 per cent of the values reached by the trees under full light.

The transpiration measurements demonstrated highly significant effects of light and soil as well as provenance (Table 4). Further, a significant interaction between light and soil treatment was observed. Transpiration rates increases by decreasing light. A significant decrease, however, seems first to be obtained at rather low light intensities. The significant effects of soil manipulation on transpiration rates can be attributed to the fact that the CaNPK-treatment shows significantly lower transpiration rates than the plants grown in the control soil. The provenances are divided into three groups. The Calabrian provenances exhibit the highest transpiration rates; the Romanian provenance shows the significantly lowest rates, whereas the two North German provenances exhibit intermediate transpiration rates. The significant interaction between light and soil can be explained by the fact that by intermediate light conditions (at 14 per cent and 36 per cent light) the transpiration reducing effect of improving the soil conditions are especially pronounced.

Water use efficiency is computed as the ratio between net photosynthesis in mol CO_2 and stomatal conductance in mol H_2O. Significant effects of light, soil, and provenance as well as a significant light/soil interaction were determined (Table 4). A continuous decrease in water use efficiency by decreasing light was observed. In contrast, water use efficiency was increased by improving the nutritional conditions in the soil. It is interesting to note that liming alone had no significant effect, whereas together with the NPK-fertilizer liming showed a significant increase in water use efficiency. The differences in water use efficiency between provenances cannot be explained due to geographic origin. The two highest values were obtained by the Romanian and one Calabrian provenance whereas the lowest value was exhibited by the other Calabrian provenance.

The highly significant interaction between light and soil is of special interest. This interaction can be explained by the fact that by very low light conditions (6 per cent) no effect of improving the nutritional status in the soil was demonstrated, whereas by higher light intensity (especially at 66 per cent light) this effect was especially pronounced.

Tabel 4: Light saturation ($\mu Em^{-2}s^{-1}$ at 90% max. photosynthesis), compensation point ($\mu Em^{-2}s^{-1}$ at CO_2-balance), transpiration (mmol H_2O $m^{-2}s^{-1}$) and water use efficiency (net-photosynthesis/stomatal conductance, mmol CO_2/mol H_2O).

Treatment	Light saturation $\mu Em^{-2}s^{-1}$	%	Compens. point $\mu Em^{-2}s^{-1}$	%	Transpiration mmol H_2O $m^{-2}s^{-1}$	%	Water use efficiency mmolCO_2/molH_2O	%
Light								
100%	407 a	100	13.5 a	100	1.32 b	100	0.068 a	100
36%	372 b	91	8.8 b	65	1.44 b	109	0.067 a	99
14%	348 c	86	3.5 c	26	1.75 a	133	0.055 b	81
6%	299 d	73	2.7 c	20	1.77 a	134	0.044 c	64
Soil								
Control	366 a	100	6.4 a	100	1.71 a	100	0.053 c	100
Ca	348 a	95	7.5 a	118	1.61 a	94	0.056 bc	105
NPK	365 a	100	6.9 a	107	1.60 a	94	0.058 b	109
CaNPK	346 a	95	7.7 a	121	1.57 b	92	0.068 a	128
Provenance								
C1 (Italy)	400 a	112	8.1 a	114	1.81 a	115	0.061 a	104
C3 (Italy)	386 a	108	6.4 a	89	1.86 a	118	0.055 b	93
HA (Ger.)	343 b	96	6.9 a	96	1.46 b	93	0.058 ab	99
LE (Ger.)	340 b	96	6.7 a	94	1.46 b	93	0.058 ab	99
RO (Roman.)	313 c	88	7.6 a	107	1.25 c	80	0.061 a	105
Mean	356		7.13		1.57		0.0587	
F-statistics								
Light	36.53 ***		58.16 ***		22.84 ***		65.65 ***	
Soil	1.60		0.75		10.65 ***		20.29 ***	
Provenance	25.02 ***		0.87		24.62 ***		2.62 *	
Light*Soil	0.71		0.52		2.50 **		5.05 ***	
Light*Prov.	0.42		0.46		0.60		0.53	
Soil*Prov.	0.94		0.63		0.59		0.44	

Different characters (a, b, c, d) indicate that there are significant differences between treatments on the 5 per cent level according to the DUNCAN-test.

4 Discussion

The aim of the present study was to improve the fundamental understanding of the effects of light and soil chemical status for the early development of beech seedlings, and further how these effects are influenced by provenances. It was therefore of importance to achieve a large variation in this three dimensional continuum of light, nutrient, and genetics. This has been achieved to a great extend; the light factor varied from full light (100 per cent) and stepwise down to 6 per cent of full radiation. Further, the manipulations of the soil by means of lime and mineral fertilizer have changed the ecophysiological conditions in the soil solution extensively. The basic rather infertile and acid soil has improved dramatically in terms of base saturation by the liming, and the mineral fertilizer improved the soil fundamentally from a nutritional point of view. With the provenances included a large part of the geographic variation within beech should be included. The two German provenances represent beech material from the north-western part of the natural range; the Romanian provenance incorporates the eastern part of the range, whereas the two Calabrian provenances are representatives from the southernmost part of the natural distribution of beech.

The results demonstrate the predominant influence of light. All measured and derived parameters were highly significant affected by the light regime. Most remarkable is the 80 % decrease in compensation point going from full light to 6 % light mostly reached by the reduction in respiration leading to a 311 % increase in photosynthetic economy. This clearly demonstrates the ability of beech seedlings to adapt to changing light conditions (Mészáros *et al*. 2002). In contrast, an increase in transpiration and a decrease in water use efficiency were observed by increasing shade. This can not be explained by the decrease in stomata density observed on the same material (Larsen and Buch 1994). Apparently shaded seedlings are not regulating the stomata as effectively as light exposed specimen. The highest rate of photosynthesis was reached at 14 % light, whereas the highest biomass production was reached at higher light intensities (between 36 % and full light according to Larsen and Buch 1994). However, the lack of close correlations between photosynthesis and growth rates are often demonstrated (Masarovicova 1981; Küppers *et al*. 1986).

The growth development of beech seedlings during the first year is of particular importance for later plant survival and development. In concordance with results obtained by Burschel and Schmaltz (1965), Hu8ss and Stephani (1978), Suner and Röhrig (1980), and von Lüpke (1987) the present results demonstrate the predominant importance of light for seedling development.

Further, Madsen (1994a) clearly demonstrates an interaction between light and water supply for early seedling growth. By optimal water supply he found a continuous increase in growth rate with increasing light up to above 65%. This light response was significantly reduced by a lowering of the water supply. The reduction in photosynthesis by high light intensities in the present investigations might therefore be explained by a periodic reduction in water supply, since water supply was not varied, and a periodic shortage of water might have occurred in the high light treatments.

It is interesting to note that the improvement of the base saturation and the nutrient supply had no effect upon the basic energetic (photosynthesis and respiration) although a slight increase in photosynthetic economy by improving soil conditions was observed. In contrast, the water relations were affected by the soil manipulations, transpiration decreased and especially water use efficiency increased by improved soil conditions. Thereby lime and mineral fertilizer acted synergistic. The limited response of the lime application to this very acid soil, increasing the (Ca+Mg)/Al-ratio from 0.16 to 2.48, is unexpected in relation to existing theories of the effects of acid stress on the development of beech regeneration (Koss 1989). It is however in close agreement with the lack of response after liming reported by Ljungström *et al*. (1990) and Ljungström and Sternquist (1993). One explanation might be the findings of Rost-Siebert (1984) that beech seedlings are less H^+- and more AL^{3+}-tolerant than Norway spruce seedlings. The obtained highly significant interaction between light and soil on transpiration and water use efficiency emphasize possible synergistic or compensatory effects of those two primary growth factors in respect to water relations.

The provenance differed showing higher photosynthesis, light saturation as well as higher transpiration and water use efficiency of the Calabrian provenances compared to the North European and East European ones. From these findings the Calabrian provenances seem to be adapted to generally higher light regimes and to dryer growth conditions than the other provenances. However, it is interesting to note that no significant interactions between provenance and light respectively soil conditions were obtained, indication that all provenances reacted relatively equal on the alterations in light and soil conditions, they posses the same degree of adaptability. The fact, that he two Calabrian provenances showed significant differences in respiration and water use efficiency might indicate a higher genetic variation within the Calabrian beech compared with other regions. A similar pattern in genetic variation has been demonstrated in European silver fir (*Abies alba* Mill.) by Larsen (1986, 1994).

4 Silvicultural aspects

Since the present investigations relate to the development during the year after germination, the achieved results can only with limitations be used in relation to silvicultural practices. However, Madsen and Larsen (1995) emphasize the predominant effect of early growth for the further development of beech regeneration, and in this context the results pinpoint a number of possibilities and constraints in the natural regeneration of beech.

From a silvicultural point of view, the two main primary growth factors, which are possible to control and to manipulate during the regeneration of beech, are light by controlling canopy density and nutrient supply by applying lime and fertilizer. To a certain degree water supply might be influenced too, by controlling canopy density. Since most beech stands are regenerated by means of natural regeneration, the possibilities to control the genetic composition by means of selecting certain provenances are rather limited. However, the extended imports of especially Southeast European provenance (Romania, Slovenia, and Bulgaria) during the last 30 years to Denmark, due to insufficient fructification of the local beech, might cause evolutionary effects in terms of adaptedness and adaptability when this material develops into the reproductive stage.

The results support the recommendation by Koss (1989) through canopy management to assure a relative light regime of 15 to 25 % of full light during the first years of regeneration. Using other provenances than the local North European seed sources, however, might imply the need for higher light intensities during regeneration, since southern seed sources require more light. Especially the Calabrian provenances seem to be adapted to higher light intensities, whereas the Romanian beech might be more comparable to North European provenances.

The significant interaction between light and nutritional status and the found synergistic effects of lime and mineral fertilizer may have silvicultural implications. Nutrient rich sites provide better opportunities to control weed by keeping the canopy more closed without threatening the regeneration than on poor soils. If liming is decided on acid and nutrient pore sites, it may be worth considering an additional mineral fertilization and guarantee sufficient light through adequate canopy thinning.

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Extended abstract: An introduction to Danish beech (*Fagus sylvatica* L.) forests and silviculture

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Abstract

Danish forests and forestry carries a history of loss and gain of forest land. 200 years ago the forests were almost completely cleared, whereas today forest land covers 11% and it still increases aiming at 20-25% of the total land area. Beech is the most important broadleaved species in Denmark. Close-to-nature forestry has gained some popularity over the past 15 years in Denmark due to poor economy in the traditional forestry based on even-aged and homogenous stand management. Additionally, close-to-nature forestry is expected to better support multifunctional management aims, forest stability and flexibility. The scientifically based knowledge is, however, limited for this management concept.

Keywords: Denmark, forest restoration, close-to-nature, stability

1 General conditions for beech forests in Denmark

Denmark is a small (43,000 km^2) lowland country situated between mainland Europe and northern Scandinavia with a population of 5.3 million people, a 7,000 km coastline and almost 500 islands. 11% (486,000 ha) of the land area is forest land. Beech is the most important deciduous tree species in present day Danish forests, and Denmark lies within the European lowland distribution range of beech (Figure 1). The country is located between latitude 55-58° N and longitude 8-13° E. The highest altitude is only 170 m above sea level. The climate ranges from Atlantic in the west to sub-continental in the east with an annual precipitation between 500-900 mm depending on site. Annual mean temperature is between 7.5° and 8.5°C with January and July means at 0°C and 16°C, respectively. The Atlantic weather conditions differ from year to year and are generally very unpredictable. Late spring frost is a major problem for regeneration of species like beech under unsheltered conditions, in particular in the interior parts of the country. Denmark is also a windy country as the low-pressure fronts travel eastwards from the Atlantic. The perpetual westerly and north-westerly winds can stress and shape the trees of the western and northern part of the country. However, the most important wind effects are created when low pressures develop into hurricanes (Figure 2), which blow down trees and forests.

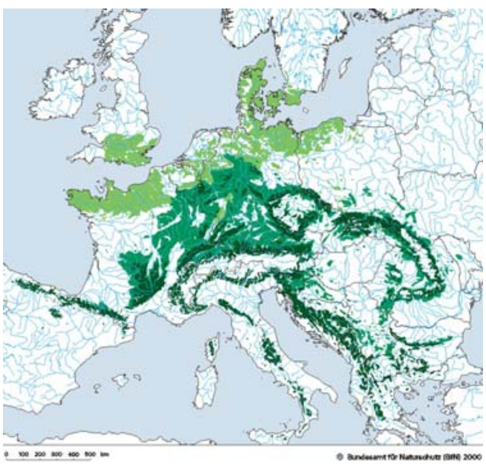

Figure 1. Denmark is situated in northern Europe, within the natural range of European beech (*Fagus sylvatica*). Source of map: Bundesamt für Naturschutz, 2000.

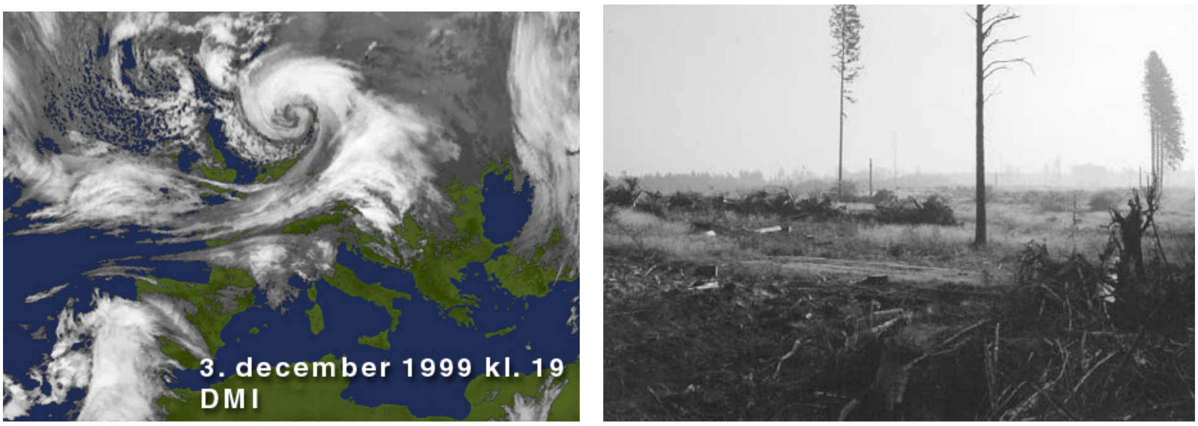

Figure 2. On December 3, 1999 southern Denmark was hit by a hurricane, which resulted in a major blow down of conifer plantation (mainly Norway spruce, *Picea abies* [L.] Karst.).

2 Danish beech forestry – the early development

The last ice age (Weichselian) ended 12,000 years before present (BP) and left by its retreat a landscape with various deposits. Accordingly, the Danish landscape can be divided into four forest regions depending on the characteristics of the deposits (Figure 3).

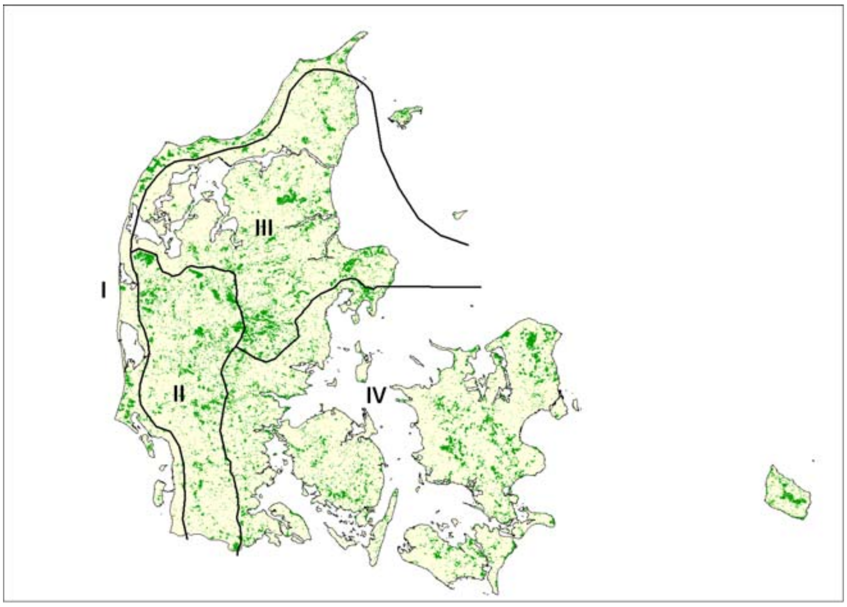

Figure 3. With regard to growth conditions, Denmark can be divided into four general regions. I: Dunes along the West Coast. II: Areas not covered by the ice, sandy soils and outwash plains. III: Areas with sandy and infertile glacial deposits from Norway and Sweden. IV: Areas with loamy and calcareous glacial deposits from the Baltic Sea. Source: Danish Forest and Nature Agency, March 2004.

Beech arrived in the Bronze age (3,500 BP), but did not become dominant until 1,500 BP. The first steps toward agriculture started 6,000 year BP, which were also the beginning of a long lasting decline in forest cover. In 1800 the forest land area reached a low of 2-4% caused by the intensive landuse including cutting, grazing and fire. Large proportions of the Forest Regions I, II and III had developed into vast areas of heathland and an ecological disaster was a reality. Heathland soils are very acidic, infertile and difficult to restore into better and more fertile conditions. In Forest Region IV the soils were too fertile to develop into heathland but the forests were generally grazed and of poor quality. The challenges to restore the country's agricultural and forest land were tremendous, requiring cooperation between land ownership and tenure reforms, improved education of the population, new technology and a national movement to restore both farm and forest land.

By around 1800-1850 AD, plantation forestry based on even-aged single species stands became the overall silvicultural approach, exotic species were introduced and tested and wood production was the most important aim. Conifer species became dominant in forestry, since they showed higher productivity than broadleaves and were easier – perhaps the only possible – to establish at the harsh heathland sites. Norway spruce quickly gained popularity and became the most important species. Mountain pine (*Pinus Mugo* Turra) played an important role as a nurse crop species for the poorest sites. Later other conifer species were increasingly used such as Sitka spruce (*Picea sitchensis* (Bong.) Carr.), European silver fir (*Abies alba* Mill.), Douglas fir (*Pseudotsuga menziesii* Mirb. Franco) and grand fir (*Abies grandis* Dougl. Lindley) in order to counteract some of the problems related to pure Norway spruce stands such as poor stability and root rot.

3 Danish beech forestry – the present setting

Today's species distribution strongly reflects the past and extensive use of exotic conifer species. 65% of the forest land area is conifer and 35% is broadleaves. Only 72,000 ha (17%) is beech forest. Danish forestry had to go through several severe storms and blow downs and drastically declining softwood timber prices before the interest in broadleaves including beech increased in the 1980´s. The beech and other broadleaves are typically much more storm resistant than the conifers.

Modern forest management need to address a whole range of aims including recreation, biodiversity, wood production, ground water protection, landscape aesthetics, cultural heritage and bio-energy production. Important management aims for the private landowners, who own 69% of the Danish forest land, are typically related to the property value, hunting and simply the „pleasure of ownership". Management challenges are not only related to the complex set of present multifunctional aims but also to changing aims and priorities over time. History has shown how difficult it is to accurately predict future aims and outputs. The rotation length usually ranges between 50 and 120 years, depending on site, species, silvicultural practice, etc. The problem is that nobody can precisely predict what will be the main role and output of the future forests. Consequently, the need for the forests to be flexible is stressed and stability seems to be crucial to obtain this flexibility. Stands with a high risk of wind throw are not flexible since the manager may not be the one who decides when the stand is to be harvested.

Close-to-nature silviculture or nature-based forest management has gained popularity over the last 10-15 years. In contrast to the traditional even-aged single species stand management, close-to-nature forest management emphasises the use of site adapted and stable species. Additionally, the silviculturist utilise natural stand and regeneration dynamics to a much larger extent than in the traditional silviculture. Spontaneous natural regeneration is the backbone of forest regeneration in close-to-nature silviculture. However, with the present tree species distribution in mind natural regeneration may not offer an acceptable species composition for the future. The lack of relevant seed sources in many conifer stands and plantations is obvious and there is still an important role for artificial regeneration (planting and direct seeding) to play in Danish close-to-nature silviculture. The extensive use of natural stand and regeneration dynamics is also supposed to support biodiversity better since it mimics the natural dynamics better. The general idea is that a wider range of forest biodiversity will take advantage of this, since their habitat is restored to a more natural stage. Close-to-nature silviculture is also supposed to improve forest economy in the long run. Reduced regeneration, early tending costs, and target diameter harvest are key elements in this strategy for improved forest economy.

In conclusion, we must admit that there are many unanswered questions and problems related to close-to-nature silviculture in Denmark. Beech is our most important native species and perhaps even more important in a forest future with an increasing proportion of close-to-nature silviculture. Much of our present research is aiming at an improved scientifically based knowledge of beech and its role in close-to-nature silviculture.

Extended abstract: Gap regeneration in a close-to-nature managed beech (*Fagus sylvatica* L.) forest in Denmark

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Abstract

Natural regeneration was studied in twelve gaps established in 1997-98 in a beech dominated broadleaved forest, Als Nørreskov, which has been managed according to close-to-nature principles for three to four decades. Six gaps were deer fenced and six gaps were left unprotected to study impact of deer browse. Relations were studied between both density and height of natural regeneration and environmental factors like light, soil moisture and soil characteristics but no correlations were identified.

Keywords: light, soil moisture, natural regeneration, deer, fence

1 Introduction

Hahn and Madsen (this volume) and Madsen and Hahn (this volume) have already briefly described forest history, forestry and the recent trends towards close-to-nature (nature-based) forest management or silviculture in Denmark. This study is part of overall research programs, which aim at development of silvicultural means and documentation of gap regeneration in selected beech dominated broadleaved forests. The selected forests have been subject to various management regimes like close-to-nature, traditional and non-intervention (Hahn and Madsen, this volume).

2 Materials and methods

2.1 Materials

The study was carried out in Als Nørreskov, which is a state owned forest (700 ha) (55°01' N, 9°55' E) (Fig. 1), and which has been managed according to the principles of close-to-nature silviculture for three to four decades. As such the forest is still in progress of a restoration process away from the traditional management of homogenous even-aged single species stands. The regeneration of Als Nørreskov is wherever possible based on natural regeneration and the gradual shelterwood harvest by the end of the rotation is target diameter based. Regeneration typically starts in groups sometimes mixed with ash (*Fraxinus excelsior* L.) and sycamore maple (*Acer pseudoplatanus* L.), which are welcome. Planting is almost only used when some of the conifer stands are felled and regenerated. The forest is approximately 1 km wide and 7 km long and located at a northern and eastern coastline of the island Als in the southern part of Denmark. The rolling landscape west and south of the forest is mostly fertile farmland. Loamy and clayey tills support the fertile and generally well-drained forest soils.

2.2 Methods

Totally, 12 gaps were established in March 1997 and February 1998 by felling three mature trees per gap in stands that were approximately 100 years old and 30 m tall. The gaps were clustered four and four in a "block" design (Fig. 2). Within each block two gaps were fenced against deer and two were left unfenced. Likewise, two gaps were established in 1997 and two in 1998 per block – inside and outside the deer fences. Within each gap a N-S grid system of totally 91 plots (0.3 m^2) were laid out. The regeneration and ground flora were recorded and canopy density, light and soil moisture were measured as described by Hahn and Madsen (this volume) for the first four growing seasons (1997-2000).

Figure 1. Als Nørreskov is located in southern Denmark (left) and the 12 gaps were created the beech-dominated part of the forest (right).

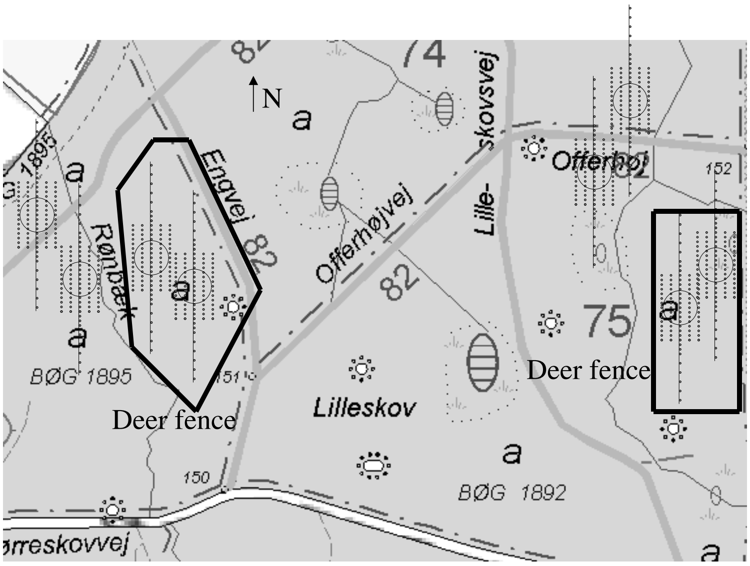

Figure 2. The location of 8 out of 12 gaps (two out of three blocks) in Als Nørreskov. In each block two gaps are fenced and two are unfenced. Likewise, two gaps within each block are established March 1997 and two in February 1998. The forest map is created by The Danish Forest and Nature Agency and shows e.g. departments of the forest, forest roads and their names, symbols of cultural heritage etc.

3 Results

3.1 Light and soil moisture availability in gaps

Average relative light intensity at the forest floor level only reached 5% in the gap centres and less outside in the first growing season following gap creation. The light level at Als Nørreskov was considerably lower than at other sites of the research programme, which is due to the dense two-layered structure.

Soil moisture showed large variation in both space and time. In dry periods of the growing season the soil moisture content remained high and close to field capacity in the gap centres whereas it declined to perhaps 50% of field capacity or lower under closed canopy. Soil moisture showed heterogeneous patterns outside the gaps due to e.g. distance to trees or stumps of trees felled by earlier thinnings.

Seedling response to gap formation

There was hardly any seedling response observed within the first four growing seasons. A beech seed mast in 1998 increased seedling density, but it fell back to the initial level after the 2000-growing season. Likewise the height increments seems to be absent to very slow. Analyses showed no effects of increased light, soil moisture, location in the gaps, deer fence or year of gap formation.

4 Discussion and Conclusion

The study showed that harvest of three mature beech trees per gap only affected light conditions very little when the forest structure includes an understory. In contrast the soil moisture was strongly influenced by the gap formation. During dry spells the soil moisture hardly dropped in the central parts of the gaps whereas it generally and rapidly declined outside the gaps. In spite of this dramatic influence of soil moisture, the gap effects on the beech regeneration was absent during the first four growing seasons. Year of gap establishment and deer fence showed no effects as well, which surprised us.

Data of more recent surveys and data on species like ash and sycamore maple are yet to be analysed and the results from Als Nørreskov need to be included in overall analyses from the other experimental sites of the research programs. Perhaps the gaps in Als Nørreskov were too small to create effects on the regeneration or perhaps the study is still too young for final evaluations. The results indicate that the creation of gaps in a closed forest canopy does not per se initiate regeneration and that not only forest managers but also forest researchers need more patience to thoroughly study means and dynamics of natural regeneration in a close-to-nature forest management regime.

5 Acknowledgements

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The relation between annual diameter increment of *Fagus orientalis* and environmental factors (Hyrcanian forest)

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Abstract

In this research, the relation between annual diameter increment (ADI) and environmental factors was studied for *Fagus orientalis* at different altitudes (from >700 m.a.s.l.) in the Hyrcanian forests of Iran. The method of sampling was the block random method; randomly 320 samples were taken by using the increment borer. A Binocular was used to mark the ADI on the samples. Measurement of ADI was done with 0.05mm accuracy. With stepwise regression, seven multiple regression models were calculated for the relation between ADI and the environmental factors altitude, rainfall, DBH, crown cover, basal area, soil and geological condition. The best model (good prediction of ADI with as few variables as possible) has been used to make a map of ADI distribution based on altitude, DBH and geological condition. The results show the variation of predicted ADI between different sites. Although altitude plays the main role, also the influence of other factors can be seen. The minimum and maximum value for ADI are 1.78mm (at 2140 m.a.s.l) and 3.4mm (at 750 m.a.s.l), respectively. The ADI distribution map can be used by forest manager for determination appropriate harvesting rotations or target diameter.

Key words: *Fagus orientalis,* annual diameter increment (ADI), environmental factors, increment core, target diameter, rotation time, site evaluation.

1 Introduction

Variation of environmental factors is important for trees height and annual diameter increment, which together form the stand's increment. This is one of the main factors for forest management planning to determine the amount of annual logging in commercial forest.

Fagus orientalis in the Hyrcanian (Caspian) forests grows on the slopes facing north and is one of the acidophyle species which needs intensive shade in the young stage. It needs a well- drained soil and regular aeration with suitable water nutrition. The effect of nutritions on growth of oriental beech has been studied by Habibi (1975). In the case of forest stand degradation and landslides, the soil texture will be changed and display hydromorphic phenomena which leads to disappearance of beech (Habibi, 1985).

Fagus orientalis grows between 700 and 2200 m.a.s.l. The precipitation decreases from 1140mm to730mm with increasing altitude from 120 to 1700 m.a.s.l as well as temperature. Based on the climatic classification, beech sites are located in the cold humid, semi-humid and mountainous zone (Sagheb-Talebi *et al*., 2000). During the past decade the main silvicultural systems which are used in the Hyrcanian forest are uniform shelter wood and selection systems. In both of these systems, final (target) diameter has a main role for determining the length of rotation and prediction of the amount of annual logging.

Table 1 compares the rotation and target diameter between *Fagus sylvatica* and *Fagus orientalis*.

Table 1. Rotation and target diameter for *Fagus sylvatica* (Anon., 2002a) and *Fagus orientalis* (Anon., 1985).

	Fagus sylvatica	*Fagus orientalis*
Target diameter (cm)	ca. 60	55 - 60
Rotation (years)	110 – 140	100 – 120

The previous study showed that diameter growth is much more related to current foliage and present environmental conditions and increment is the quantitative increase in size in a specified time interval due to growth (Anon., 2002c). Increment varies with species, internal conditions (genetic and physiological) and external conditions (climatic, edaphic, biotic).

In periodic case studies carried out by Forest and Range Organization of Iran (F.R.O.I), *Fagus orientalis* formed 32.7% and 29.9% of the total volume at Hyrcanian forest in 1986 and 1999, respectively (Anon., 1986; Anon., 1999). Statistics showed a decrease in total volume because of the over exploitation, which is a serious treat for this community. At present, in Caspian forest management, only one target diameter and rotation are considered in different environmental condition, whereas the changes of environmental factors could be reflected in target diameter and rotation. Information about these relations can be useful for forest management planning to determine the appropriate rotation and target diameter in different sites and avoiding of over exploitation and forest degradation.

The main aim of this study was finding the relation between annual diameter increment of *Fagus orientalis* and environmental factors (i.e. rainfall, soil, geology, altitude, slope and aspect) and other quantitative factors (i.e. crown cover, basal area and dbh).

2 Materials and Methods

2.1 Field data

The main data and most of the variables (altitude, slope, aspect, crown cover, DBH, basal area and trees crown diameter) for sample sites have been collected in field work. There are different methods to study the annual diameter increment (A.D.I) such as, disk sample (from cross section of trunk) or periodic measurement of the dbh at different years and obtaining increment core by using increment borer (Zobeiri, 2002). The last method has been used in this study. Filed data were collected during months of July and August 2002. Considering the objectives, time, facilities, budget and accuracy, a Block Random method was used for sampling. At forest the blocks were the parcels. Sampling and measurement had been done in chosen parcels (or blocks). Based on the altitude and beech behaviour, the study area was divided into three categories: **a**) 700-1100 m.a.s.l. (as the general fog line), **b**) 1100-1600 m.a.s.l. (as the general snow line) and **c**) >1600 m.a.s.l. As an example, the number of samples at each subdivision in the first category is given in table 2.

Randomly 320 increment core from 320 sample trees were taken by using the increment borer. The wood of *Fagus orientalis* is diffuse porous (Hejazi, 1975), and annual increments is not directly visible by eye on increment core. Therefore Binocular X50 (stereomicroscope) has been used to mark the annual diameter increment on the sample core, and then ADI was measured by using Coils (with 0.05 mm accuracy). To decrease the effect of competition between the trees of stand, the samples are taken from dominant trees with good health. Due to absence of beech at south aspect it was not possible to take predicted samples at this aspect.

Table 2. Number of samples in each subdivision for the "a" category (700-1100 m.a.s.l.).

Division (based on aspect)	Sub-division (based on slope) %	No. of sample sites	No. of sample trees
North	0-30	3	12
	30-60	3	12
	>60	3	12
East	0-30	3	12
	30-60	3	12
	>60	3	12
West	0-30	3	12
	30-60	3	12
	>60	3	12
South	0-30	3	12
	30-60	3	12
	>60	3	12

2.2 Exist data

These data are collected from different sources as following:

-Topographic map, 1:25000**.**

-Rainfall data, collected from 10 rain stations for 10 years 1992-2001 (Anon., 2001).

-Digital data (Soil type map, Geology map, Forest map, Forest division, parcels, series, Contour lines map, Stand condition).

-Forest management plan's data and reports (N/ha and V/ha, mean DBH).

2.3 Analyses

After data processing, analyses have been done in two main phases (Fig. 1). First phase for statistic analyses (Bozorgnia and Tehranian, 1996) and calculating the multiple regression between annual diameter increment (ADI) and variables which most of them collected at field work and second phase for creating the ADI distribution map that calculated by using map calculation feature of ILWIS software. The process of this phase are based on the calculated multiple regression models and digital maps of accepted variables (rain, altitude, dbh, crown cover, basal area, soil and geology maps).

Geology data have been used to quantify the bedrock condition based on the soil generation and the permeability for water and roots and soil profile data were used to quantify the soil condition based on texture, structure, depth, pH and C/N.

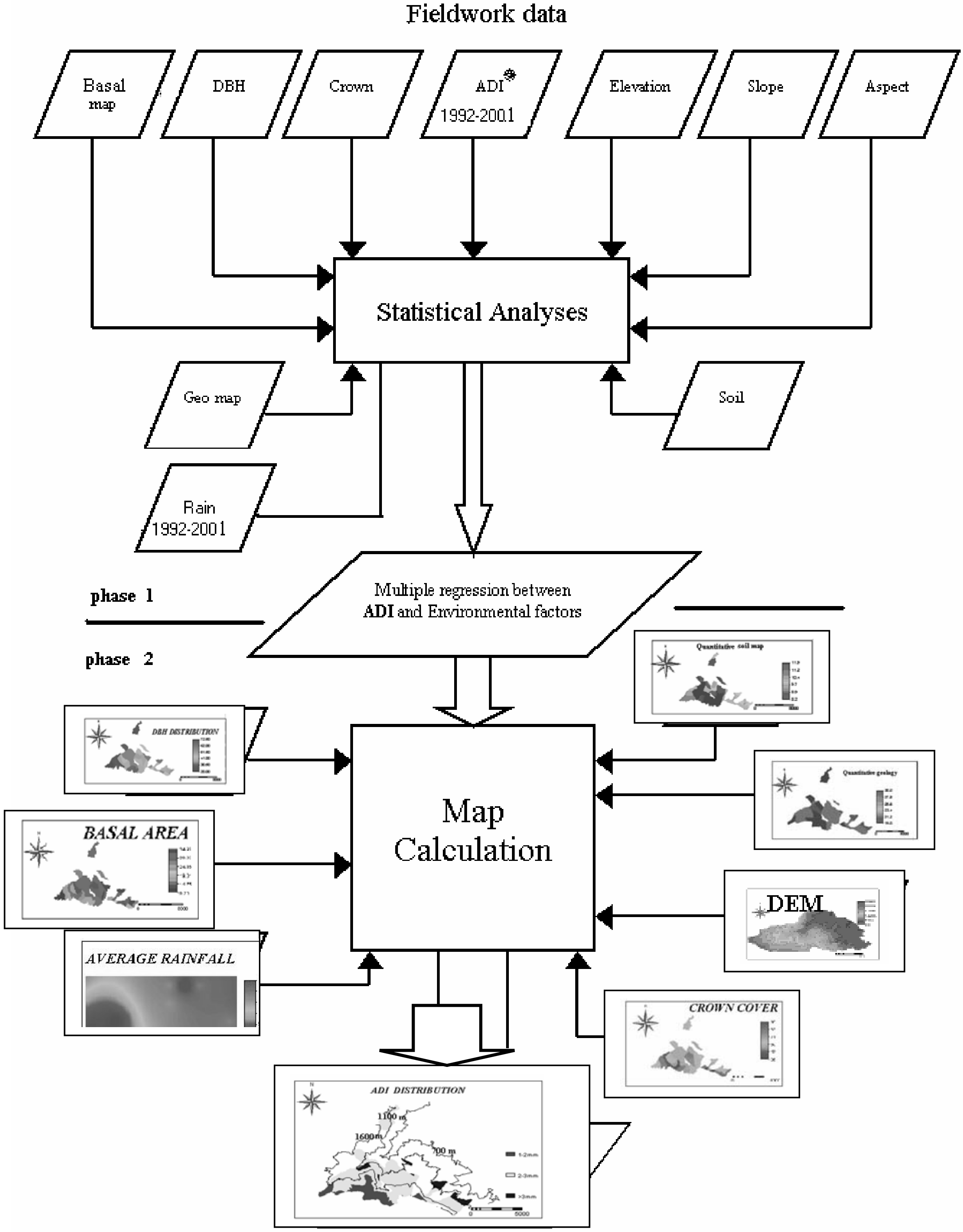

Figure1. The process of generation ADI distribution map.

3 Results

3.1 Elementary results

The minimum and the maximum value for ADI are calculated to 1.78mm (at 2140 m.a.s.l.) and 3.4mm (at 750 m.a.s.l.), respectively.

The kind of correlation (positive or negative) between annual diameter increment and accepted environmental factors (with significant relation) is shown in Table 3. The slope and the slope aspect were the variables, which have been automatically omitted in statistic analyses.

Table3. Kind of correlation between annual diameter increment (ADI) and environmental factors (E.F.)

E.F.	Rain	Altitude	DBH	Crown	Basal area	Geo	Soil
ADI	+	-	+	+	+	+	+

3.2 Generated models

Based on Table 3 and the regression formula that is described in analyses method, the models for estimating annual diameter increment (ADI) are given in Table 4.

Table 4. Generated models (multiple regression).

Model	Formula	R^2
Model-1	ADI=1.3194 + 0.0017 ∗ DBH - 0.0005 ∗ rain - 0.00033 ∗ altitude + 0.086 ∗ Geo + 0.002 ∗ crown cower - 0.009 ∗ basal area + 0.022 ∗ soil	71.26
Model-2	ADI=0.6737 + 0.0018 ∗ DBH - 0.00028 ∗ altitude + 0.086 ∗ Geo + 0.002 ∗ crown cower -0.009 ∗ basal area + 0.022 ∗ soil	71.26
Model-3	ADI=0.8413 + 0.0018 ∗ DBH - 0.00029 ∗ altitude + 0.087 ∗ Geo - 0.009 ∗ basal area + 0.020 ∗ soil	71.25
Model-4	ADI=1.2004 + 0.0020 ∗ DBH - 0.00038 ∗ altitude + 0.084 ∗ Geo - 0.009 ∗ basal area	71.20
Model-5	ADI=1.1864 + 0.0022 ∗ DBH - 0.00042 ∗ altitude + 0.076 ∗ Geo	70.96
Model-6	ADI=1.0290 - 0.00037 ∗ altitude + 0.085 ∗ Geo	69.83
Model-7	ADI=-0.2244 + 0.114 ∗ Geo	68.39

To consider the ability of variables to estimate the annual diameter increment in simple regression, their equation was calculated. The equations for the acceptable variables are the following:

(1) $y = -0.0012x + 4.3074$ (where y = ADI, x = Altitude) ($R^2 = 0.60$)
(2) $y = 0.0127x - 11.24$ (where y = ADI, x = Rain) ($R^2 = 0.53$)
(3) $y = 0.1146x - 2.3059$ (where y = ADI, x = Geo) ($R^2 = 0.68$)

3.3 Annual diameter increment (ADI) distribution map

Based on each one of the regression models, annual diameter increment (ADI) distribution map could be created but the Model-5 (table 4) as the best model (good prediction of ADI with as few variables as possible) had been used to create a map of ADI distribution for study area (Fig. 2). In this phase the map calculation function of ILWIS were used, by applying the formula from the regression model on the base maps (DBH, altitude, geology). The map (Fig. 2) shows the decrease of ADI with increasing altitude.

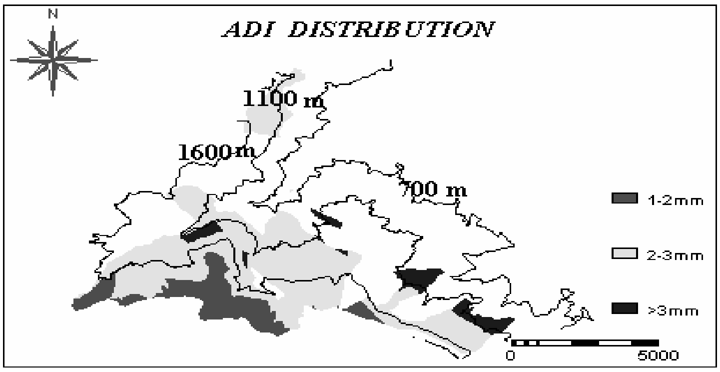

Figure 2. Annual diameter increment distribution based on altitude.

4 Discussion and conclusions

The correlation suggests that rain, altitude, geology and soil condition have more effect on ADI than the crown cover, DBH and basal area (with week correlation). Almost all of accepted factors have a positive correlation with ADI, except altitude which has negative correlation. It is logical that the condition of a site will be better with an increase of rainfall or improvement of the soil fertility or a more suitable geology, but for DBH, crown cover and basal area the preliminary assumption was that there would be a negative correlation between these factors and the ADI. However, the result shows a positive and weak correlation between DBH, crown cover, basal area and ADI.

These results confirm the previous studies where it was shown that ADI will start to increase from the age of 40 and continue to increase till the end of tree life (Mirbadin and Shahriary, 1999). ADI is independent of DBH, because it is affected by phenomena like heavy seeding period. Previous studies show that heavy seeding in open forest is more than the closed stand and during the heavy seeding (which starts from the age of 60), ADI reaches a minimum rate (Siahipour *et al*., 2002; Mirbadin *et al*., 2005). In dry years, annual rings may not grow in the DBH of some beech trees (Anon., 2002b)

Compared to the other broad-leaved species, beech in mixed stands attracts attention because of an enormous capacity to expand it's crown even at a late age (Anon., 2002b). A bigger crown cover of a tree leads to more ADI (Siahipour *et al*., 2002).

Also there is not a strong correlation between ADI, DBH, crown cover and basal area, because various factors have an effect on diameter increment and basal area or crown cover size. Therefore the ADI doesn't follow a fixed and same process of those factors. Parsapajuh (1974) showed in a similar study that the ADI of oriental beech decreases by increasing of altitude from 4.36mm at 750 m.a.s.l. to 2.28mm at 1250 m.a.s.l.

Altitude is a main factor, which has a negative relationship with rainfall and temperature. Reduction of the temperature is a limiting factor for plants and micro-organism activities. At high altitude beech can be severely damaged by late spring frosts (Anon., 2002b; Gorgi Bahri and Sagheb-Talebi, 1992). Although, slope aspect was omitted in analysis because of no significant relation with ADI, the absence of this species at south aspects or low percentage at east aspects is the evidence that main aspects (not secondary) play a big role in distribution of beech.

Taking into account the calculated minimum and maximum ADI, the appropriate time to reach the target diameter (60 cm) differs between 176 and 260 years, therefore the rotation time should be varied in different sites. The ADI distribution map can be used by forest management planers for determination of harvesting rotation.

Annual diameter increment combines the effect of climate, site specific factors, natural and human disturbances and site generally refers to the totality of the environmental condition which exists at a specified location. Site is a complex concept, which combines a multitude of environmental factors affecting tree's ADI. The effecting factors are: climate, soil, topography and competitive factors. This study recommended that to avoid the over-exploitation, site evaluation and classification is important in forest management to improve the estimation of the yield. This can be easily done and by the collected data in forest management plans.

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Dynamics of Woody debris in a Beech (*Fagus sylvatica* L.) Forest in central Germany

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Abstract

In an 8 ha beech (*Fagus sylvatica*) stand of about 160 years in Solling, south Lower Saxony, the input and decomposition of woody debris were observed over a period of 14 years. To asses the rate of wood decomposition, carbon dioxide evolution from decomposing wood was measured.

Since the beginning of the investigation input has increased. In 2002 the volume of the coarse woody debris was 67,5 m³ ha^{-1}. Storm and the white rot exciting fungus *Fomes fomentarius* were identified as causes of mortality. The infestation of *Fomes fomentarius* increased and resulted in death of single trees. The oldest, still identifiable, strongly decomposed logs fell down in the 1970ies. Under the given climatic conditions the decomposition period is more than 30 years. The highest rate of wood decomposition is reached about 4 years after tree fall.

The determined volume of woody debris is in the range of the amounts from natural beech forests and natural forest reserves. The results indicate that the amount and origin of mortality as well as the mortality pattern depend on the age of the stand. On the basis of the properties of woody debris a decomposition key will be presented.

Keywords: Solling, *Fagus sylvatica,* Stand structure, Monitoring, Woody debris, Decomposition, CO_2.

1 Introduction

The presence of woody debris is an essential criterion when estimating how closely a forest approximates a natural forest. Virgin forests are characterized by an abundance of woody debris (Korpel 1997). The amount of woody debris in managed forests in Central Europe has been reduced significantly as a consequence of timber utilization and forest management (Albrecht 1991; Schmitt 1992). The supply of woody debris increases again as soon as forests are no longer managed. Research conducted in strict forest reserves in Germany shows that the amount of woody debris increases within a few decades of forest management ceasing (Meyer 1999, 2003).

What functions does woody debris fulfill?

Woody debris increases the structural diversity of forests (Huston *et al*. 1999) and is an essential part of forest ecological processes (Albrecht 1991; Lugo et al. 1999). Numerous organisms have adapted to the woody debris habitat. Many varied inter-relationships occur between the substrate and it's occupants, affecting nutrient and energy cycles, the self regulation and stability of forest ecosystems as well as the establishment of regeneration of tree and other plant species (Franklin *et al*. 1987; Weiss 1991).

It is necessary to manage woody debris effectively so that its functions can once again be fulfilled in our managed forests. Therefore it is necessary to now: (i) How much woody debris, and in what dimensions and state of decay is necessary in particular managed forests to maintain ecosystem functions? And (ii) how can the accumulation and maintenance of this supply of woody debris be achieved?

2 Materials and methods

By way of example for other tree species, the ecological basis for the management of woody debris from beech (*Fagus sylvatica)* is currently being investigated in a research project conducted by the Institute of Silviculture at Göttingen University (Müller-Using and Bartsch 2003).

Fagus sylvatica is the most competitive tree species in almost all forests in Central Europe. Under natural conditions beech would dominate Central Europe forests. In Germany beech forests currently comprise less than 25 % (AID 2003) of the forest area.

The research project presented here has been developed in the context of process studies investigating the release of nutrients from woody debris. Input and decomposition of woody debris are sampled regularly. The yield of woody debris, the cause of its formation and the decomposition dynamics including the activity of decomposing Organisms are presented for the 14 year observation period.

2.1 Study site

The study site is located in the Solling, a hilly landscape in the centre of Germany at an altitude of 500 m. a.s.l. The climate is humid with an annual average temperature of 7.0 °C and an average annual precipitation a little over 1000 mm. The soil comprises a podsolic brown earth, poor in base cations that has developed from sandstone covered with an 80 cm deep loess layer, formed by solifluction (Ellenberg *et al*. 1986; Bartsch *et al*. 2002).

The stand has the typically poor structure of an old beech forest on a nutrient poor site. Since 1967 forestry operations have not been carried out in this approximately 160 year old single storey beech forest. The study area comprises 8 ha.

2.2 Sampling and analysis

We have recorded the accumulation and supply of dead wood over a 14 year period. The location of the dead stems has been mapped. In 2000 the extent of decomposition of the stems were classified according to their external appearance. A specific decomposition key for beech woody debris was developed for this purpose (Fig. 1). The following parameters have proven to be appropriate for the classification of the extent of decomposition were: the cause of death, bark appearance, branching, strength of the wood, cross-section form, fungal and moss cover.

The decomposition key also enables a quick, clear approximate classification of the extent of decomposition of woody debris of beech on comparable sites.

As a measure of the current decomposition activity, the CO_2 emissions from woody debris were recorded. The CO_2 emissions from 21 stem sections at different stages of decomposition under natural weather conditions in the stand were measured fortnightly over 12 months. The diameter of the stem sections ranged between 20 and 30 cm. The length of the sections was about 40 cm. To calculate the CO_2 emissions for the total stem the area of the radial cut was covered with aluminium foil. The stem sections had been in contact with the soil.

For the incubation gas exchange chambers made from PVC with a volume of 78 l were used. The gas samples were analyzed in the laboratory using gas chromatography (GC 6000; Carlo Erba) with an electron detector (ECD) (Loftfield *et al*. 1992; Borken 1996).

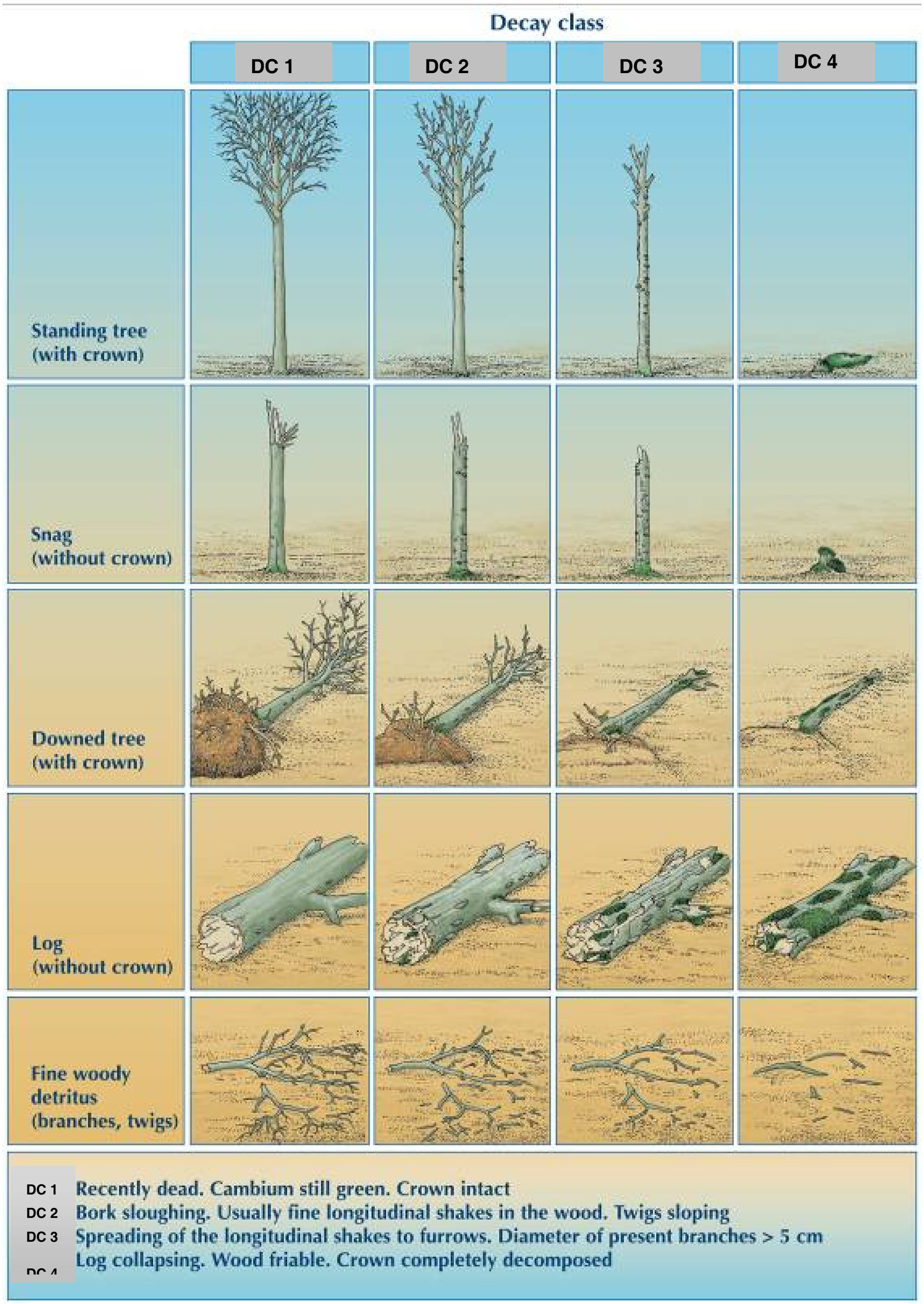

Figure 1. Decomposition key for woody debris of beech

3 Results

The annual yield of woody debris increased from 1988 to 2002. In the Tables 1 and 2 the average Input year^{-1} for the period between the woody debris inventories are given.

Table 1. Input of woody debris from 1988 to 2002

Year of Inventory	1988	1990	1994	1998	2000	2002
	(Number of stems ha^{-1})					
Living trees	199	198	191	186	179	175
Dead trees	12.5	14.1	20.3	25.7	32.9	37.1
Mortality rate year^{-1}		0.76	1.55	1.36	3.61	2.09

Table 2. Volume of living trees and coarse woody debris (m³ ha^{-1} and % of total living and dead volume) of the 2nd and 4th inventory

Year of Inventory	Volume			
	Living trees		Dead trees	
	(m³ ha^{-1})	(%)	(m³ ha^{-1})	(%)
1994	500.5	94.7	28.3	5.3
2002	497.9	88.1	67.5	11.9

In 1990 the mortality rate was 0.76 trees ha^{-1}. In the periods since 1.6 trees ha^{-1}, 1.4 trees ha^{-1} und 3.6 trees ha^{-1} died. The mortality rate derived from the 2002 survey data was 2.1 trees ha^{-1}. The ratio of live to dead trees determined in 1988 was 16:1 and had decreased to 5:1 by 2002.

The total volume of coarse woody debris (> 10 cm) derived from the 2002 inventory was 67.5 m³ ha^{-1}. When compared to the woody debris inventory from 1994 it can be seen that the woody debris supply had more than doubled. A similar increase in the proportion of woody debris to the total volume of the stand was found. Clearly the beech stand investigated is in a stage where the increment in live volume is low and the yield of woody debris high. High woody debris accumulation and low volume increment are characteristic of a mature stand (Leibundgut 1993; Meyer 1999). For European beech forests an average yield of woody debris of 50-200 m³, amounting to 10-35 % of the total volume, can be assumed.

A review of the survey to ascertain why the trees had died revealed that 70 % of the trees fell after being snapped off at the middle of the stem. The remaining 30 % of the trees had been uprooted by storm. The presence of the bracket fungus *Fomes fomentarius* was evident on about half the tree stems with signs of early decay (DC 1). The fungus causes decay by penetrating the wood of weak trees through wounds in the bark or branch scars, producing a white rot. If wood damage is extensive the strength of the wood is reduced, which may cause the tree to fall.

The state of decomposition of dead stems enables conclusions about the temporal dynamic of mortality. 77 % of the trees that had been wind thrown were found to be in an advanced state of decomposition (DC 4). It may be assumed that they fell as a result of one or more storms with particularly strong winds. Storms causing windthrow occurred in the study area in 1972 and 1976. The accrual of large amounts of woody debris as a result of a disturbance has not recurred at the site since.

Figure 2 shows the distribution of the CWD by volume and number of stems to the 4 decay classes. The number of stems in decomposition stage 4 is very high due to the storm events. However the volume amounts to only about 10 % of the total wood volume due to the reduction in volume through the process of decomposition.

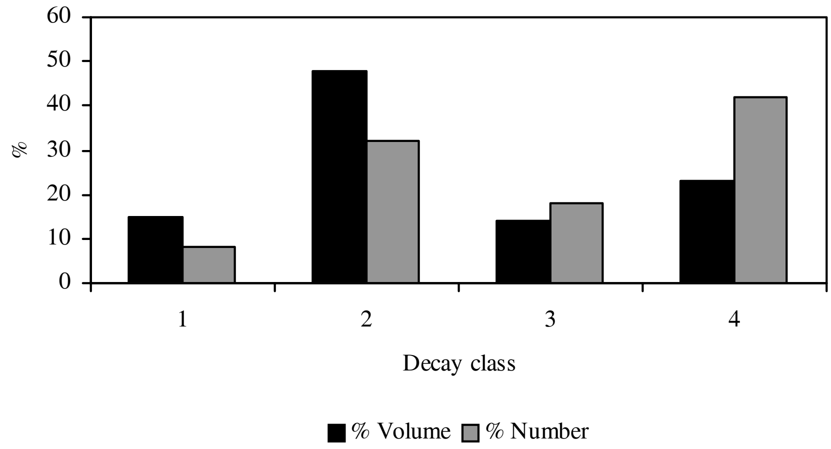

Figure 2. Distribution of CWD by volume and number of stems to the 4 decay classes (explication of the decay classes s. Fig. 1)

The greatest volume and a large number of stems occur during the 2nd stage of decomposition. This is caused by an increase in the annual rate of accrual characteristic of a stand at the beginning of the mature phase. The smaller percentage of woody debris found in decomposition stage 1 occurs because the have fallen 1 or 2 years earlier at the most that means that the duration of class 1 is short.

The CO_2 emissions are used as a measure of the activity of the organisms involved in wood decomposition. Figure 2 comprises the annual sum of the CO_2 emissions from 1 m³ stem wood for the 4 stages of decomposition.

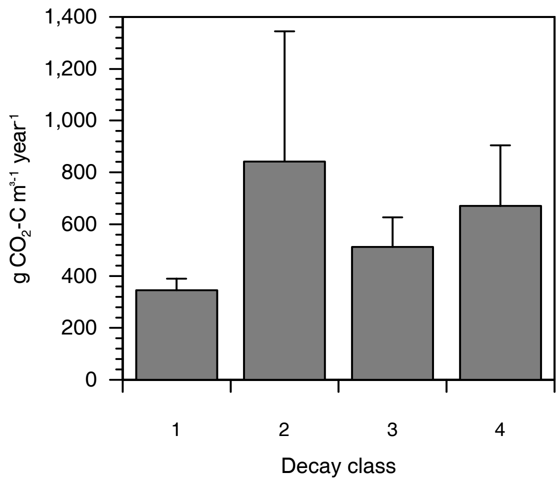

Figure 3. Annual CO_2-C emission of beech logs per decay classes (explication of the decay classes s. Fig. 1). Error bars indicate standard deviation.

The process of decomposition begins slowly. In decomposition stage 2 the activity is clearly at its peak. A second peak occurs during the end stage of decomposition. The trees in decomposition stage 1 comprise trees that have died naturally as well as healthy trees that were felled. The low variability in values during decomposition stage 1 indicates that the microbial activity does not differ significantly between these two types.

The broad range of values measured in the decomposition stage 2 is conspicuous. The reason is evident when viewing the values along a time axis (Fig. 4). In these 6 years, the approximate length of this decomposition stage, the biological activity increases rapidly and then falls after a short peak. Further investigations are required to determine whether these stages of activity can be identified from morphological characteristics of the woody debris. This could make changes to the decomposition key necessary.

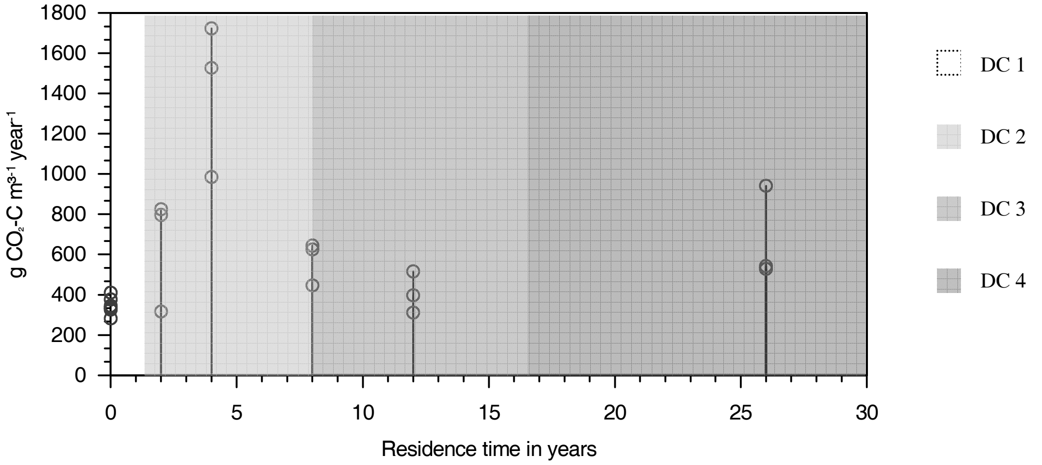

Figure 4. Annual CO_2-C emission of beech logs per residence time and decay class (explication of the decay classes s. Fig. 1)

The relatively high CO_2 emissions in decomposition stage 4 are also interesting. Here decomposition appears to occur in two phases. Once sapwood decomposes and passes by fragmentation into the humus layer, only the biological still active heartwood remains.

The CO_2 emissions from the woody debris amounted to 44 kg CO_2 ha^{-1} y^{-1} in total. This is less than the CO_2 emissions from the soil. In a beech forest 50 times more CO_2 is produced from the soil (2,3 t CO_2 ha^{-1} y^{-1}) (Brumme 1995).

4 Conclusions

For the management of woody debris in beech forests the following preliminary conclusions may be drawn:

To attain the large supply of woody debris in production forests that can be found in virgin forests would be associated with an unjustifiable loss of value because it would be necessary to pass the optimal phase.

The decomposition process is not linear. So it is not enough to count with volume data when estimating the role of woody debris in nutrient cycle and CO_2 balance. Information about stage of decay or residence time is also required. If one aim of the management is to count with woody debris of all decay classes at any time, the different duration of the 4 stages of decomposition must be considered.

The process of decomposition in healthy trees that have been felled does not differ from trees that have died naturally. Dead wood, created by felling sound trees would fulfil the same functions as woody debris of naturally fallen trees. The process of complete transfer of large beech woody debris into the humus layer under the climatic conditions in the Solling takes more than 30 years.

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Silvicultural interventions in young European beech (*Fagus sylvatica* l.) stands of Romania - a new approach

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Abstract

A research project on European beech silviculture in Romania has started back in 1999. Based on its main findings some preliminary conclusions can be drawn as follows:

- At early ages natural beech stands should be kept dense to allow for the formation of straight and pruned trees.
- Owing to high stand densities and frequency of defects the cleaning-respacing interventions should be of both positive and negative selection type favouring the best-quality trees.
- Future crop trees should be selected in the second half of pole stage when their social and qualitative differentiation is obvious. Such trees should be subsequently favoured by high intensity thinning from above in order to reduce the rotation age down to maximum 100-120 years and avoid the presence of a high proportion of *red heart*.

Keywords: *Fagus sylvatica* L., Stand density, Natural pruning, Cleaning-respacing, Correlation.

1 Introduction

European beech (*Fagus sylvatica* L.) is the most important forest species in Romania, where it covers over 1.95 million ha (about 30% of forestland). It is found in either pure or mixed stands (with sessile oak – *Quercus petraea* (Matt.) Liebl.– and other broadleaved species – *Carpinus betulus* L., *Fraxinus excelsior* L., *Acer pseudoplatanus* L., *Acer platanoides* L.*, Tilia* spp.) in the hill regions (Subcarpathians) and with Norway spruce (*Picea abies* (L.) Karst) and Silver fir (*Abies alba* Mill.) in the Carpathians.

European beech is regenerated naturally by seed following application of uniform shelterwood systems involving 2 to 4 cuts (preparatory, seeding, removal, and final).

Traditionally the tending silviculture of beech in Romania involves three different interventions (Milescu *et al*. 1967; Petrescu 1971; Constantinescu 1976; Anon. 1986; Giurgiu *et al*. 1989; Armã°escu 1990):

- 1-2 low-moderate intensity *weeding* in mixed European beech-sessile oak (*Quercus petraea* (Matt) Liebl.) forests (almost never necessary in pure beech stands) where especially pioneer species such as *Populus tremula* L., *Salix caprea* L. or *Betula pendula* Roth. are removed;
- 1-2 *cleaning-respacing* of low-moderate intensity (maximum 15 per cent by number of trees) in sapling-thicket stage;
- 5-6 *mixed thinning* of moderate intensity (from 15% by volume at 21-30 years down to 9% at 71-80 years, when application of thinning ceases).

This approach leads to relatively high densities (at least 200-250 trees/ha) at rotation ages reaching 100-120 years (sawn logs) and 140-150 years (veneer logs) when the proportion of abnormal coloration (*red heart*) is high and dramatically reduces the market value of logs.

Taking into account the importance of this defect as well as the rather small size of logs at rotation age (usually less then 50 cm) a research project was launched to provide information on some characteristics of young stands (e.g., density, natural pruning, forking, stability (slenderness index), mean diameter, mean height, etc.) that are closely related to the timing and intensity of silvicultural interventions (cleaning-respacing and thinning) carried out at young ages.

2 Materials and Methods

Since 1999, a long-term network of experimental blocks and individual plots (150, 400 and 500 sq.m. of size) has been established in five young (sapling and thicket stage) beech stands (sub-compartments 51, 57A, 59D, 97, and 99A) belonging to the Teliu and Braºov Forest Districts. All stands were naturally regenerated by seed following shelterwood systems and their mean age is 15 years (scpt. 99A), 20 years (scpts. 51, 57A and 59D) and 25 years (scpt. 97). Since establishment all stands have either been left untended (scpt. 99A) or tended by low-intensity cleaning-respacing removing the pioneer species as well as defective beech trees (especially wounded and forked). Because of their high density and complete canopy closure a series of cleaning-respacing has been performed in all stands since 1999 (1999 and 2002 in scpt. 97, 1999 and 2000 in scpt. 99A, 2001 in scpts. 51 and 57A, 2004 in scpt. 59D).

3 Results and Discussions

3.1 Stand density

Due to natural regeneration and no subsequent interventions or only of low intensity all stands have been extremely thick, with initial number of trees ranging between 5,470-7,900 trees/ha (scpt. 57A) and 23,700-29,600 trees/ha (scpt. 99A). These values of density are higher than those recommended by the Romanian (Giurgiu *et al.* 1972) yield tables under similar age (15-25 years) and site (yield classes II and III) conditions.

These very high densities make the access into stands as well as application of tending operations very difficult. Under such circumstances the opening of a network of silvicultural racks, even very expensive and time-consuming (i.e. 1-2 m wide, at maximum 10-20m spacing), as recommended in both Romania (Petrescu 1971; Anon. 1986) and abroad (Teissier du Cros (coord.) 1981; Brouillet 1991; Duplat and Roman-Amat 1996; Joyce *et al.* 1998), is compulsory.

The dimensional variation (in terms of diameters and heights) of European beech trees is very high and exceeds in all plots the coefficient of variation considered as normal for even-aged European beech stands (20-35% according to Giurgiu 1979). Such situation has been corrected in all experimental plots and blocks during the application of cleaning-respacing (values of coefficient of variation after intervention between 18 and 37%, as shown in Table 1).

Table 1. Statistical indicators of dispersion (variability) of diameters in scpt 99A, block II, in 2000 (before and after cleaning-respacing).

Statistical indicators	Plot 1 (P1)		Plot 2 (P2)		Plot 3 (P3)		Plot 4 (P4)	
	2000b*	2000a*	2000b*	2000a*	2000b*	2000a*	2000b*	2000a*
Mean diameter, cm	2.31	4.65	2.27	4.46	2.30	4.19	2.24	3.70
Variance	2.88	1.49	3.09	2.66	2.36	1.76	1.88	1.23
Standard deviation	1.70	1.22	1.76	1.63	1.54	1.33	1.41	1.11
Coefficient of variation, %	73.51	26.25	77.44	36.59	66.85	31.68	62.81	29.99

b* - before intervention; a* - after intervention

3.2 Silvicultural interventions

All silvicultural interventions, of *high* intensity (in all cases - with the exception of scpt. 97 in 2002 - over 40% by number of trees but reaching 87% in scpt. 99A, block II, plot 1), were aimed at reducing the stand density but keeping the canopy as closed as possible to help natural pruning. Therefore the type of cleaning-respacing was *from below*, both *positive* (protection of best-quality trees) and *negative* (removal of smallest and most defective – with cankers, logging wounds, bad pruning, forked, crooked, etc. - trees in the lower storey) selection (Fig. 1).

In addition the intervention was intended to reduce the percentage of very slender trees. This is an important but undesired effect of very high stand densities at early ages, feature of which many trees were indirectly affected (bent over or even broken) by the late and heavy snows. The effect of cleaning-respacing on the reduction of mean slenderness (stability) index (h/d) is shown in Table 2.

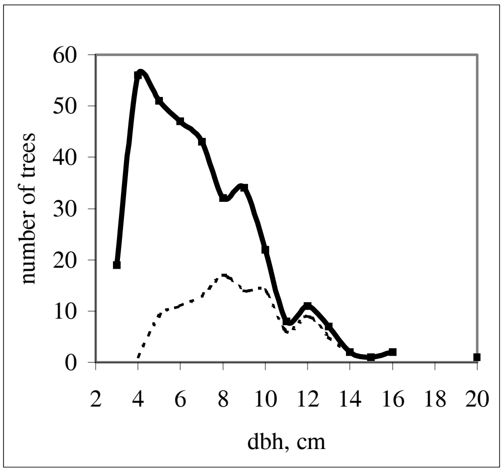

Figure 1. Distribution of number of trees by diameter classes before (continuous line) and after (dotted line) cleaning-respacing (1999) in plot 1, scpt. 97, Teliu Forest District.

Table 2. Variation of mean slenderness index of initial, extracted and remaining trees in the two blocks of scpt. 51.

		Block I			Block II		
		P1	P2	P3	P1	P2	P3
Mean slenderness index (h/d)	Before intervention	130	145	154	209	185	171
	Extracted trees	147	165	168	220	219	191
	After intervention	115	128	128	146	132	126

The stand density after intervention was reduced down to 1,100-3,100 trees/ha (scpt. 51), 1,800-3,500 trees/ha (scpt. 57A), 1,800-2,800 trees/ha (scpt. 59D), 2,500-4,500 trees/ha (in 1999) and 1,500-3,000 trees/ha (in 2002) in scpt. 97, as well as 7,100-9,700 trees/ha (scpt. 99A). These densities are lower than those recommended for Romanian beech forests (Giurgiu *et al.* 1972) but similar to those proposed for other European countries such as France (Teissier du Cros (coord.) 1981; Brouillet 1991; Duplat and Roman-Amat 1996) or Slovakia (Stefanèik 1977).

3.3 Natural elimination of trees

Owing to high density, quite many trees are dead or dying, the maximum proportion of such trees being found in the control plots established in scpt. 51, block I (11%) and scpt. 97 (12%) as compared to the minimum value of 3% in scpt. 51, block II. This rather low level of natural mortality of beech trees at early ages confirms the ability of species to survive and grow under dense conditions as stressed by the classics of Silviculture such as Bagneris (1878) and Boppe (1889).

3.4 Natural pruning

The effect of high stand density at early ages on natural pruning is shown in Table 3.

Table 3. Natural pruning of European beech trees in scpt. 97.

Naturally pruned height, over….m	Percentage of trees by pruning height classes, %			
	Plot 1		Plot 2	
	Extracted trees	Remaining trees	Extracted trees	Remaining trees
6	79.49	38.46	76.66	59.72
7	61.54	29.22	48.33	36.80
8	25.64	10.76	15.00	9.03

After the second intervention in this 25-year old stand, stand density decreased down to 1,540 trees/ha in plot 1 and 2,960 trees/ha in plot 2. The number of pruned trees over 6m was 500 trees/ha (i.e. 38.86% of 1,540) in plot 1 and 1,740 trees/ha (i.e. 59.72% of 2,960) in plot 2. Th number of pruned trees over 7m was 380 trees/ha in plot 1 and 1,060 trees/ha in plot 2. In case of pruned trees over 8m their number was 140 trees/ha in plot 1 and 260 trees/ha in plot 2. These figures show that the target proportion of individuals pruned over 7-8 m (2 veneer logs) has already been achieved therefore *the phase of natural pruning* has already been finished. As a consequence the subsequent thinning should focus on favouring the trees pruned at least 7-8 m of their bole and chosen as *future crop trees* based on three well-known criteria (vigour, quality and spacing).

In case of scpt. 99A (not shown in the above table) the proportion of trees pruned over 4 m is 32.67% (2,475 trees/ha) and of those over 5 m is 9.90% (750 trees/ha). There are no trees pruned over 6 m so the desired pruned height for the production of veneer logs has not been reached yet. In this case the stand should be still kept under dense conditions so that the natural pruning continues at high rates.

3.5 Correlation between different characteristics of European beech trees

Taking into account all sub-compartments some very significant correlation between the following European beech tree characteristics have been found:

- diameter at breast height (d.b.h) and mean crown diameter;
- diameter at breast height and d.b.h increment;
- mean crown diameter and d.b.h. increment (Table 4 and Fig. 2).

Table 4. Correlation coefficients between different characteristics of remaining trees in plot 1 and 2, scpt. 97 (2003).

Correlation between….	Values of coefficient of correlation in plot…	
	1	2
d.b.h.-mean crown diameter	0.635***	0.771***
d.b.h.–d.b.h. increment	0.745***	0.809***
mean crown diameter-d.b.h. increment	0.414***	0.616***

*** = very significant correlation

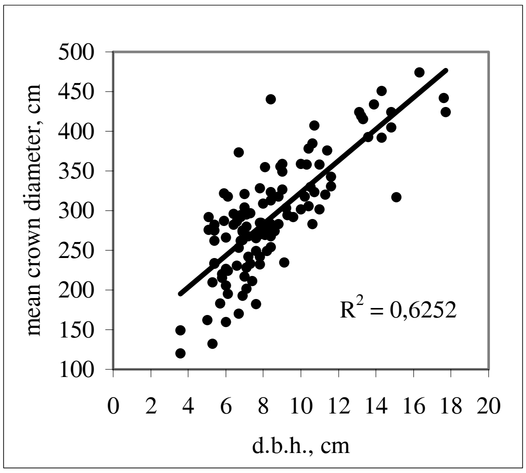

Figure 2. Correlation d.b.h.-mean crown diameter of remaining trees in plot 2, subcompartment 59D (2004)

These correlation suggest that the trees to be chosen as future crop trees should be not only the healthiest, defect-free and as evenly spaced as possible but also the most vigorous (the tallest, thickest, with wide annual rings – at least 4-5 mm - and no growth stresses (Polge 1973, 1980), with large and regular crowns). Owing to their obvious social and qualitative differentiation it is possible to select and mark such valuable trees no later than mid- pole stage such in the case of scpt. 97 (mean age – 30-35 years; mean diameter 14-15 cm; mean height 14-15 m). These trees will be treated independently (*individual tree silviculture*, *dynamic silviculture*) and subsequently favoured by *high intensity thinning from above* such as those proposed in France (Teissier du Cros (coord.) 1981; Brouillet 1991; Duplat and Roman-Amat 1996), Switzerland (Schütz 1998) or Ireland (Joyce *et al*. 1998).

Such approach is expected to allow for shorter rotations (no longer than 110-120 years) when theoretically the proportion of red heart is low and does not reduce significantly the market value of logs.

4 Conclusions

The paper has tried to outline the results of a research project on European beech silviculture started back in 1999. Even after a relatively short time some basic conclusions can be drawn as follows:

1. At early ages (sapling-thicket-beginning of pole stage) natural beech stands should be kept dense to allow for the formation of straight and pruned trees;

2. Owing to high stand densities and frequency of defects the cleaning-respacing interventions should be of both positive and negative selection type, favouring best-quality trees and removing defective ones (wounded, with cankers, bad pruning, forked, crooked, etc.);

3. Future crop trees (most vigurous, healthy, defect-free and evenly spaced) should be selected in mid-pole stage when social and qualitative differentiation of trees is obvious. Such trees should be subsequently favoured by high intensity thinning from above so that the rotation age can be shortened down to maximum 100-120 years, in order to avoid the presence of a high proportion of abnormal coloration.

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The early and heavy snowfalls, a major threat to the young European beech (*Fagus sylvatica* L.) stands

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Abstract

An early and heavy snowfall occurred in the surroundings of Brasov (east corner of Carpathian Mountains) in October 2003. It had provoked important and irreversible damages to the young (end of thicket-beginning of pole) European beech stands as follows:

- Under untended and very dense stand conditions the majority of trees (but mostly those tall and slender forming the lower part of canopy layer) are bent over.
- Under tended and differently spaced stand conditions many of the largest but defective trees (especially forked) were either split at the fork level or broken above or below forking. The percentage of bent over trees under such conditions is lower than in the untended parts of stand.

Keywords: *Fagus sylvatica* L., Snowfall, Bent over trees, Split trees, Broken trees

1 Introduction

Since a long time ago it is acknowledged that the snow can become very destructive when soon after the snowfalls the temperature rises so that the snow starts to melt, becomes heavy and sticky and can cause the bent over, split or breakage of young, mature or even old trees and stands (Boppe 1889). The most affected are the young and dense stands, with a continuous canopy cover and comprising thin and tall trees, with high slenderness indices *h/d*.

According to the literature conifers (pines - *Pinus* spp., spruces - *Picea* spp., firs – *Abies* spp) are among the most affected forest species but sometimes black locust (*Robinia pseudoacacia*), oaks (*Quercus* spp.), trembling aspen (*Populus tremula*), alders (*Alnus* spp.), willows (*Salix* spp.) are also affected (Dracea 1923; Fron 1923; Simionescu and Zeicu 1926; Anonymous 1949; Anonymous 1950, Tkacenco 1955)

European beech (*Fagus sylvatica* L.) is also considered as one of the species facing such problems, but only at early ages no later than pole stage. In this respect it is worthwhile mentioning the massive snowfall of 28 September 1885, devastating a pole-stage European beech stand, 53-years old, in the Sihlwald Forest (near the city of Zurich, Switzerland) (Jolyet 1916).

In Romania such accidents are not that common in the young stands even though the undesired effects of early and heavy snowfalls to the young European beech stands have been mentioned since a long time ago (Dracea 1923; Anonymous 1949; Anonymous 1950).

Under such circumstances, the aim of the paper is to underline the main characteristics of a massive early snowfall, occurring in the month of October 2003, as well as its effects to a young European beech stand located near the city of Brasov, Romania.

2 Materials and Methods

The research work regarding the effects of early and heavy snowfalls on a young European beech stand were performed in the sub-compartment # 51A, Management Unit VI Braşov, subsidiary of Braşov Forest District. It has an area of 12.6 ha and is located at about 940-1,000 m elevation, on a south-east-faced slope of about 15 degrees. The above stand consists of 100 % European beech trees, showing the following characteristics: mean age approximately 20 years, mean d.b.h. about 11 cm and mean height about 12 m. Two blocks (I and II) including four research plots each (3 experimental - P1, P2, and P3; one control – P4, 150 sq.m. each) were established back in 2001. Immediately after the establishment, cleaning-respacing interventions of various intensities were performed inside the six experimental plots.

The stand densities in the two blocks after the completion of these interventions were as shown in table 1.

Table 1. Remaining stand densities after cleaning-respacing in the two blocks.

Plot #	Number of trees per ha	Basal area, m^2/ha
	Block I	
1	1,067	11.43
2	2,400	17.34
3	2,400	15.95
4 (control)	6,666	35.32
	Block II	
1	1,266	7.80
2	3,133	23.04
3	2,266	17.43
4 (control)	8,332	27.89

According to Table 1, the stand density in the six experimental plots after intervention was reduced down to 1,067-3,133 trees/ha. As stressed in the second paper of these proceedings (Nicolescu *et al*. 2004), the above densities are lower than those recommended for European beech forests of Romania but similar to those proposed for other European countries such as France or Slovakia.

Owing to the *negative selection from below* performed into the two blocks, removing the most defective trees as well as those suppressed, tall and slender, prone to natural, non-forced bent over after intervention, the values of mean slenderness decreased considerably as shown in Table 2.

Table 2. Variation of mean slenderness index of initial, extracted and remaining trees in the two blocks and six experimental plots of scpt. # 51.

		Block I			Block II		
		P1	P2	P3	P1	P2	P3
Mean slenderness index (h/d)	Before intervention	130	145	154	209	185	171
	Extracted trees	147	165	168	220	219	191
	After intervention	115	128	128	146	132	126

Even after such high intensity interventions many slender trees remained untouched and the slenderness index of a few individual trees in these six plots showed values up to 160-170.

3 Results and Discussions

3.1 Weather conditions

In mid-October 2003 the air temperature in the surroundings of the research area dropped from low positive values to low negative ones (minimum -5.0 Celsius degrees). Such switch was combined with a 2-days period with rather massive snowfalls so that the snow layer reached the thickness of 33 cm. Immediately afterwards the temperature switched again to rather high positive temperatures up to 12.2 or even 15.8 Celsius degrees (Table 3).

Table 3. Weather conditions in the days (October 2003) before and after the occurrence of snowfalls (Poiana Brasov Meteorological Station – same local conditions as the research area).

Day	Air temperature (°C) at hour….				Air temperature (°C)			Snowfalls, cm	Thickness of snow layer, cm
	1	7	13	19	Mean	Max	Min		
16	1.0	- 0.5	3.9	2.5	1.7	4.5	- 0.7	4.0	
17	1.2	- 0.3	0.0	- 1.4	- 0.1	2.7	- 1.4	23.8	2
18	- 2.0	- 2.2	0.7	- 0.5	- 1.0	3.4	- 2.5	***12.8***	***33***
19	- 4.2	- 3.4	4.2	4.8	***0.4***	5.5	- 5.0	0.7	24
20	3.4	3.2	11.0	11.4	***7.3***	12.2	1.4	-	10
21	12.2	12.0	15.4	10.3	***12.5***	15.8	10.0	-	-

Under such very changing conditions the snow started to melt, became heavy and sticky and remained attached to the crowns of individual trees in the tended plots as well as to the continuous canopy of non-tended, control plots. Similar effects were also encountered in the stand surrounding the two blocks but as the stand and contained blocks look differently the data analysis will be carried out and subsequently shown independently.

3.2 Effects of snowfalls inside and outside the research blocks

Inside the two blocks the effects of snowfalls consist of bent over as well as broken trees as shown in Table 4.

Table 4. Effects of snowfalls inside the two blocks.

Plot #	Total number of trees	Bent over trees		Broken trees		Total affected trees	
		Number	%	Number	%	Number	%
			Block I				
1	16	3	18.75	3	18.75	6	37.50
2	36	7	19.44	2	5.56	9	25.00
3	36	19	52.77	-	-	19	52.77
4 (control)	85	63	**74.12**	3	3.53	66	**77.65**
Total	**173**	**92**	**53.18**	**8**	**4.62**	**100**	**57.80**
			Block II				
1	19	8	42.11	-	-	8	42.11
2	48	9	18.75	4	8.33	13	27.08
3	34	10	29.41	5	14.71	15	44.12
4 (control)	124	69	**55.65**	1	0.81	70	**56.46**
Total	**225**	**96**	**42.67**	**10**	**4.44**	**106**	**47.11**

As one can notice the proportion of *bent over trees* varies from less than 20 per cent up to 74 per cent. The proportion of such trees was minimal in plots with rather low densities such as plot 1 in block I but also in plots with higher densities such as plot 2 in block II. In both blocks the maximum proportion of bent over trees was encountered in the control plots, with very high densities forming a continuous canopy cover and not providing any access of snow to the ground floor.

The bent over trees were especially the smaller ones, located in the lower storey, as well as some of the trees in the upper storey, both of them with high slenderness indices.

In case of *broken trees* their proportion was not as high as the previous category reaching a maximum of only around 19 per cent. In two plots there have been no broken trees at all, with a mean value of broken trees around 4.5 per cent in both plots. In all conditions the broken trees consisted mostly of those forked and especially larger than the average trees in each plot.

Outside the two blocks the fieldwork was carried out in an area of about 2 ha, where cleaning-respacing were performed in 2000 as a practical exercise with the students of Faculty of Silviculture and Forest Engineering in Braşov. In October 2003, according to a rough estimation, the stand density was about 2,000 trees/ha.

The trees affected by the snowfall in the above area have to be split into two categories:

A. Broken trees (97 individuals)

B. Bent over trees (much more as detailed below and sometimes found in patches of various sizes).

Among the *broken* trees, 70 individuals (72.2 per cent) were *forked*, of which 74.2% with the fork occurring at heights lower than 6 m, the other 27 individuals (27.8 per cent) having straight and unforked stems.

The *forked trees* have to be again divided into some categories:

a. *Broken* ***at the forking height*** *= 18 trees (25.7%)*, of which:
- with both branches broken at the height of forking = 11 (61.1%)
- with one branch broken at the height of forking, the other left untouched = 5 (27.8%)
- with one branch broken at the height of forking, the other broken above forking = 2 (11.1%)

b. *Broken* ***below*** *the forking = 19 trees (27.1%)*, of which:
- 26.3% in the first 1 m below the forking
- 63.2% in the first 2 m below the forking
- 89.5% in the first 3 m below the forking

c. *Broken* ***above*** *the forking = 33 trees (47.2%)*, of which:
- with both branches broken = 14 trees (42.4%), of which 3 trees (9.1%) at the same height and 11 trees (33,3%) at different heights (21.2% with a difference of heights between the breakage points of less than 1 m and 12.1% with a difference of heights between the breakage points between 1 and 2m)
- with only one branch broken = 19 trees (57.6%), of which 89.5% in the first 3 m above the forking.

Individual or grouped bent-over trees occurred especially in the non-tended and very dense parts of the stand, where the majority of trees (but mostly those tall and slender forming the lower part of canopy layer) were badly affected by the heavy snowfall. Their percentage in such areas was much higher than in the tended areas no matter the intensity of intervention.

4 Conclusions and Recommendations

As detailed above when using a young European beech stand as a case study, the early and heavy snowfalls are able to produce very important damages that can jeopardise the future of such stands. Based on such undesired effects some conclusions and recommendations for the practical management of young European beech stands located in areas where early and heavy snowfalls are unavoidable can be drawn as follows:

1. Do not leave the stands (even in the sapling-thicket stage) dense and untended, even though the need for a good natural pruning is obvious. Such high densities will definitely lead to the production of tall and slender trees, with very high slenderness indices, which can be easily affected (***bent over***) by the early and heavy snowfalls.

2. Try to remove as many as possible forked trees because they will be probably ***broken or split*** by the heavy snowfalls. Such removal of the forked trees should be carried out as early as possible (no later than the beginning of pole stage, during the cleaning-respacing interventions).

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Extended abstract: Stand structure and development stages in two different forest communities of oriental beech (*Fagus orientalis* Lipsky) in Iran

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Abstract

Having more knowledge about development stages in different typs of virigin forests, could be a good guide for selecting and practicing proper silvicultural operations in managed stands. For this purpose, two natural forest communities of beech (*Rusco-Fagetum* and *Carpineto-Fagetum*) were selected and six sample plots, each 1 ha, were laid out in different development stages. This paper presents only the results of two plots of the initial stage in the studied stands.

Results indicate that the first stand is in the late initial stage and had a higher volume than the second stand, although the number of stem per ha doesn't differ significantly. In the studied stands, the highest proportion of stem number was calculated in the small size timber, whereas the highest volume was concentrated in the large size timber. The first stand was multi-layer and multi-age, while the second stand showed a two layer structure with beech in the upper- and hornbeam in the under storey.

Keywords: Caspian region, *Fagus orientalis* Lipsky, Structure, Development stage, Uneven-aged

1 Introduction

The oriental beech forests were discribed as uneven-aged with regeneration establishing in small sized gaps (Sagheb-Talebi and Schütz, 2002). Development stages have been already studied and described in different forest types in Europe (Leibundgut 1993; Parviainen *et al*. 1994; Korpel 1995; Emborg *et al*. 2000) and recently in Iran (Sagheb-Talebi *et al*. 2003; Mataji 2003). Almost all of them have emphasized on three main stages, namely initial, optimal and decay stages. In some literature differences have been made between development stage and phase. Leibundgut (1993) has more focused on study of mixture, storey, volume, crown cover and dynamic of development phases, whereas the studies of Korpel (1995) have more emphasized on bigger scales, called as successional stages.

This study is part of overall research project, which aim at describing of development stages in protected natural oriental beech forests. Taking into account the recent trends on close-to-nature (nature-based) forest management, the results could be used for selecting and practicing of proper silvicutural operations in different stages.

2 Materials and methods

2.1 Materials

The study was carried out in the unmanaged 4th district at the experimental forest (Kheiyrood) of the University of Tehran, which is located in Mazandaran province (Caspian region) at 51^{o}35' N and 36^{o}35'E. The study area is extended between 750 and 1750 m.a.s.l. with a mean annual precipitation of 1500mm. The most important forest associations of the region are *Rusco-Fagetum* and *Carpineto-Fagetum*. The soil type is forest brown soil and soil texture varies between clay-loam and clay. Soil pH varies between 5.2 and 7.7 in different layers and sites. Tree species contains beech (*Fagus orientalis* Lipsky), hornbeam (*Carpinus betulus* L.), maple (*Acer velutinum* Boiss.), alder (*Alnus subcordata* C.A.M.) and other broad leave species.

2.2 Methods

In two forest associations of Caspian region, *Rusco-Fagetum* and *Carpineto-Fagetum*, six sample plots each 1 ha (100x100m) were selected. Each forest association contained three plots with different development stages. All trees with dbh over 7.5cm were recorded and dbh and height of them were measured. In order to describe the horizontal and vertical structure of the stages, one transect (10x100m) was selected in each plot and the position of trees were assessed aditionaly.

This paper presents only the results of two plots of the initial stage in each forest association.

3 Results

3.1 *Rusco-Fagetum*

This was a beech stand composed of 347 stem ha^{-1} consisting of almost 80% beech, 9% hornbeam and 11% other species (table 1). Total basal area and total volume of the stand reached to 45.6 m^{2} ha^{-1} and 689.2 m^{3} ha^{-1}, respectively. Beech accounted for some 90% of basal area and volume of the stand. Figure 1 shows the frequency of trees in diameter classes, which indicates a muti-aged stand. It is obvious that the highest number of trees is distributed between dbh classes of 10 and 20 cm, while a few numbers of trees are distributed in dbh classes over 100cm up to 160cm. The highest number of trees was observed in the height class of 20m (Fig. 2).

Table 1. Stem number, basal area and volume of tree species in the initial stage of studied Rusco-Fagetum and *Carpineto-Fagetum* sample plots.

Tree species in	Number ha^{-1}		Basal area (m^{2} ha^{-1})		Volume (m^{3} ha^{-1})	
Rusco-Fagetum	N	%	m^{2} ha^{-1}	%	m^{3} ha^{-1}	%
Beech (*Fagus orientalis*)	279	80.4	40.6	89.0	624.1	90.6
Hornbeam (*Carpinus betulus*)	30	8.6	2.7	5.9	35.3	5.1
Maple (*Acer velutinum*)	27	7.8	1.6	3.6	21.6	3.1
Other species *	11	3.2	0.7	1.5	8.2	1.2
Total	347	100	45.6	100	689.2	100
Carpineto-Fagetum						
Hornbeam (*Carpinus betulus*)	198	62.5	11.6	35.3	143.3	31.6
Beech (*Fagus orientalis*)	82	25.9	17.1	52.0	252.3	55.6
Alder (*Alnus subcordata*)	16	5.0	1.8	5.5	24.0	5.3
Maple (*Acer velutinum*)	14	4.4	2.2	6.7	32.8	7.2
Other species **	7	2.2	0.2	0.5	1.4	0.3
Total	317	100	32.9	100	453.8	100

* contains Alder and Elm.
** contains Oak, Elm and Lime tree.

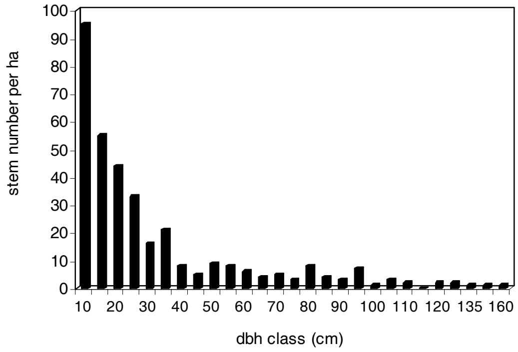

Figure 1. Frequency of stem number in dbh classes (*Rusco-Fagetum*).

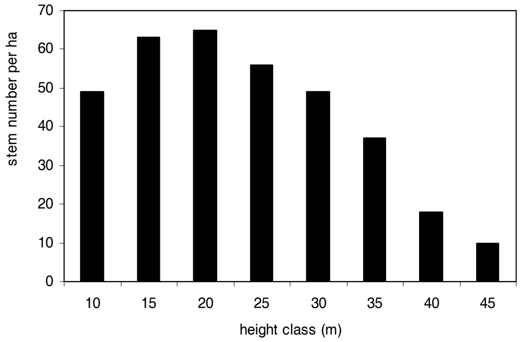

Figure 2. Frequency of stem number in height classes (*Rusco-Fagetum*).

3.1 *Carpineto-Fagetum*

This was a relatively young mixed beech stand composed of 317 stem ha^{-1} consisting of almost 26% beech, 62.5% hornbeam and 12.5% other species (table 1). Total basal area and total volume of the stand reached to 32.9 m^2 ha^{-1} and 453.8 m^3 ha^{-1}, respectively. Beech accounted for some 52% of basal area and 55.6% of volume, whereas hornbeam accounted for 35.3% of basal area and 31.6% of volume of the stand. Figure 3 shows the frequency of trees in diameter classes, in which the highest number of trees is distributed between dbh classes of 10 and 20 cm, while a few numbers of trees are distributed in dbh classes between 70 and to maximum 120cm. Also the highest number of trees was observed in the height class of 20m (Fig. 4).

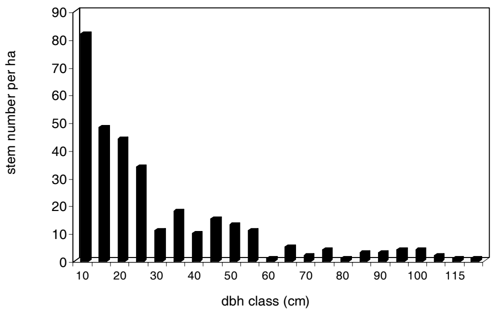

Figure 3. Frequency of stem number in dbh classes (*Carpineto-Fagetum*).

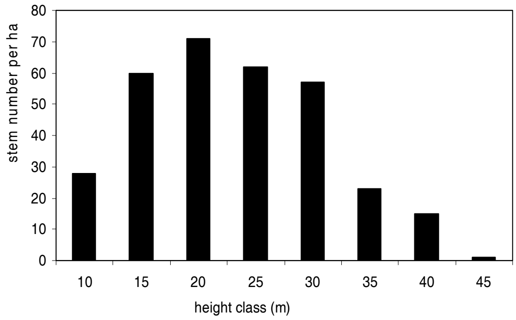

Figure 4. Frequency of stem number in height classes (*Carpineto-Fagetum*).

4 Discussion and Conclusion

The studied stand in the Carpineto-Fagetum association shows more stem number in the lowest dbh and height classes, which indicates the strong potential of hoernbeam regeneration in occupying the area after falling of trees in decay stage. On the contrary, the stem number of trees at dbh and height classes in the Rusco-Fagetum stand determines a slow process of beech regeneration. Figure 5 shows the vertical and horizontal profile of the beech stand in *Rusco-Fagetum* association. The spatial pattern of beech and hornbeam and the differences in height classes as well as regeneration in the small gaps are obvious in this figure.

Like other investigations of Korpel (1995) in Europe and of Sagheb-Talebi *et al*. (2003) in Iran, the highest number of trees were measured in the lowest dbh classes (small timber size ≤35cm), whereas the highest proportion of volume was calculated in the highest dbh classes (large timber size ≥55cm).

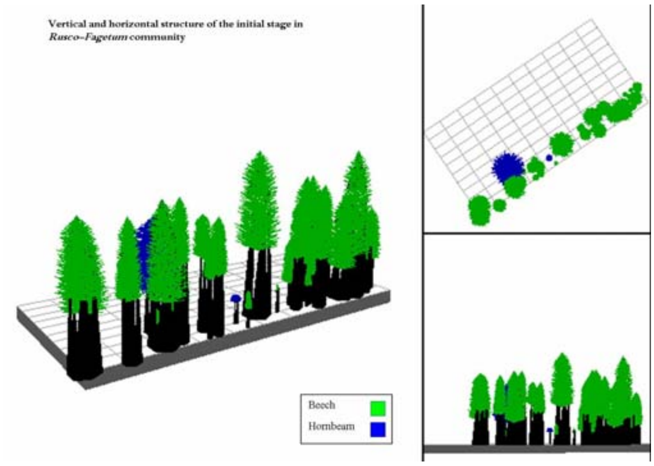

Figure 5. Vertical and horizontal structure of the studied initial stage in Rusco-Fagetum.

Understanding of species behaviour and growth rate of them as well have having knowledge about natural development and succession of undisturbed stands could be a good guide for silviculture experts to manage different forest stands in different development stages and to practice close to nature oriented suitable silvicultural operations. Establishing of regeneration within gaps with suitable area and keeping uneven-ageness (Sagheb-Talebi and Schütz, 2002) as well as looking for a rich mixture of trees could be our next goals to achieve the sustainable managment of natural forest stands.

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Variation of humus forms and nutrient properties in pure and mixed beech stands in north of Iran

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Abstract

In this research, humus forms and their variation in pure and mixed beech (*Fagus orientalis*) stands in a part of Chelir district at Kheiroodkenar forest with a bout 700 ha area has been studied. To identify and describe humus forms we used methods described in Green *et al*. (1993), that is based on morphological characteristics. In addition all samples were analyzed in 11 chemical properties (pH, total C, total N, C/N ratio, (Ca + K), K/Ca, $CaCO_3$, moisture, silt, sand and clay) and then all of these properties were estimated for each humus form group and each forest type.

A multivariate analysis (PCA) was used to examine correlation between ectorganic soil layer and humus forms and also with forest types. We used regression analysis to identify possible linear correlations between chemical properties, too.

According to this study, two humus form orders, Mulls and Moders, and six groups were identified. 87 percent of the samples were Moder and other samples were Mull. The result of chemical properties analysis confirmed all morphological similarities and differences between all humus forms and all forest types. These results indicate that morphological properties of the horizons and humus forms are related to the chemical properties and also, tree species have a strong effect on humus form and site chemical properties.

Furthermore, some of these properties represented a good variation in relation to the tree species such as: total N, C/N ratio, exchangeable (K & Ca) and (Ca + K), but the others like pH and total C didn't represent patterns which were expected.

1 Introduction

Soil organic matter has various roles in forest ecosystems. According to many studies, the most important ones are maintaining soil productivity and its role as a source or sink for atmospheric carbon (Fisher and Binkley, 2000). It has a deep impact on the physical, chemical and especially biological properties of the soil, although it consists of a small portion of most forest soils. Many soil organisms gain their energy by decomposing soil organic matter. The quality and quantity of organic matter in the soil determine the rooting zone temperature, aeration, moisture, and nutrition.

Humus form, which is another term of forest floor, has an important role in carbon and nutrient sink and resource. As such, they are an important factor for site productivity. Theses characteristics and the intimate relationship among humus forms, vegetation, and soil make them one of the principal components of the principal components of terrestrial ecosystems (Green *et al.* 1993).

It is long known that there are differences in the humus beneath various forest types and perhaps beneath the same forest types growing on different soils (Wollum, 1973). But little attention has been paid to the variation of humus forms and their morphological and biotic characteristics due to the variation of tree species accompanying the major species. These results would be helpful for forest managers in making better decisions of choosing the composition of tree species for several purposes.

Since Green *et al.* (1993) method is comprehensive, sufficiently detailed taxonomic differentiae, based on readily observable morphological properties and has well developed hierarchical structure, it has been used as the basis for humus form identification.

In this research we tried to identify humus forms existing in beech (*Fagus orientalis*) forests and the main goal of present study was to figure out the probable relationship between morphological, nutrient and biotic properties in pure and mixed beech stands.

2 Materials and Methods

2.1 Study sites

Beech forests are one of the most important and richest parts of Hyrcanian forests lying on the northern slopes of Alborz mountain ranges, adjacent to the Caspian Sea coasts in north of Iran. The study site with about 900 ha is located in the middle of this area within Kheiroodkenar Research Forest of Tehran University beside Noshahr city. The range of altitude in this area is between 750 to the 1450 m a.s.l.

Mean annual temperature in this natural unmanaged temperate forest is around 15 ˚C, respectively. While the average annual rainfall is estimated to be around 1300 mm, high number of foggy days is particularly effective in supply water to the soil and developing beech forests. The soils of this region are usually acidic located in Alfisol order, however he biotic activity in organic matter is considerable (Sarmadian and Jafari, 2001).

Because of specific physiographic condition and various microclimates, many different ecosystems are existed in this district. Dominant forest types in this region consist of pure and mixed beech (*Fagus orientalis*) forests and mixed oak (*Quercus castaneifolia*) forests. *Taxus baccata, Ulmus Glabra, Ulmus carpinifolia, Fraxinus excelsior* and *Ceracus avium* are some of the valuable tree specious in this area.

2.2 Sampling and analysis

Kuchler physiognomic method (1988) was used for forest classification. Then pure and mixed beech stands, which beeches with more than 50% crown canopy density were dominant in all of them, were separated from other types (table1). They cover around 360 ha of this region.

Table 1: Six types of beech forests studied for humus form.

Forest type	Canopy density of beech (%)	Range of altitude (m a.s.l.)
Pure beech	>90	950-1750
Beech-hornbeam	70	800-1400
Beech-maple	70	850-1500
Beech-alder	65	1050-1650
Beech-maple, alder	65	1000-1550
Beech-hornbeam, alder	65	1100-1400

Landform units (Naveh and Leiberman, 1984) were used to humus form sampling in each forest types, since rapid transition of physionomic factors like slope and aspect in small scales was observed in this area. 100 m altitude classes, 20% slope classes and five major aspects, north, south, west, east and without aspect was selected to make the landform map. 76 sample plots were randomly identified after overlapping this map on the forest type's map in each homogenous site.

In each sample plot, all master and subordinated horizons were identified using Green *et. al.* (1993) method and collected for chemical analysis. Three master horizons of organic layer, L, F & H, Ah and the upper 15 cm of the mineral soil, called A1 (Habibi-Kaseb, 1991), were studied. Morphological properties used for identification of humus forms consist of sequence and thickness of horizons, color, structure, consistence, character and root's size and abundance. Soil fauna and fungal mycelia as part of soil flora were also studied. All samples were analyzed for pH, total carbon, total nitrogen, C/N ratio and exchangeable potassium and calcium in all layers and K/Ca ratio, (K+Ca), texture and moisture percentage in mineral horizons.

PCA was used to examine correlation between ecto-organic layer nutrient properties and humus forms and also forest types. Regression analysis was also used to identify possible linear correlations between some of chemical properties.

3 Results and discussion

3.1 Morphological properties

Based on similarity in humus form morphological properties, 76 samples were stratified into 6 groups: Group 1: Lv, Fa, Fz, Hr or Hz (n = 22), Group 2: Lv, Fz, Hr or Hz (n = 19), Group 3: Lv, Fz or Fa, (Hz), Ah (n = 10), Group 4: Lv, Fa, Hr (n = 12), Group 5: Lv, Fa, Fz, Hz or Hh (n = 9), and Group 6: Lv, Fz, Hr, Ah (n = 4). The information about the thikness of horizons in these groups is presented in table 2.

Table 2. Range, mean and standard deviation (SD) of thickness (cm) of organic horizons in the six groups of study humus forms

Horizon		Group1	Group2	Group3	Group4	Group5	Group6
	Range	2 - 4	1.5 – 4.5	1.5 – 3.5	1.5 – 3.5	2 - 5	1.5 - 4
L	Mean	3.2	2.4	2.3	2.5	3.1	2.8
	SD	0.72	0.83	0.83	0.76	0.95	1.26
	Range	2-4.5	0.5-4	1-2.5	1-5	0.5-3.5	3-3.5
F	Mean	3.2	1.7	1.8	2.2	2.1	3.3
	SD	0.66	0.87	0.44	1.13	0.90	0.29
	Range	0.5-1.5	0-1.5	0-2	0.5-1.5	3-5	0.5-1.5
H	Mean	0.6	1.1	1.6	0.8	3.5	1.0
	SD	0.26	0.22	0.48	0.40	0.65	0.71
	Range	-	-	2-4	-	-	0.5-1.5
Ah	Mean	-	-	3.1	-	-	1
	SD	-	-	0.79	-	-	0.5
	Range	4.5-9.5	2-6	3-7	4-9.5	6-12	6-8
LFHAh	Mean	6.6	4.3	4.8	5.6	8.7	6.8
	SD	1.19	1.28	1.52	1.71	1.89	1.04

On the basis of morphological properties, group 5 had the most well- developed root system. Group 3 represented the most fauna activity and an opposite trend was observed in group 1 and 4 with the least activity. Furthermore, most of these characteristics such as horizons' sequence, thickness, structure, consistence and also root and fauna activities were similar in both group 1 and 4, except for the presence of a thin (1 – 1.5 cm) Fz horizon in group 1. So, we can put them in one group.

The most important character in group 3 is the presence of Ah horizon with ≥2 cm in thickness (table 1). In group 5, the thickness of organic layers was more than other groups (6 –12 cm) and also the thickness of Hz layer was considerable (3 – 5 cm). As a result of slow decomposition of beech litter, in 78% of the samples F horizon contains more than 50% of F+H, however it's not too thick.

According to the taxonomic classification of Green et al. (1993), the samples of group 1 and 4 were identified as Mormoder. In this group the mean thickness of F+H>2 cm, the dominant Fa layer contains more than 50% of F horizon and fauna activity is few. Samples in group 3 were identified as Vermimulls. The total thickness of F and H horizons is ≤ 2 cm. They have an Ah horizon with more than 2 cm thickness, a granular structure and common to abundant root and fauna activity. In the samples of group 5, the total thickness of F+H is more than 2 cm and fauna activity is common, so they are considered as Leptomoders. Samples of group 6 had different condition. They were observed under the influence of excessive moisture so the Hh layer had a greasy character. The combined thickness of F and H horizons was ≤ 2 cm and Ah>2 cm. Group 6 was identified as Hydromoder. Identification of group 2 was difficult, based on this method. Samples in this group had some characteristics between Mulls and Mullmoders. The combined thickness of F and H horizons is less than 3 cm and H horizon's thickness is less than 1 cm if it was present. In the other hand, they don't have Ah horizon. The roots were few in organic layer but common in A1 horizon. The fauna activity was common, although the A1 horizon has dry and firm structure.

3.2 Nutrient properties

Principal component analysis (PCA) was used to study the correlation between nutrient properties and humus form groups (table 3).

Table3. Means of selected chemical properties in the six groups of studied humus forms.

property	Group 1 Mormoder	Group 2	Group 3 Vermimull	Group 4 Mormoder	Group 5 Leptomoder	Group 6 Hydromoder
LFH PH	5.72	5.73	5.63	5.57	5.52	5.97
A1 pH	4.93	5.11	5.00	4.76	4.79	4.80
LFH C/N	30.46	27.27	28.34	30.52	27.67	27.83
A1 C/N	11.88	12.35	11.06	11.00	12.27	10.27
LFH tC	43.73	42.90	40.36	43.12	41.95	43.38
A1 tC	3.30	4.03	4.09	3.10	4.19	3.10
LFH tN	1.49	1.69	1.42	1.46	1.61	1.58
A1 tN	0.29	0.33	0.38	0.30	0.34	0.30
LFH K	96.77	124.18	83.08	112.32	85.55	104.89
A1 K	17.41	19.00	13.29	16.05	10.86	14.94
LFH Ca	88.64	86.89	86.00	83.33	86.46	94.33
A1 Ca	29.70	43.56	46.22	26.36	28.75	46.67
LFH K+Ca	185.41	211.06	155.24	195.66	172.01	199.22
A1 K+Ca	47.11	62.55	59.51	42.42	39.61	61.60
LFH K/Ca	1.09	1.43	0.97	1.35	0.99	1.11
A1 K/Ca	0.59	0.44	0.29	0.61	0.38	0.32

The first three axis of the PCA ordination (figure 1) accounted for 77% of the total variance. The first axis, which accounted for about 36% of the variance is described with C/N, tC, tN, Ca in L horizon, tN, K in F horizon , C/N, tC, K, K+Ca in H horizon and tN, Ca, K/Ca, K+Ca and in A1 layer (Table 4). So, the first axis introduces organic layer productivity with nutrient elements of the soil. The second axis accounted for about 27% of the total variance and was related to the properties of lower horizons especially physical properties like: C/N, tC, tN, sand and clay in A1 layer, C/N, K+Ca, in F layer, Ca in H layer. The third axis which accounted for about 16% of the total variance was related to the K, K+Ca in L layer and pH in A1 layer.

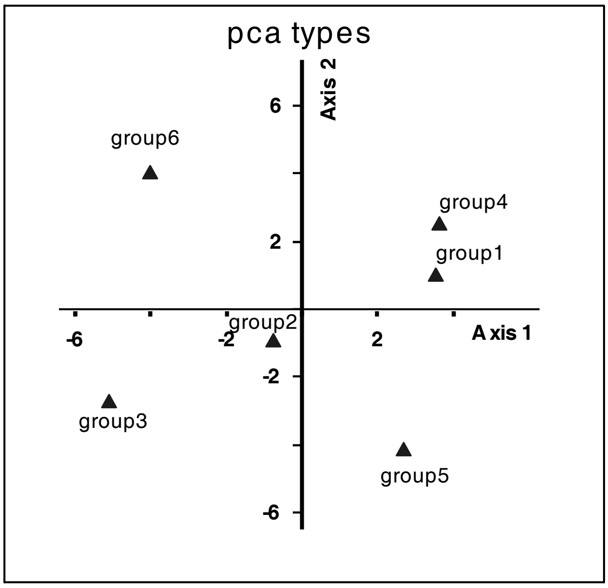

Figure 1. Ordination of humus form groups along the first two axes of PCA on 34 humus form properties (table 4).

Table 4. Correlations of nutrient properties (L, F, H, A1) with the first three axes of PCA in relation to the humus forms.

property	Axis 1	Axis 2	Axis 3
L C/N	**0.94**	0.06	-0.23
F C/N	-0.05	**0.75**	-0.47
H C/N	**-0.74**	0.23	-0.54
A1 C/N	0.54	**-0.62**	0.48
L tC	**0.94**	0.12	-0.09
F tC	**0.83**	0.19	-0.16
H tC	**0.75**	-0.58	0.04
A1 tC	-0.26	**-0.95**	0.18
L tN	**-0.79**	-0.13	0.57
F tN	**0.59**	0.33	0.02
H tN	**0.63**	**-0.59**	0.48
A1 tN	-0.63	**-0.71**	-0.08
L K	0.15	0.16	**0.75**
F K	**0.78**	0.13	0.51
H K	**0.59**	0.15	-0.31
L Ca	**-0.62**	-0.28	-0.42
H Ca	0.25	**-0.85**	0.45
A1 Ca	**-0.97**	0.04	0.22
A1 K/Ca	**0.86**	0.43	0.07
L K+Ca	0.12	0.34	**0.83**
F K+Ca	0.47	**0.86**	-0.04
H K+Ca	**0.92**	0.00	0.31
A1 K+Ca	**-0.85**	0.19	0.39
silt %	**0.81**	-0.35	-0.32
sand %	-0.36	**-0.65**	-0.18
clay %	-0.38	**0.80**	0.40

Table 5. Pearson and Kandall correlations with ordination axes for humus forms.

	Humus form	Axis 1 (r)	Axis 2 (r)	Axis 3 (r)
Group 1	Mormoder	**-0.65**	-0.2	0.50
Group 2		-0.3	0.19	**-0.68**
Group 3	Vermimul	**0.76**	0.42	0.43
Group 4	Mormoder	**-0.65**	-0.46	0.00
Group 5	Leptomoder	-0.5	**0.7**	-0.23
Group 6	Hydromoder	**0.60**	**-0.66**	-0.15

Location of groups in two – dimentional ordination in figure1 and table 5 clearly shows the similarities between group 1 and 4. Some of properties studied in this research such as pH and total carbon didn't present a significant variation in relation to the variation of humus forms, however a considerable relationship was found between variation of humus forms and total N, C/N ratio, exchangeable K and Ca and (K+Ca) .

The correlation between forest types and nutrient properties was also studied by PCA method. The first three axis of PCA ordination was accounted for 80% of the variance, 36, 27 and 60 percent respectively (Figure 2). The first axis has the most proportion of this variation is described with pH, C/N, tN, K and (K+Ca) in L horizon, C/N and (K+Ca) in F horizon, Ca and (K+Ca) in H horizon and tC, tN and (K+Ca) in A1 horizon (table 5). As a result the first access is described with organic layer productivity with nutrient elements of the soil. The second axis is related to pH, K and Ca in F horizon, tC and K in H horizon, K, Silt percent and moisture percent in A1 horizon. The third axis is described with tC in L horizon, tN in F horizon, C/N in H horizon and clay percent in a1 horizon.

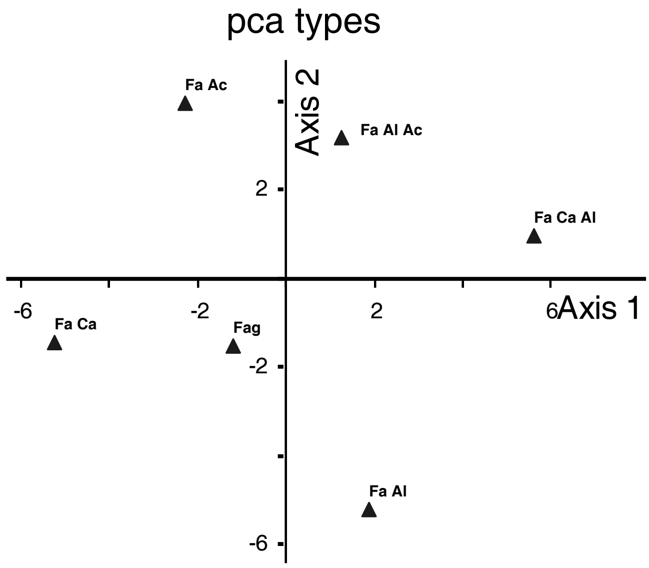

Fig. 2. Ordination of beech forest types along the first two axes of PCA on 34 humus form properties (table 5). (Fag: pure *Fagus* type, Fa Ac: mixed of *Fagus* and *Acer*, Fa Al: mixed of *Fagus* and *Alnus*, Fa Ca: mixed of *Fagus* and *Carpinus*, Fa Ca Al: mixed of *Fagus* with both *Carpinus* and *Alnus*, Fa Al Ac: mixed of *Fagus* with both *Alnus* and *Acer*).

In fact, second and third axes are described with base cautions and physical properties of the soil. In other word, caution exchanging, nutrient storage in soil and changing of organic to mineral form of these elements are strongly correlated to the physical properties of the soil. According to this analysis pure beech stands have the least condition for the composition of organic matters and humification and it doesn't show any relationship with any of those axes.

Most of humus forms in these stands are Moder. The best condition of humification and biotic activities was observed in *Fagus- Carpinus, Alnus* and *Fagus-Acer, Alnus* stands. Perhaps it is the results of hornbeam, Alder and maple presence which has more nitrogen in the litter. In Fagus-Alnus type pH of A1 horizon is lower than the others. As a result, fungal mycelia distribution is common, whereas in *Fagus-Acer* type the pH of A1 horizon increases, so biotic activities, mineralization and humification increases too and humus forms of this forest type are more active.

In another part of this research regression analysis was used to examine the relationship among chemical properties. In these beech stands, C/N ratio's correlation with tC is low, whereas its correlation with tN is considerable (Fig.3 and Fig.4). In mineral layer, R^2 of regression relationship between C/N and tN and tC is 0.93 and 0.01 respectively.

Table 5. Correlations of nutrient properties (L, F, H, A1) with the first three axes of PCA in relation to the forest types

property	Axis 1	Axis 2	Axis 3
L pH	**0.79**	0.2	-0.47
F pH	-0.65	**0.72**	0.24
L C/N	**-0.78**	-0.34	0.08
F C/N	**-0.73**	0.43	-0.52
H C/N	-0.16	-0.04	**-0.7**
L tC	0.38	0.21	**-0.73**
F tC	-0.1	0.52	**-0.63**
H tC	-0.5	**-0.74**	-0.1
A1 tC	**-0.76**	0.31	0.35
L tN	**0.79**	0.49	-0.13
F tN	**0.61**	-0.37	**0.69**
A1 tN	**-0.82**	0.36	0.31
L K	**0.77**	-0.39	0.21
F K	0.35	**-0.87**	0.04
H K	-0.46	**-0.78**	-0.21
A1 K	-0.58	**-0.78**	-0.17
L Ca	0.36	**0.87**	0.23
F Ca	-0.02	**0.9**	0.28
H Ca	**-0.89**	0.01	0.27
A1 Ca	**-0.6**	**0.63**	0.22
L (Ca+K)	**0.9**	-0.14	0.17
F (Ca+K)	**0.71**	-0.54	0.19
H (Ca+K)	**-0.82**	-0.42	0.24
A1 (Ca+K)	**-0.89**	0.25	0.14
Silt %	0.44	**0.72**	-0.17
Clay %	-0.04	-0.15	**-0.73**
Moist %	**-0.69**	**-0.66**	0.15
CaCO3%	0.11	0.35	**0.65**

Table 6: Pearson and Kandall correlations with ordination axes for forest types

Forest type	Axis 1 (r)	Axis 2 (r)	Axis 3 (r)
Pure beech	-0.28	0.31	-0.11
Beech - hornbeam	**-0.85**	0.21	-0.36
Beech - maple	-0.28	**-0.78**	0.13
Beech - alder	0.26	**0.80**	0.47
Beech - alder, maple	0.21	**-0.61**	0.53
Beech - hornbeam, alder	**0.84**	-0.05	-0.53

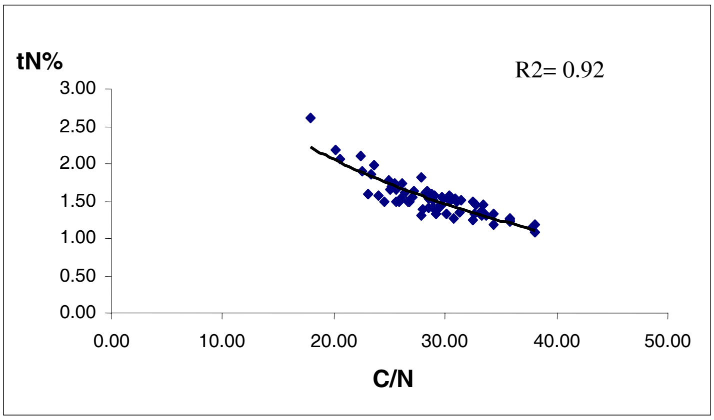

Figure 3: Regression relationship between C/N and tN in organic horizons

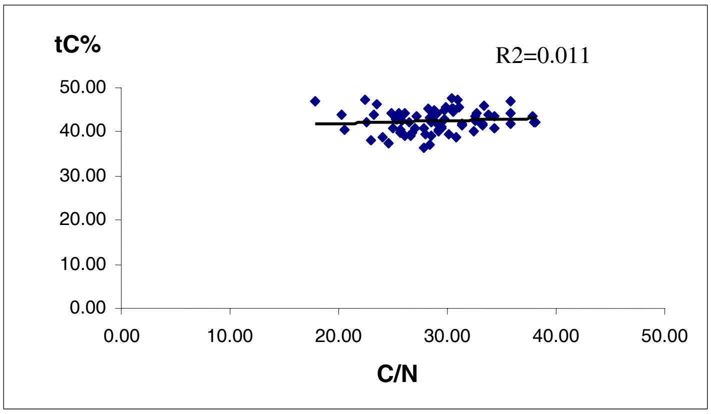

Figure 4: Regression relationship between C/N and tC in organic horizons

4 Conclusions

Decomposition speed in beech forests, which beeches are dominant, of Iran is slow, because Moders contain 87% and Mormoders 43% of the whole area. Although the range of pH in the first mineral layer was low (range: 4.1 - 5.7, mean = 4.9, SD: 0.3), it's not the main reason for slow decomposition. Physical properties of the soil and nutrient properties of the organic matter are the most important factors in decomposition speed of beech stands.

In Areas in which beeches are dominant, total nitrogen is a good indicator of forest productivity and it clearly shows a good variation in relation to the composition of tree species. As a result, managers can raise productivity of beech forests by increasing the number of species which have more amount of nitrogen in their litter like alder or ash.

There isn't any relationship between beech forest types and humus forms. In other word, various kinds of humus forms from Mull to Moder can exist in beech forests. It depends on environmental condition such as soil physical characteristics, light etc. and tree species composition.

Almost all morphological properties of subordinated horizons and humus form groups described by Green *et al*. (1993) were observed and confirmed by nutrient properties analysis; however there were some imperfections in identification of humus forms with characteristics between Mors and Moders and also in Mulls. So, Green *et al.* (1993), method is a useful method for humus forms studies.

Since, there is a close relationship between morphological and nutrient properties, humus form is a good indicator of site productivity.

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Alteration Process of an Uneven-aged Oriental Beech Forest after Shelterwood Fellings

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Abstract

Alteration process a three-storied uneven-aged oriental beech (*Fagus orientalis* Lipsky) forest with shelterwood system aim was investigated in north of Iran. For this intent, 40 circular sample plots of 1000m^2 occupied by ingrowth and advance regeneration were randomly chosen in a 40-ha stand, where the first shelterwood fellings was accomplished in past 30 years. In the plots, variety and frequency of naturally regenerated species as well as basal area were recorded at different growth stages. The results demonstrated that after a 30-year period, the aim of shelterwood system, which is indeed creating a regular even-aged one-storied forest, was not yielded. In contrast, the research area was remained as an irregular uneven-aged two to four-storied forest, owing to occurrence of recruitments, retaining advance growths and mature trees as well as caution in marking small and large pole groups on sharp slopes.

Keywords: Advance regeneration, Alteration process, Oriental beech (*Fagus orientalis* Lipsky), Shelterwood fellings, Structure, Uneven-aged forest

1 Introduction

Caspian forests with an area near to 2 million ha., in length of 800 Km, is situated between –20 m and 2200 m from a.s.l. in north of Iran (south of Caspian Sea). Main tree species of these forests are including oriental beech (*Fagus orientalis*), oak (*Quercus castaneifolia*) and hornbeam (*Carpinus betulus*), depending on the site are accompanied with *Acer velutinum*, *Tilia cordata*, *Fraxinus excelsior*, *Prunus avium* and *Alnus subcordata*. Since four decades ago in forest management plans shelterwood system has been implemented in stands of beech and also oak. Recently, in most of stands, shelterwood system has been replaced by selection system, owing to some technical reasons (Sagheb-Talebi *et al*., 2002). A number of reports related to effect of shelterwood system on regeneration condition of beech stands were made by Iranian researchers. Taheri-Abkenar (1993) in his evaluation shows that at the end of a 30-year period, after fourfold fellings, 75% of the forest area was of insufficient regeneration. On the other hands, Biglar-beygi (1985, unpublished) mentions that prosperity of shelterwood system is satisfactory if 60% of the project area is occupied by ingrowths. Marvi-Mohadjer (2001) declares that due to topography restrictions shelterwood system is not an accepted method for the Hyrcanian mountain forests. Amani and Hassani (1998) believe that the marking and exploitation problems are the reasons for the natural regeneration deficiency in stands managed with shelterwood goals. Espahbodi and Mohammad-Nejad (2001) demonstrate that unsuitable secondary thinning felling was caused to invade berry (*Rubus fructicosus*) in gaps. The current paper is aimed to evaluate dynamics process of an irregular uneven-aged beech stand managed with objectives of shelterwood system since 3 decades ago in north of Iran.

2 Materials and methods

The experimental forest is a 226 ha area between longitudes 53° 42′ 25″ and 53° 42′ 50″ and latitudes 39° 38′ 35″ and 39° 39′ 06″. Minimum altitude is about 1250 m and the maximum 1450 m. The slope inclination with the majority of 20-30% ranges from 2% to 65%. Climate is humid with cold winters, whereas the site is covered by snow four months (November-February). Growing season takes about 5 months (May-September) and vital drought period with 30-45 days mostly occurs in mid-summer. Mean annual rainfall is 1400 mm and mean annual temperature is 10.4 °C. Dominant tree species is oriental beech, appeared as *Carpino-Fagetum* association.

For doing this research, in a 40-ha stand of this forest where 30 years was backed from the first shelterwood fellings, with sampling density of 10%, 40 circular plots of 1000 m^2, occupied by ingrowths and advance growths (d.b.h < 30 cm) were randomly chosen. In the sample plots, firstly, basal area, variety of species, frequency at different growth stages (seedling, sapling, thicket and pole) and quality of species at juvenile phase were recorded. Then primary structure and present structure of forest were compared. Typology and structure of stands created after fellings were evaluated, too.

3 Results

The data analysis demonstrated (Table 1) that totally in beginning of investigation 49.3% of frequency, 54.5% of basal area and 58.4% of standing volume allocated to beech, while the shares for hornheam was 36.5%, 37.7% and 23.0%, respectively. At the end of the research period the attributes increased respectively to 82.5%, 73% and 71% for beech and reduced to 10.5%, 17% and 11% for hornheam. In reality, with increased beeches after fellings average basal area of individuals decreased, exhibiting the presence of young beech stands. Generally, before cuttings forest type was dominated by beech and hornbeam but after final cutting it was altered to pure beech. It is noteworthy that at the end of the period approximately one-fourth of the standing volume (120 m^3/ha.), mostly including beech, was retained in the forest. A quantity of stocking was laid on sharp steep where not any cuttings were executed during the period. Likewise, in scattered parts of the forest mature small groups as well as advance growths never were marked. Besides that, in most of forest area, where removal felling was operated 1-30-yrs old beeches were appeared.

Table 1. Characteristics of the species before felling and after felling in the study site

Species	Before felling			After felling		
	Frequency (%)	Basal area (%)	Volume (%)	Frequency (%)	Basal area (%)	Volume (%)
Fagus orientalis	49.3	54.5	58.4	82.5	73.0	71
Carpinus betulus	37.7	36.5	23.0	10.5	17.0	11
Alnus subcordata	4.2	4.9	8.4	3.5	6.2	6
Acer velutinum	3.8	2.8	9.2	2.0	2.3	8
Other broalleaved species	5	1.3	1.0	3.5	1.5	5

3.1 Forest structure

Fig. 1 illustrates distribution of d.b.h. classes in primary condition (before felling) and secondary condition (after felling). In reality it indicates that at the end of the period study site was maintained as uneven-aged structure. On the other hands, it can be stated that, otherwise the shelterwood objectives, forest was not directed towards homogenous even-aged stands. The Fig. 1 also implies that aged groups were decreased and by contrast, thickets, small and large pole groups of 15-40 cm in d.b.h. were increased. In addition, a great quantity young individual (< 15 cm in d.b.h.) was added to forest. However forest structure did not differ chiefly and still remained as uneven-aged.

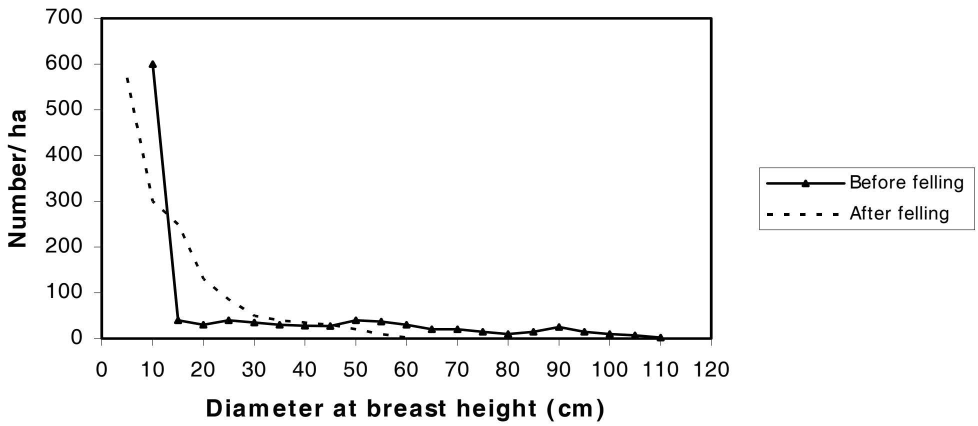

Fig. 1. Frequency of d.b.h. classes of forest trees in the study site before and after felling

3.2 Stands typology

Though the present forest structure is exhibited as uneven-aged, by further survey of sample plots throughout the forest, different typology forms with even-aged and uneven-aged structures can be considered. In fact by integration of similar forms four forms are assessed and classified. Map 1 illustrates the areas confined by different forms. Fig. 2 illustrates distribution of d.b.h. classes for different stands at the end of the period (after fellings).

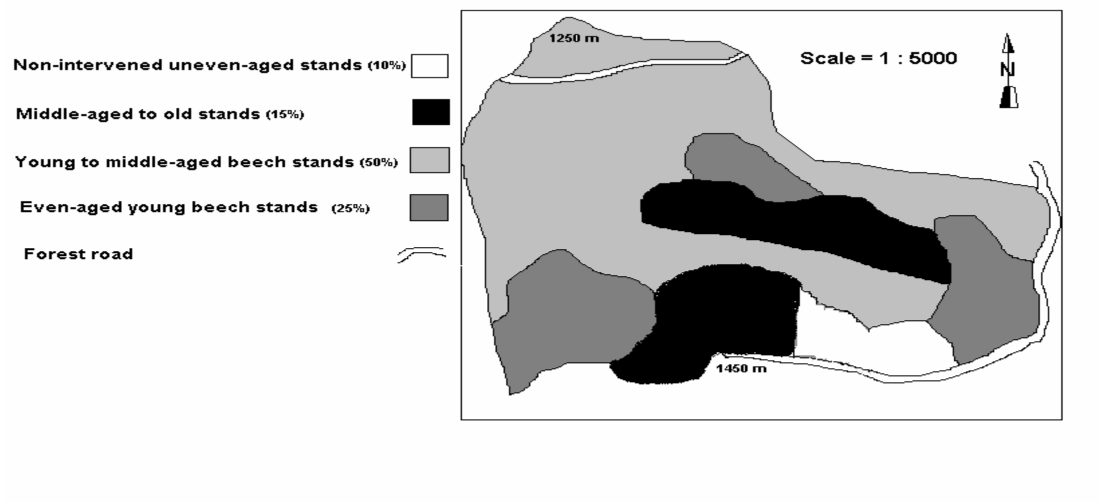

Fig. 1. Different stand structures in the study site, created after cuttings

3.2.1 Non-intervened uneven-aged stands

This form with a surface about 10% of the research site is found in stands established with 40-60% inclination. In these stands, in reality, sharp slope and the problem of landslide are the reasons for preventing the fellings. It should be stated that in the plane notebook a slight removal and exploitation was proposed for these stands but not any intervention was made during the period, due to slope inclination and landslide problems. These stands consisted of a four-storied structure, distinguished by dominant aged beeches, co-dominant middle-aged beeches, dominated thin thickets, and suppressed thick saplings.

3.2.2 Middle-aged to old stands

This form is found in 15% of the investigated forest area. There are evidences presenting that the preparatory and seeding fellings were conducted with removal of beeches and hornheams. In the gaps established it looks like that after primary cuttings, regeneration deficiency and invasion of luxuriant berry (*Rubus fructicosus*) and fern (*Petridium aquilinum*) has been the restricting factors to operate the following fellings, specially thinning fellings. Three-storied stands are mostly located on moist exposures with moderate to sharp inclination (20-65%).

3.2.3 Young to middle-aged beech stands

This form appears in 50% of forest area. The stands are mostly two-storied but in parts, due to presence of recruitments, a three-storied structure is observed, whereas upper-storey is distinguished by a middle-aged beech, middle-storey by a dense small pole groups, and under-storey by the thickets and saplings of beech. Indeed, during the research time almost all regeneration cuttings were made in these stands. The aged beeches and hornheams were felled but middle-aged beeches and other trees with d.b.h. of 25-45 cm were kept, whereas the patches of young beeches were appeared by generating the middle-aged beeches. Generally the stand was established mainly on wet exposures (northern, west and east northern) with slight to moderate gradient (< 30%). No prominent damage of snow and wind affected on saplings of these stands.

3.2.4 Even-aged young beech stands

This form occurs in 25% of forest area. The landscape is lacking parent trees, while it has been mostly covered by advance growth from the beginning of research. It is now presented as one-storied even-aged small pole groups and in parts more or less with sapling and thicket groups. Though this form is found on various gradients of geographical directions but often appears on slight steeps. Competition among some individuals is relatively severe. Snow and wind damage is principally obvious on saplings.

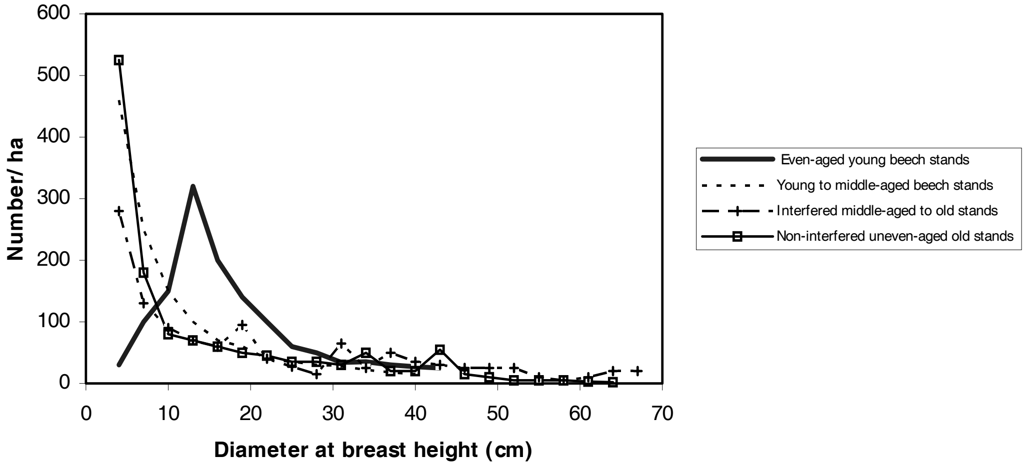

Fig. 2. D.b.h. Distribution at four different stands, conducted after fellings

3.3 Ingrowths quality

In 15% of plots, particularly on the sharp slopes, young beeches were appeared with poor quality, such as forked and broken stems, bends in lower part of stem and even as uprooted. 75% of the recently established individuals, especially saplings, were injured by snow and wind. Damage was the least where the advance regeneration was accepted and played the shelter role for recruitments. Due to strong competition young beeches were observed with tall stem and big h/d ratio.

4 Discussion and Conclusion

By comparison of present condition of forest and target of shelterwood system, it is concluded that generally forest structure is still multi-storied while the main aim of forest management plan was to create a regular even-aged forest. Indeed, natural regeneration would be appeared throughout the forest if shelterwood was correctly performed; however, beech number increased in some parts and forest became some to extent young. In this research, with removal of overstorey a large number of saplings were injured by snow and wind as well as intensive exploitation. Four different stand structures created after fellings were mainly owing to: a) accepting advance regeneration b) reserving individuals on sharp slopes c) retaining mature trees in different parts of forest d) avoiding secondary thinning felling in non-regenerated gaps and the areas occupied by *Rubus* and *Pteridium*) defect of proposed formula, which was caused to reduce the interventions and removal amount and as a result influence on stand structure, too. Gentle gradient is normally the main factor for success of shelterwood system. The experience of this system is observed in Europe, particularly north Germany, north France and Denmark (Marvi-Mohadjer, 2001). Generally, shelterwood is adapted in forests with light and deep soils and slight inclinations (<40%) (Mossadegh, 1996). In fact, under these conditions ground will be favored to establish regeneration by primary cuttings of this system (Dorostkar, 1984).

The study site has different geographical directions (northern, eastern, east northern, west and west southern). Likewise, slope gradient ranges between 2% and 65% whereas majority of the forest area is considered with gradient > 40%. In reality, harsh gradient has been the reasons for reserving trees in various exposures and scattered points of the forest. In addition, by retaining trees on these slopes and accepting advance regeneration and other tree individuals and groups, creating the structure of homogenous even-aged young beech stand which is in fact the main objective of the sheterwood system was not yielded but by contrast, an irregular uneven-aged two to four-storied forest was appeared. This reveals that, as a whole, regarding to above problems, instead of shelterwood system other silvicultural practices such as tree selection system and group selection system be advised for exploitation and management of mountainous beech stands of the Caspian forests in northern Iran, so that the stability, sustainability and health of forest nature to be secured, as far as possible.

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Prediction of seed crop size for successful natural regeneration of *Fagus crenata* Blume in northern Japan

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Abstract

Fagus crenata Blume, one of the dominant tree species in the cool temperate zone in Japan, is generally associated with dwarf bamboo species which densely covers its forest floor and hampers natural regeneration of beech trees. For successful natural regeneration, it is indispensable to remove such dwarf bamboo by site preparation before seed fall in the best mast years. If the seed fall fails, the site preparation is wasted. We analyzed the 13-year records of seed production of beech forests in northern Japan. Seed crops fluctuated largely from year to year and they were controlled by the numbers of female flowers and pre-dispersal seed predation by insects, particularly moth larvae. We developed a model to predict the seed crop precisely and early enough to properly support the decision about site preparation.

Keywords: *Fagus crenata* Blume, natural regeneration, masting, pre-dispersal predation, seed crop forecast, beech nut

1 Introduction

One of the distinguishable characteristics of *Fagus crenata* Blume from European, Oriental and American beeches is association with dwarf bamboos, which dominate the forest floor and hamper natural regeneration. Dwarf bamboos grow up to 3m tall, and the above ground biomass reaches 8kg/m^2. In Japanese forest managements, successful regeneration of *Fagus crenata* requires dwarf bamboo removal prior to the seedfall in a good mast year. There are typically 5-7 years between good mast years. The dwarf bamboo vigorously resprouts, and removal in poor seed years will only produce beech regeneration failures.

The recent studies on the performance of seed production in *Fagus crenata* Blume have revealed that the seed crop size was determined by two factors: first, the number of female flowers; second, the extent of pre-dispersal predation of seeds (Terazawa *et al*. 1995; Igarashi and Kamata 1997). The periodic synchronous production of large seed crops, called "masting" (Kelly 1994), is supposed to have an adaptive significance to escape from seed predation (Yasaka *et al*. 2003, Kon *et al*. 2005). Therefore, the aim of our study is to apply these ecological findings to practical forest management by quantitative seed crop prediction at least one year prior to seedfall and ultimately improve the regeneration practices in natural beech stands.

2 Materials and methods

2.1 Annual seed production

Quality and quantity of fallen seeds were surveyed for 13 years (1990-2002) in five natural beech stands in southwestern Hokkaido, northern Japan. All the study sites were located between 230 – 400 m a.s.l. The mean annual temperature in the study area is 8.5 – 9.7 ^{o}C and the annual precipitation is

1040–1400mm. Stand volumes ranged from 207 to 298 m^3/ha, and the relative dominances of beech were 69 – 96% in the basal area. Forest floor of the study sites were covered with dwarf bamboos (*Sasa* sp.) . We set up 8 to 11 seed traps (opening area: 0.3 – 1.0 m^2) under the beech canopies in each stand and collected fallen seeds every month from May to November. Fallen seeds were brought back to the laboratory and divided into three categories: Sound seeds, insect-damaged seeds, and empty or immature seeds. The seeds in each category were counted. Total amount of fallen seeds of all categories for a year is assumed to be the approximate number of female flowers produced per unit ground area in the year, because the seed traps were set up immediately after flowering of beech trees and loss of seeds on the trees is supposed to be negligible.

2.2 Estimation of female flower density

At least five twigs longer than 30 cm were sampled from upper parts of the crown in each of more than five beech trees in November or December from 1995 to 1999 at four stands among the study sites. Contents of winter buds on the sample twigs were surveyed in the laboratory. Flower bud ratio (number of flower buds / total number of winter buds) was determined for each stand in each year.

3 Results and discussion

3.1 Annual seed production

Large year-to-year variations were found in the total amount of fallen seeds at all sites (Fig.1). The highest numbers of the total seed fall were 583, 900, 812, 683 and 906 for the sites 1, 2, 3, 4, and 5, respectively. The number of sound seeds also varied from year to year (Fig.1). Except for site 1, there were three to four good seed years in which more than 200 sound seeds per m^2 were produced.

A large number of seeds were damaged by insects, mainly by larvae of lepidopteran species, such as *Pseudopammene fagivora* Komai and *Venusia phasma* Butler. These insects feed on immature beech nuts (Igarashi and Kamata 1997), which then lose their germinability. The percentage of insect-damaged seeds to total seeds exceeded 80% in most years with a total seed production less than 500 beech nuts per m^2 (Fig.1). Heavy predations were often seen (e.g. 1990 and 1995 at sites 2 and 5) even in good seed years.

The proportion of insect-damaged seeds to total amount of seeds was negatively correlated with the current year/previous year ratio of the total number of seeds (CPR) (Fig. 2A). The percentage of insect-damaged seeds was quite high when the CPR was lower than 20. At the higher range of the CPR, however, the percentage of insect-damaged seeds was markedly lower. These results suggest that beech nut predators were satiated and did not consume all the seeds in years with a 20-fold higher female flowers than those in the previous year (Yasaka *et al*. 2003). Consequently, the percentage of sound seeds increased with the CPR-value when this threshold value was exceeded (Fig. 2B).

3.2 Estimation of female flower density

We obtained the relationship between the flower bud ratio and the total amount of fallen seeds in the following year which was supposed to be the approximate number of female flowers per unit ground area (F_{t+1}), as mentioned above. Total amount of fallen seeds increased with the flower bud ratio (Fig.3). This relationship can be used for the estimation of the number of female flowers which will be produced in the following year.

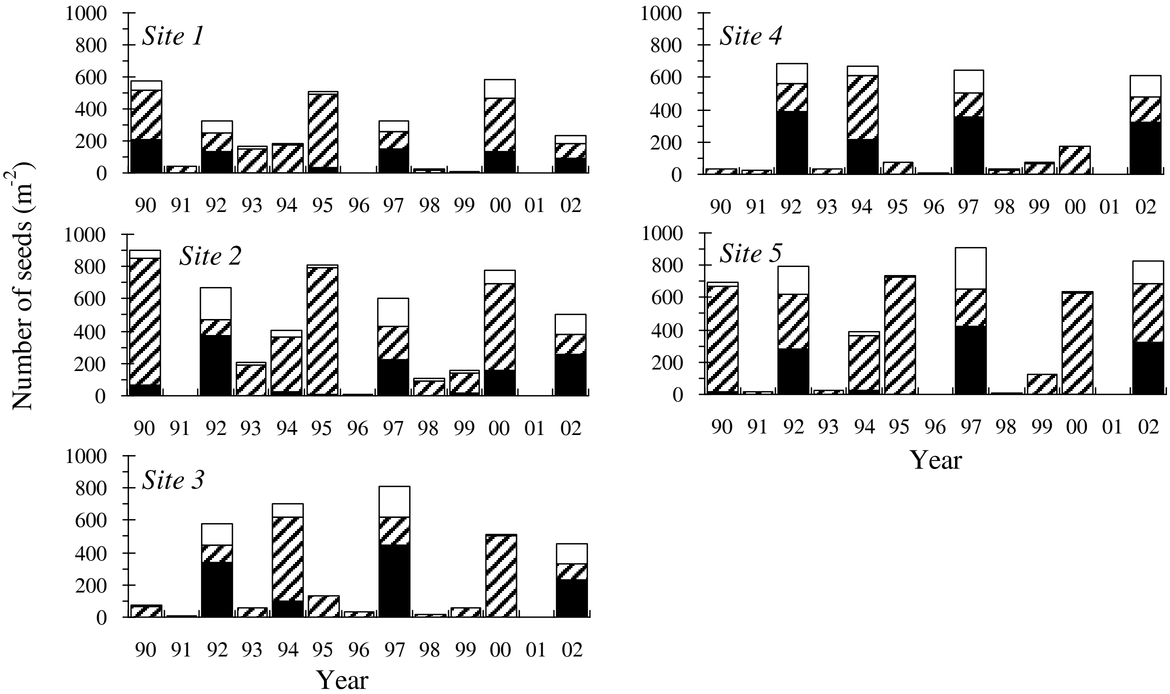

Figure 1. Annual seed production of *Fagus crenata* Blume in the five natural stands in Hokkaido, northern Japan, from 1990 to 2002. Solid bars represent sound seeds; hatched bars represent insect-damaged seeds; open bars represent empty and immature seeds.

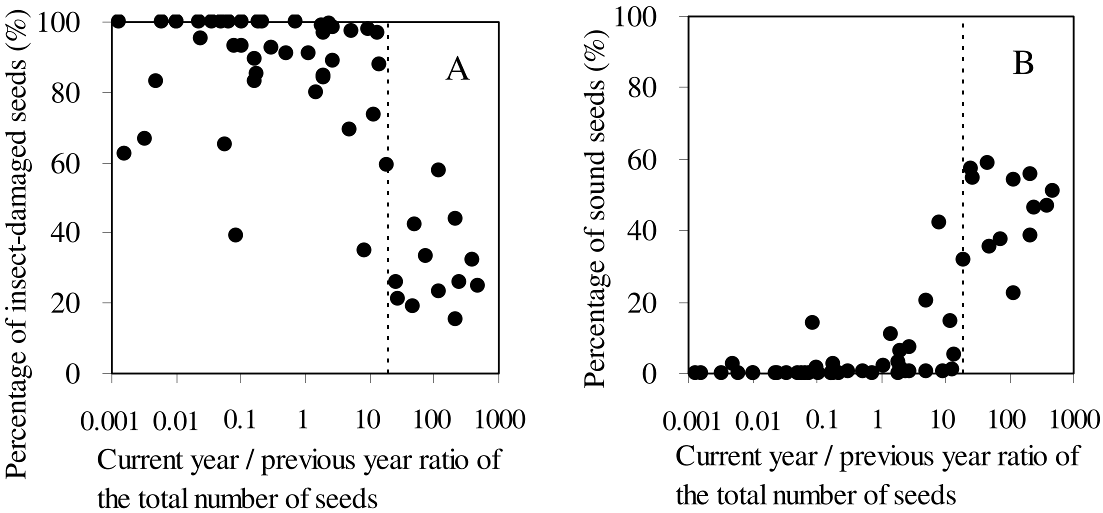

Figure 2. Relationships between the current year/previous year ratio of the total number of seeds (CPR) and the percentage of insect-damaged seeds (A) and sound seeds (B) of *Fagus crenata* Blume in five natural stands in Hokkaido, northern Japan. Data were taken by seed traps from 1990 to 2002.

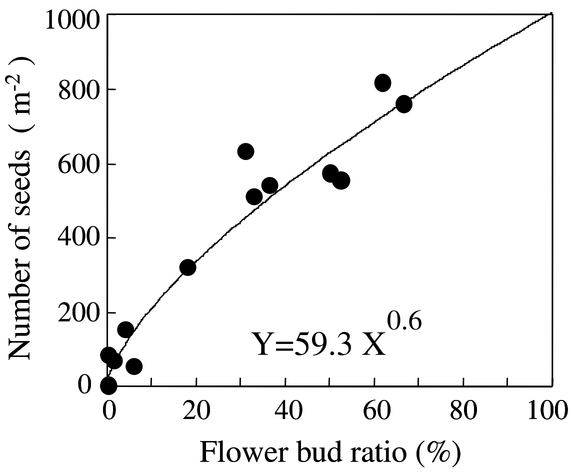

Figure 3. Relationships between the flower bud ratio of winter buds and the total amount of fallen seeds of *Fagus crenata* Blume. Data were taken in four natural stands in Hokkaido, northern Japan, from 1995 to 2000.

3.3 Prediction of seed crop size

It is concluded that a good mast year is characterized by (1) a female flower number higher than 500 per m^2 and (2) a CPR (Current year / previous year ratio) higher than 20 to escape heavy insect predation of the beech nuts.

The number of female flowers (F_{t+1}) can be estimated from a bud sampling in the winter prior to the seed set and the relationship between flower bud ratio and total seed production shown in Fig.3. Additionally, total seed production data of the previous year obtained by seed fall census are needed to calculate the CPR value.

3.4 Prediction error

The seed crop sizes were accurately predicted in nearly 90 % of studied cases. In a few cases, the predictions underestimated the seed crop probably due to insufficient bud sample sizes.

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Ecology based prediction of seed crop size for successful natural regeneration of *Fagus crenata* in northern Japan; Development of prototype for prediction

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Abstract

The prototype method for prediction of beech seed crop size demonstrated in previous report still has disadvantage in practical standpoint. Since setting litter traps and frequent visiting is required to estimate the current year's female flower production, it is difficult to predict over a wide rage of areas simultaneously. We developed an advanced method using inflorescence scars left on shoot branches. The amount of scars on each year shoot was highly correlated with actual flower production in each year. Thus, shoot sampling followed by FIS examination makes it possible to estimate current year flower production without traps and to predict crop size of next year at unspecific stands.

Keywords: *Fagus crenata*, Seed production ,flower production, masting, prediction method

1 Introduction

Fagus species is well known for its masting behavior (Mathhews, 1995; Takeda, 1992; Hilton and Packham, 1997). In Japan, *Fagus crenata*, one of the most typical climax species, also shows high year-to-year variation in seed production. Long term observations have demonstrated that good seed years occur at 5-7 year intervals (Igarashi and Kamata, 1997; Yasaka et.al.2001). This phenomenon prevents successful regeneration at natural stands and constant production of seedlings at commercial nursery. The situations would greatly be improved if we can forecast the seed crop size beforehand.

For this purpose, the prototype method to predict the beech crop size was developed (Yasaka et. al., 2001). Yasaka et. al. (2001) reveled that annual seed production is mainly determined by amount of flowers and its percentage predated by insects. More than 500 female flowers per m^2 are required for a beech stand to be a good seed crop (Condition1). Further, percentage of predation is affected by annual increase rate of flower density between two consecutive years. Insects are saturated when flower density is more than 20 times as much as those of previous year (Condition2). Thus, to predict the next year's seed crop size, we must quantify the flower densities of current year (Ft) and next year (Ft+1). Ft is obtained from litter trap data and Ft+1from winter bud examination and following equation (r^2=0.81 p<0.01).

$$Ft+1 = 59.3\ x^{0.6} \qquad \text{equation (1)}$$

Where x is percentage of flower buds among winter buds examined. This method can predict with high percentage of accuracy (nearly 90%). Indeed seedling emergence was significantly enhanced at the site where the scarification was carried out in predicted good seed year following this method (Koyama, et.al.2000).

However it has still disadvantage from a practical standpoint. As mentioned above, the prototype method estimates Ft from litter trap data. It is, however, hard to obtain Ft over a wide rage of areas simultaneously, because number of litter traps possible to be set and visited frequently will be restricted. Thus it is desirable to find the way to estimate Ft (current flower production) without traps.

It is known that beech trees left female inflorescence scars on its shoots when they flower in spring. Consequently, in the year of mass flowering, most of the current shoots have these scars on them. We considered that amount of inflorescence scars make it possible to estimate the annual flower production. Validity of this assumption may depend on whether the flower density produced in each year and amount of inflorescence scars left on the corresponding year-shoots are really synchronized each other. Thus the specific objective of this study is to test this assumption and to obtain Ft form inflorescence scars left on the shoots. If it is, we can predict next year's seed crop size of beech tree stands at every unspecific site without setting litter traps.

2 Materials and methods

As described in previous report, since 1990, 6-10 litter traps have been set at each of six study sites in Hokkaido, northern part of Japan (i.e. Esan, Otobe, Kaminokuni, Kuromatunai, Kitahiyama, and Hakodate). Detail description of study sites was shown by Terazawa et.al. (1995) and Yasaka et.al. (2001, 2003). We use these trap data (from 1994 to 1999) as actual flower density.

In the spring of 2000, at least10 branches form each of five individual trees at six study sites are collected. Then female inflorescence scars (FIS) were examined on each year-shoot back to the six years (1994-1999) by checking bud scale scars which indicate annual shoot increment. Percentages of shoots having any one of FIS among observed shoots were calculated.

Relationship between FIS percentage and flower density was investigated. The two variables were regressed to logistic curve. With this relationship, we estimate the flower density in each year from FIS percentage and seed crop size.

3 Results

Percentages of FIS obtained by annual shoot examination greatly varied between years and sites (maximum was 85.6% occurred at Kaminokuni in 1997 and minimum was 0.97% at Otobe in 1999; Table1).

In each study site, FIS percentage and the annual flower density actually captured by litter traps synchronized with each other fairly well between 1994-1990. During this period, 1994, 1995 and 1997 were the year of mass flowering (>500 flowers/m^2) at many of sites. Accordingly, FIS in these years generally reached at high percentages (Table 1). On the contrary, the year of no or less flower production (e.g. 1996, 1998 and 1999), FIS percentages were also negligible (with a few exceptions in 1998 at Kuromatunai and in 1999 at Kityahiyama). Pooled data of FIS percentages and flower densities involving all sites and years were regressed to logistic curve as follows:

$$Ft+1=1000\{1+ \mathit{exp}\ (3.73 -0.067a)\} \qquad \text{equation (2)}$$

Where a represents FIS percentage. Since high correlation was obtained (R^2=0.86, p<0.01), this equation would provide the authentic estimates of each year's flower density from FIS percentage.

Table 1. Female inflorescences scars (FIS) percentage and acutual flower density captured by litter traps between 1994-1990.

Site	1994	1995	1996	1997	1998	1999
Esan	43.0	68.8	4.3	52.7	16.6	2.3
	(185)	(512)	(0.8)	(322)	(28)	(4.8)
Otobe	73.7	12.7	3.0	63.2	2.8	0.97
	(704)	(130)	(29)	(812)	(20)	(55)
Kaminokuni	50.5	78.0	3.04	85.6	10.7	2.4
	(403)	(809)	(8.3)	(603)	(107)	(155)
Kuromatunai	44.1	70.1	5.2	68.7	30.3	5.18
	(392)	(735)	(3.9)	(906)	(9.3)	(124)
Kitahiyama	71.1	19.9	1.3	74.2	8.6	40.0
	(670)	(71)	(5.6)	(647)	(37)	(71)
Hakodate	50.0	69.6	3.5	54.7	18.6	10.9
	no data	(1180)	(30)	(76.7)	(147)	(87)

*In each study site, upper figure represents FIS % and lower figure in parentheses represets acutual flower density.

Investigation with litter traps has began since 1995 in Hakodate site, thus there is no flower data is on table in 1994.

Table 2. Verification at representative site; Kaminokuni.

year	1994	1995	1996	1997	1998	1999
FIS %	50.5	78.0	3.04	85.6	10.7	2.4
Estimated Ft(/m^2)	413.6	816.8	28.6	881.4	46.8	27.4
Actual flower density (/m^2)	(403)	(809)	(8.3)	(603)	(107)	(155)
Estimated Ft/Ft-1	-	2.0	0.03	30.9	0.1	0.6
Estimated crop	Poor	Poor	Poor	Good	Poor	Poor
Actual crop	Poor	Poor	Poor	Good	Poor	Poor

4 Discussion and Conclusion

We could identify FIS (female inflorescence scars) left on sampled shoots back to, at least, 6 or 7 years. Percentage of FIS and actual flower density captured by litter traps which have long been set and investigated were highly correlated with each other. This result suggests that flower density produced not only in current year but also in the past few years can be estimated only by sampling of branches at every unspecific stand.

The verification at representative site; Kaminokuni is shown in Table 2. Estimated flower densities (Ft) calculated from FIS % shows great variation between years. The mass flowering satisfying condition1 (>500 flowers per m2) are supposed to occur in 1995 and 1997. In 1995, however, the annual increase rate of flowers compared to those of previous year was calculated as 2.0 which did not satisfy the condition 2, then it is supposed that mass flowering in this year resulted in poor seed crop due to heavy insect attack. On the contrary, in 1997, both condition1 and condition2 were presumed to be satisfied. Accordingly this year must be a good seed year. Rest of years, 1994, 1996, 1998 and 1999, should be poor seed year, since estimated Ft were less than 500 / m2 unsatisfying the condition 1. Compared to real trap data, all above estimations were turn out to be correct (Table 2).

In the same way, verification conducted at all six sites over five years indicated that all estimations except for one case were correct (96.7% of accuracy). This indicates estimation based on FIS examination is effective for quantifying annual flower production.

We propose the newly advanced method for unspecific stands which can predict the next year's seed crop size only by shoot sampling without litter traps. As same as the prototype method, flower density of next year (Ft+1) will be obtained from equation 1 following winter bud examination. Then, as this study pointed out, FIS examination and equation 2 make it possible to estimate the current year flower density (Ft). With these two estimates, judged by condition 1 and condition 2, the next year's seed crop size will easily be predicted. Since the procedure requires no litter trap, the prediction is possible at everywhere if only we conduct branch sampling. This may have great practical advantage for forest planning and nursery operation.

Moreover, the new method and/or FIS examination introduced here may contribute to various kinds of scientific understanding or practical management of forest or wildlife. For example, FIS examination can inform us the reproductive behaviors on individual base, whilst flower density obtained from litter traps are fundamentally on stand based data. It is often observed that a great variation was found among individuals in reproductive potential. Some trees are more prolific and the others have no sigh of flowering even in a good seed year. If we can identify the reproductive potential on individual base, it may somewhat contribute to sustainable forest management. Particularly, in the case of selective cutting or shelter wood systems, sterile trees should be preferentially harvested and leave more prolific ones for success of next regeneration.

Further, the prediction would also become an effective tool for wild life management. Beech forests provide habitats for various kinds of animals including bears which highly relay on beech seed production as a food resource. Therefore, in the poor seed year, they often come down to the farm land searching for agricultural products and sometimes encounter the local people resulting in serious problems. Recently, negative trend between beech seed production and number of bears captured or shot by hunters at lowland are demonstrated (Saito and Oka, 2003). Therefore, the prediction method for seed crop size could also be applied for bear appearance alert system for local people to arouse adequate attentions and preparations. Then, we might be able to find the way to coexist with wild life. Of cause, other possible use of the prediction method would be considered in various kinds of scientific and practical fields.

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Regeneration of beech-oak-mixed stands in Central Europe under continuous cover management

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Abstract

Continuous cover management is defined as a silvicultural system which maintains woodland conditions all over. This excludes clear cutting and canopy openings of more than 40 m in diameter, or 0.12 ha in area. Therefore, during the regeneration stage shade tolerance of the seedlings becomes an important trait.

In order to compare the regeneration success of sessile oak (*Quercus petraea* LIEBL.) and beech (*Fagus sylvatica* L.) under continuous cover management an experiment beneath an unevenly opened canopy of an old beech stand was installed (close to Göttingen/Germany). Height growth and mortality were observed for the first six years after planting. Under dense canopy and corresponding low values of photosynthetically active radiation (PAR) beech showed superior height growth, under high PAR oak. The break-even point moved towards higher PAR with increasing age. Mortality of sessile oak reached nearly double the beech value under low light. After eliminating root competition of the overstory, sessile oak responded with a higher increase in growth than beech. Therefore, the lower shade tolerance of sessile oak can be attributed partly to a higher sensitivity against root competition.

It can be concluded that continuous cover management will favor the competitiveness of beech while putting the light demanding species like sessile oak into a disadvantage. Therefore, regenerating successfully beech-oak mixed stands requires a modification of continuous cover management towards cutting types emulating greater disturbances than usually found in natural beech forests.

Keywords: Continuous cover management, mixed species forests, shade tolerance, root competition, PAR, seedling mortality

1 Introduction

The widely accepted concept of close to nature forestry in Central Europe contains among others two major goals. One is directed towards the enlargement of mixed-species forests, preferably with European beech (*Fagus sylvatica* L.) as a principal component, and the other towards the application of continuous cover silviculture. It is the objective of this contribution to point at a conflict inherent in these two goals in the case of admixing sessile or pedunculate oak (*Quercus petraea* LIEBL., or *Q. robur* L. to beech stands. Both species are important mixed species in beech forests as well from an economic point of view as from their adaptive traits regarding risks caused by the expected climate change. The problem arises from the competitive inferiority of both oak species. In even-aged stands beech regularly is overtopping them from the age of 40 years onwards, sometimes even from the beginning, reaching finally a height lead of 4-6 m. Combined with the pronounced ability of beech to cast shade, and the sensitivity of the oaks against shade this results in reduced oak growth, or even in mortality.

It can be expected that this situation is getting worse under the scheme of continuous cover silviculture like generally for all more light demanding tree species. Continuous cover silviculture goes back to the philosophy of the German silviculturist Möller (1922). Today it is regarded as an essential of close to nature forestry in Europe by which the following goals should be fulfilled: Natural biodiversity of species and stand structure, higher stability, and optimal qualification for multipurpose forestry including timber production, nature protection, and recreation. Up to now, there is no broadly accepted definition of continuous cover forestry. In this contribution I follow the proposal which is included in the list of definitions given by Hasenauer (2004): "A forest management system without clear-cutting including shelter wood cuttings and group or single tree selection, as well as target diameter cuts." A certain degree of canopy cover should be maintained all the time in order to preserve woodland conditions. By this, a certain amount of shade is provided always and all over.

To make it more concrete for Central European conditions I add the following supplement to the definition given by Hasenauer: "Continuous cover management is a silvicultural system that does not tolerate canopy openings of more than 40 m in diameter or 0.12 ha in area." This is based on the assumption, that every spot on the forest floor should be hit by shade of a neighboring tree at least once a day during the main growth period (in Central Europe from May to August between 9 am and 3 pm) to provide a minimum of woodland conditions. A spot is shaded when the distance to adjacent trees in southerly direction remains under ca. 120 % of the tree height. With an average tree height of 30 m, for a gap of 40 m diameter we can expect ca. 30-45 % photosynthetically active radiation (PAR) of above canopy PAR in the central part of the gap.

Continuous cover forestry, particularly in the form of single tree selection cutting, emulates to some extent the conditions in natural beech forests in Europe (Table 1). The data for the stand with target diameter cutting refer to a relatively advanced stage of regeneration which contains more and larger gaps with comparatively more light on the forest floor. However, the average PAR value has still to be regarded as only sufficient for the light requirements of fairly shade tolerant species like beech, silver fir (*Abies alba* Mill.), and hornbeam (*Carpinus betulus* L.). This is confirmed by the composition of the regeneration which is made up almost entirely by beech seedlings in all three stands.

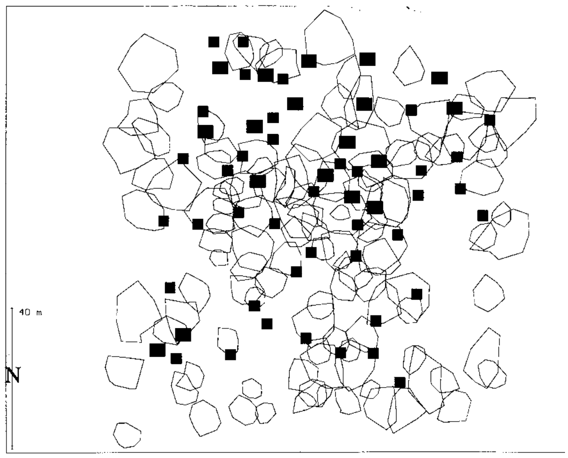
In order to adapt the continuous cover management to the requirements of the regeneration of beech-oak mixed stands it is necessary to know how much shade oak is able to tolerate without loosing its capability to compete successfully with beech. Therefore the institute of silviculture in Göttingen laid out a corresponding experiment in 1995 for which the results after six years of observations are given below. An earlier presentation covering the first two years of growth was published by Hauskeller-Bullerjahn (1997).

Table 1. Some characteristics of old beech forests (*Fagus sylvatica* L.) comparing a primary forest near Puka/Albania with two German forests managed in accordance with the principles of continuous cover forestry (after Tabaku 1999).

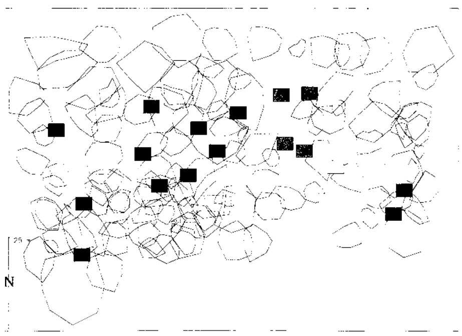
Forest	Basal area (m^2 ha^{-1})	PAR (%)	Gap mean size (m^2)	Gap proportion of total stand area (%)
Primary forest (Puka/Albania)	45.6	4.5	61	3.4
Single tree selection forest (Bleicherode/Germany)	25.9	7.2	97	8.4
Target diameter cutting (Solling/Germany)	22.6	14.0	142	17.9

2 Materials and Methods

The research to be presented here was carried out in a 145 years old beech stand near Göttingen (Fig. 1) on an acid soil with moderate nutrient and water supply. Two small research areas were outlined where an irregular crown thinning was performed in order to achieve a broad range of canopy densities and PAR values. The density extended from closed canopy to gaps of 40 m diameter, and PAR from 5.7 to 66.9 %. 36 plots of 16 m^2 each covering the whole range of light conditions were planted with 54 beech and 54 sessile oak seedlings (2-years old) in dense spacing in spring 1995. Half of the plots were surrounded by trenches made at the end of the second growth period after planting to exclude root competition of the overstory beeches.



Experimental stand 1 (1.6 ha)



Experimental stand 2 (1.0 ha)

Figure 1. Map of the two experimental stands showing the locations of the overstory beeches, their crown projection area, and the planted plots (black quadrats). Research stand Reinhausen / Göttingen (after Hauskeller-Bullerjahn 1997).

PAR was measured in the centre of each plot above the seedlings during the first growing season after planting by hemispherical fotos according to Wagner (1994). The following analysis includes in most cases only the top heights of the seedlings (defined as the height of the five highest seedlings per species and plot) because it can be assumed that they received the measured PAR intensity whereas the other seedlings were more or less shaded by taller neighbors.

Height growth and mortality was observed for the first six years after installation of the experiment.

Height values at the end of the 6th growing season dependent on PAR could be optimally fitted by using the following monomolecular growth function (Hunt 1982):

$$H = a * \left(1 - b * e^{-c * PAR}\right)$$

with H = height of dominant plants; a = asymptotic value (maximal height); b,c = parameters for form of the curve; PAR = photosynthetically active radiation in % of above canopy value.

Mortality as number of dead seedlings after six growing seasons in per cent of the initial number of planted seedlings could be best fitted by the following function:

$$M = a + \frac{b}{PAR}$$

with M = Mortality in % of initial number per plot; b = functional parameter; PAR as before.

3 Results

Figure 2 shows the heights of oak and beech seedlings depending on PAR at the end of the 6th growing season after planting. The fitting of the model is quite satisfactory giving the following coefficients of dertermination: 0.71 for oak, and 0,65 for beech. Extrapolating the model to zero height growth and calculating the corresponding PAR value enables an estimation of the threshold value at which height growth completely ceases. For oak a value of 10.6 % is calculated, for beech of 5.3 %. This parameter can be regarded as a compensation point for height growth. As expected it clearly shows a lower value for beech.

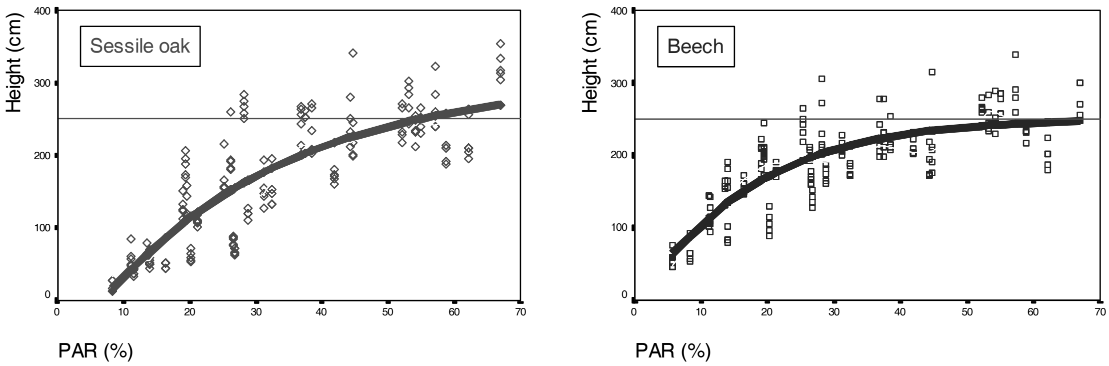


Figure 2. Scatterplots of top heights of sessile oak and beech seedlings at eight years depending on PAR in % of above canopy value. The seedlings grew for six years under an irregularly opened canopy of an old beech overstory. Open marks: measured values; continuous line: modelled values using the monomolecular function.

A direct comparison of height growth is given in Figure 3 using the modelled values. The young oak seedlings needed more light with increasing age to reach the same value as beech. At the age of five years (three years from planting) the point of intersection of the two growth curves is located at 38 % PAR, at the age of eight years at 50 % PAR. The break-even point of height growth of the two species moved towards higher PAR with increasing age. Only above this PAR value oak seedlings were able to overtop beech.

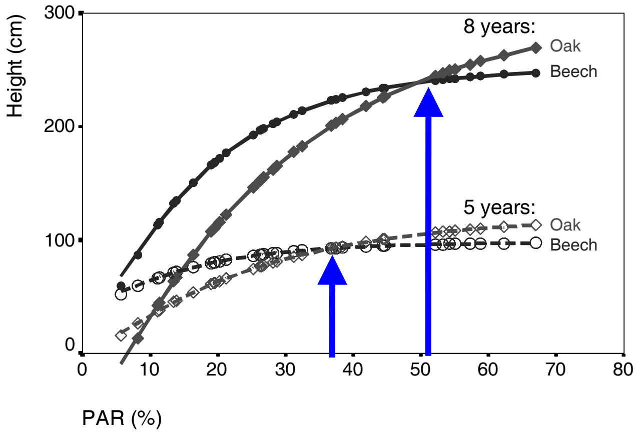


Figure 3. Modelled top heights of sessile oak and beech seedlings at age five and eight years depending on PAR in % of above canopy value. The points of intersection of the two pairs of curves are marked by arrows.

The effect of root competition of the overstory beeches on annual height growth of the young seedlings during the first three growing seasons after performing the root trenches is shown in Figure 4. Overstory root competition had a much greater effect on oak seedlings than on beech. Without competition oak started overtopping beech already at ca. 25 % PAR, whereas under the influence of root competition oak showed only a weak dominance starting at ca. 35 % PAR. Therefore, the lower shade tolerance of sessile oak could be attributed partly to a higher sensitivity against root competition from the old stand.

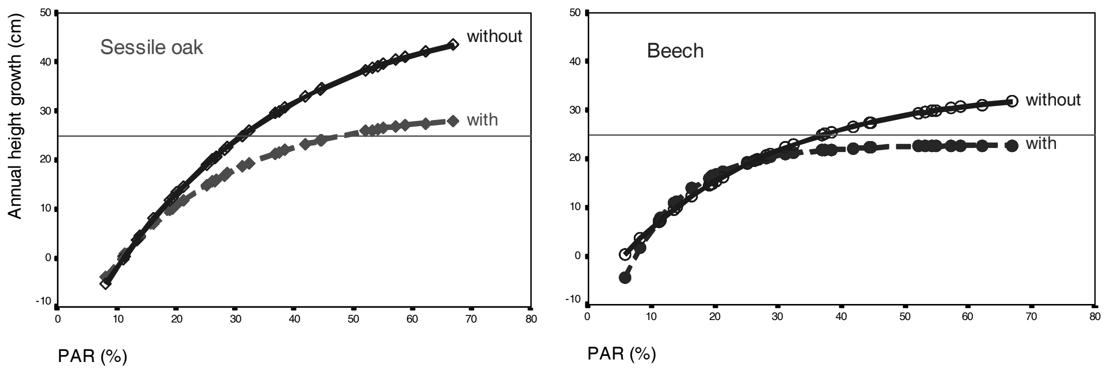


Figure 4. Annual height growth of sessile oak and beech depending on PAR in % of above canopy value with and without overstory root competition. The depicted annual height increment is the average of the first three growing seasons after trenching (seedling ages 4-6 years).

Under low light (PAR 5.7 % – 18 %, on average 11,2 %) mortality until the age of eight years of sessile oak amounted to nearly double the beech value (65 % of initial seedlings, as compared to 35 % with beech). Under bright conditions (PAR 50 % – 66.9 %, on average 57 %) the difference in mortality between the two species was negligible (10 %, respectively 12 %) (Fig. 5).

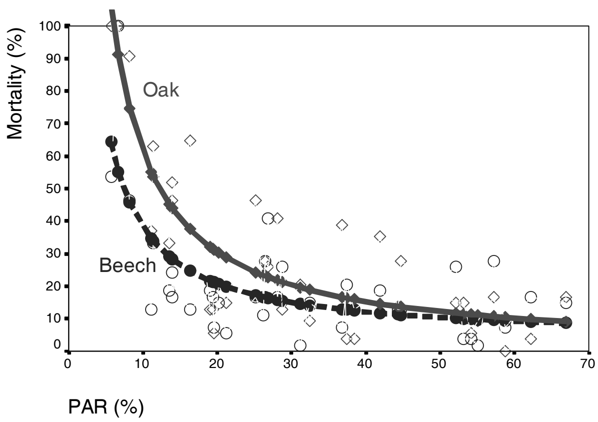


Figure 5. Mortality during the first six years after planting (at age of 8 yrs), in % of the initial amount of seedlings. The graph shows the measured values (open rhombuses: oak; open circles: beech) and modelled values (filled symbols, oak values connected by continuous line, beech values by broken line).

4 Discussion and Conclusion

Usually shade tolerance of young tree seedlings is understood as the ability to grow relatively fast under low light and relatively slow under high light. The observed height growth of beech seedlings did not fit well into this scheme. They grew faster than oak in deep shade, but the inferiority under bright conditions was small. Oak fits a bit better in this scheme. However, a clearer picture evolves by taking into account survivorship in deep shade instead of growth in deep shade, according to the proposal of Kobe *et al.* (1995). In comparison to the usual classification using the trade-off between the features high-light growth and low-light growth, they received a much more consistent ranking in shade tolerance of 10 dominant tree species in the American north-eastern hardwoods, by taking into account low-light survivorship. “Growth rates in high-light and low-light survivorship are inversely correlated across species; as level of shade tolerance increases, a species grows more slowly in high light and exhibits increased survivorship under low light.” Applied to the presented results a clear difference could be found between the two species (Fig. 6).

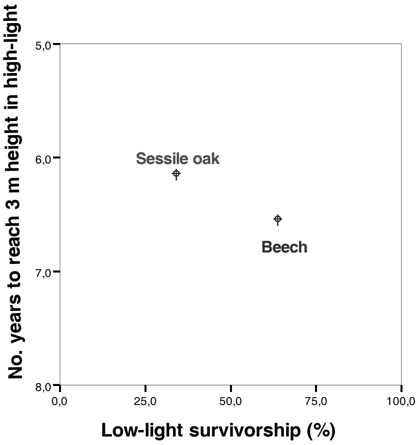


Figure 6. Classification of sessile oak and beech seedlings according to the shade-tolerance scheme of Kobe *et al.* (1995). Y-axis: Height growth expressed by number of years to reach 3 m height under high light (here as mean of the brightest plots with 57 % PAR, ranging from 50 to 66,9 % PAR); X-axis: Survival rate (%) under low light (here as mean of the darkest plots with 11,2 % PAR, ranging from of 5,7 to 18 % PAR).

Beech clearly showed a superior survivorship in deep shade, but only a small decrease in height growth in high light. The trade-off between these two features was less expressed as with oak. This certainly contributes to the great competiveness of young beeches as compared with oak.

Coming back to the initially outlined problem of growing oak in mixture with beech under a continuous cover management the following conclusions can be drawn:

- Continuous cover forestry resembles to a large extent the conditions in late successional beech forests in Central Europe. These forests are low in biodiversity. Early and mid successional stages are more diverse.
- The ideal form of continuous cover forestry is a single tree selection forest, but in practice by far the most important cutting methods will be shelterwood, group selection, and target diameter cutting
- They all create low-light conditions for regeneration. This favors beech, but has an adverse effect on all more light demanding species what contradicts another important objective: The creation and maintenance of mixed-species forests.
- Therefore, to maintain mixed stands with beech and oak, silvicultural methods have to emulate greater natural disturbances than continuous cover forestry can provide to meet the ecological demands of the oaks. To get a reasonably large area (ca. 0.5 ha) with sufficient PAR value of 45 – 60 %, the total canopy opening has to be greater than ca. 0,7 ha.

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Series of International Provenance Trials of European Beech

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Abstract

The ability of European Beech to cope with the different environments encountered in the species range, both spatially and temporarily, is an important issue. Populations have adapted locally during evolution which leads to a degree of adaptedness. Above that, populations must stay adaptable to be able to survive in future. To investigate these qualities, provenances trials located in the different regions inhabited by the species were laid out. Details are given on a set of 60 field trials located throughout the range of distribution of beech in altogether 21 European countries. The trials were established in 5 series of 1986, ‘87, ’88, ’95, and ’98 including in total 396 provenances. The data is being collated in a data base at Grosshansdorf where it is available to participants. Results show a strongly differentiated situation indicating a local adaptation to the different environments inhabited by the species. Only for bud-burst a Europe-wide longitudinal cline could be determined. Although effects of trial sites are strong, variation due to provenances is higher. A new series of beech trials is planned to be established in 2006.

Key words: *Fagus sylvatica* L., genetic variation, provenance trial, evaluation of genetic resources

1 Introduction

European Beech (*Fagus sylvatica* L.) is a major forest tree species in Western and Central Europe covering roughly 12 million ha of forest land. It is of interest not only for economic but also for ecological reasons. Beech is a species of high silvicultural value which favourably effects forest ecosystems. Beech forests are beneficial for instance for the catchments of ground water and soil regeneration.

However, despite of their importance, many beech forests were eliminated in former time. As a tree species of fertile soils, much of the original beech forest has been cleared to gain land for agriculture. Furthermore, many beech forests of higher elevations were cleared and reforested with coniferous trees, e.g. Norway spruce, because the timber gives earlier monetary returns. Additionally, beech is being damaged by air pollution, endangering beech populations near industrialised regions.

Climate scenarios anticipate a reduction of the beech range. Most endangered are stands in the lowlands, where precipitation is expected to be reduced while at the same time evapotranspiration increases due to higher temperatures. Thus, beech stands of the southern and south-eastern range of the present distribution are threatened most. However, conditions north and northeast of the distribution range may become favourable for beech and its ecosystems.

1.1 Earlier Provenance Trials with European Beech

Beech provenance trials have been planted in Belgium, Czech Republic, Denmark, Germany, France, The Netherlands, Italy, Poland, Slovakia, and Spain. A compilation of the beech provenance trials is given by Muhs and von Wuehlisch (1992). Usually, mostly local provenances were included in these trials. The results show a large variation between and within provenances in most of the characters as determined by morphological, phenological and biochemical (isozymes) studies. Basing on these results it has generally been established that the geographic variation is rather discontinuous than clinal (Muhs 1985; Muhs and von Wuehlisch, 1992; Madsen 1995). Older Danish trials have been evaluated, investigating the economic consequence of provenance choice. I was shown that rather than growth potential, trunk form and length is more important for the economic income (Hansen *et al.* 2003).

1.2 Series of international provenance trials

When looking at European Beech as a whole species, little is known about the genetic variation of the populations throughout the species distribution range. This, however, is important for evaluating the genetic resources of the species to develop possible schemes of action (Muhs and von Wuehlisch, 1993). Above that, it is important to know of the genetic structure of the species for reintroductions, where beech has been replaced by other tree species or by agricultural crops in former times. Natural regeneration can obviously not be utilised in such places and little knowledge exists about other suitable provenances.

For these causes, three series of field trials were established in the 1980ies and two, more comprehensive series were added in the 1990ties (Table 1) to study the genetic variation of beech on a species-wide scale (Muhs, 1985, 1988; von Wuehlisch and Muhs, 1992; Madsen, 1995; von Wuehlisch *et al.*, 1995a, 1998). A new series of beech trials covering the south-eastern part of the beech region is planned to be established in 2006.

2 Material and Methods

2.1 Aims and purposes of the trials

The trials are laid out and planned to serve several purposes. The objectives are:

Tree improvement: testing suitability of provenances for different sites, selection of basic material, setting up recommendations for trade and use of provenances at national and international level.

Gene conservation: assessment of genetic and phenotypic variation; development of conservation strategies, identification of evaluation methodologies and estimation of ecodistances.

Evolution biology: adaptedness and adaptability, natural selection forces and their significance, research on impacts of global climate change.

Stimulation of European co-operation in forest research.

2.2 Seed collection and establishment of trials

It was aimed at having trials in all regions covered naturally by European Beech. However, due to differing seed sets and availability because of political restrictions (e.g. former East Germany, former Yugoslavia) the number of trials and the regions represented vary considerably between the trial series. Figure 1 shows the location of the 26 field trials in 17 countries throughout the range of distribution of beech. In most of the regions a trial is located, except in the regions of Bosnia and Herzegovina/Serbia and Montenegro as well as Switzerland/France (western Alps/Jura). A number of trials are near the border of the range of distribution and the trial in Ireland is outside the natural range of beech.

The different parts of the area of distribution of beech are sampled with different intensity. Czech Republic, Germany, Romania, Slovakia, are well represented. Quite well represented are Bulgaria, France, Poland, Spain, Slovenia, and Ukraine. Poorly represented are Austria, Croatia, and Italy, especially southern Italy. Not represented is the area between Bosnia and Herzegovina, Serbia and Montenegro, Macedonia, Albania, and Greece. This is a bad omission because in this area due the long period beech has been able to adapt to these sites, a large genetic variation can be expected. Therefore a new trial series is being established to also cover this important area. Additionally, eight provenances of *Fagus orientalis* Lipsky are included, seven originating from Turkey and one from Bulgaria (Gailing and von Wuehlisch, 2004). Figure 2 shows the origins of the provenances included in the trials of Series 5.

2.3 Seed quality and treatment

The seed samples differed strongly in cleanliness, means and duration of transport, kind of collection (by hand, by nets), water content, fungi-attack, and damages. After cleaning and determination of the water content the seed samples were left for a period of after-ripening. Seeds to be stored for more than one year were desiccated to a moisture content of about 10% and were stored at -5°C. Before seeding, the seeds were remoistened to 30% water content and stratified at 3°C. When dormancy was broken, the seeds were kept with some water at -2°C until seeding. Seeds collected during autumn prior to seeding were stratified to break dormancy and as all other seed samples frozen with some water at -2°C until seeding time.

The time required to break dormancy differed strongly between the provenances. This was due to the preconditions (e.g. after-ripening) and possibly also genetic differences. These effects could not be studied because the pre-conditions (harvesting, transport, treatments) were too different.

2.4 Seeding and rearing of plants

Also, the germination frequency and rate differed strongly between provenances. There seemed to be a relationship between the time required to break dormancy and germination. Provenances which needed a long time to break dormancy seemed to have low germination frequency and were slow to germinate. Moreover, these provenances were prone to fungi attack (e.g. *Phytophthora sp.*) in the seed bed. After the critical post-germination stage had passed, no further attack by fungi was observed. Following this, there was some irregular attack by aphids *Phyllaphus fagi* L. The plants of the '95-series, sown in spring of 1993, were undercut during the first growing season for easier lifting and lifted in autumn of 1994 at two years of age. The plants of the earlier series were lined out after one year, transplanted for further two years and were planted as 1+2 seedlings.

2.5 Design of the field trials

The layout of the trials is a randomised incomplete (series 1-3) or complete (series 4 and 5) block design with three replications. The planting was done in rows with a space of 2 x 0.5 m (series 1-3) or 2 x 1 m (series 4 and 5). Each plot was laid out with 100 (series 1-3) or 50 plants (series 4 and 5) which results in a plot size of 10 x 10 m. Plots are considered large enough to maintain the trials for 60 years. There are no bordering rows between the plots, usually only two rows were planted around the trials. The number of provenances included in each trial is around 50 (Table 1). A large number contain only around 30 provenances and in five trials 100 or more provenances are represented.

2.6 Traits to be recorded

The large number of trials and joint partners involved in this experiment requires precise definition of the characters to be recorded. Survival, plant height, trunk diameter (when the trees have reached measurable sizes), flushing time, growth cessation, proleptic shoots, stem form, and any damages that might be observed have been recorded primarily and will be focussed on in future. Additional traits are other form characters (branching, spiral grain,), genetic markers, and wood quality. Important is that the position of the single trees measured is recorded in order to be able to calculate effects of neighbouring trees as well as stand density effects and meaningful age-age correlations.

2.7 Participating institutions

Table 1 gives the institutions that have planted and are maintaining these trials. We are very thankful for their endeavour and contribution. Also we are very thankful to the many, mostly foresters, who have provided the numerous seed samples for this trial. Neither without the field trials nor without the seed samples would the establishment of the trials have been possible at a European-wide scale.

2.8 Data Base

A data bank is located at Grosshansdorf, where the geographical and site data of the provenances (stand age, soil, climate, etc.), the location data of the field trials (position, soil, climate, etc.), management of the trials, and the data collected in the field trials of the different traits are being kept centrally and made available to the joint partners. Processing will also be performed at the data bank.

3 Results and Discussion

3.1 Survival

The survival differed between trials, depending on the local conditions during planting and the weather in the year of establishment. Drought and strong late frosts after planting caused higher mortality in some trials (Bayreuth, Bavaria, Bjelovar, Croatia; Nedlitz, Saxony-Anhalt). At other locations (Attendorn, Northrhine-Westfalia), extreme high soil acidity (pH 3.2 - 3.7), and damage by voles (Sweden) caused high mortality rates during the years. At a polder site in The Netherlands there was high mortality due to flooding and deer. Of the 64 trials in total four had to be given up and two trials are reduced in their use because the survival rate is less than 50%. Thus, 60 trials are in a state to give reliable data for an extended phase which is important in a species with long rotation periods. Between the provenances also marked differences in the survival rates were observed. Though, no general trend could be established so far.

3.2 Height growth

Plant heights have been recorded in the year after planting and in the following years at regular intervals. No general trends could be established. In all regions studied, fast as well as slow growing provenances could be recorded. In some trial series distinct differences between provenances were shown, in others not. In some trial series with contrasting sites, e.g. poor, extremely acidified soil, as opposed to neutral soil, rich in nutrients, clear genotype by environment interactions were found. However, among other trials series no genotype by environment interactions could be proven.

Some results have been published (Gračan, 2003; Madsen, 1995; Stener, 2002; von Wuehlisch and Muhs, 1992; von Wuehlisch *et al.* 1995a). A local trend could be found for provenances within Germany growing at two sites of contrasting elevations, showing an expected interaction. Provenances from high elevations survived better and grew higher at the higher site whereas those of low elevations survived and grew better at the lower of the sites (Liesebach, 2000). This interesting result will be observed again when the trials are more older.

Generally, at this early stage, the height increment does not reflect the potential growth and the effect of the local environment on the genotype. Mainly effects of how the plants took root and how they overcame the planting shock is reflected by the height increment. Therefore it is too early, especially for the trials planted 1995 and 1998 to present height data. To conclude, in a species known for its compatibility and ability to change rank even above 42 years of age (Kleinschmit and Svolba, 1995), the trials are still too young to reflect the growth potential of the provenances.

3.3 Phenology

The time of flushing of the leaves have been recorded on a number of the field trials in different years (Liesebach *et al.*, 1999; Madsen, 1995; Muhs, 1985, Stener, 2002; von Wuehlisch *et al.*, 1993, 1995b, 1995c) showing large tree to tree and provenance variation. Provenances from eastern and south-eastern parts of the distribution range (e.g. Slovakia, Romania, Bulgaria) and provenances from high elevations require a smaller heat sum for flushing and flush early. Provenances from western parts of the distribution range (Spain, France, The Netherlands, Belgium, England) and from low elevations, require a higher heat sum and flush late.

There are exceptions to this trend, where frequent local late frosts caused an adaptation, e.g. Idrija, Slovenia, is an extremely late flushing provenance which Sittler (1981) already showed earlier. The difference between the earliest and last individuals to flush in a set of provenances in a trial can be four to six weeks. Between the different years and over a number of sites a definite constancy in the ranking of flushing time was found among provenances.

More studies are necessary to also study year to year and site to site interactions in the flushing reaction of provenances. It can be concluded that this character is highly adaptive and reflects the adaptation to a certain site with respect to late frost occurrence. This makes flushing a very important character for estimating adaptation and adaptability of beech populations.

3.4 Diseases

At two provenance trials located in the Black Forest, Germany, the attack by *Nectria ditissima* causing bark canker was assessed for all trees (Metzler *et al.* 2002). The results show a clear correlation between canker incidence and distance to the diseased shelterwood. Trees planted up to 20 m from diseased shelterwood were infected most, up to 48% per plot. Thus, the abundance of infecting ascospores and conidia were unfortunately not exerting an equal infection pressure on the provenances. Therefore, provenance differences in the tolerance against the canker could not be proved. There are strong indications though, suggesting provenance differences in tolerating attacks by this fungus.

4 Conclusions

The collections of provenances in the series of field trials throughout the area inhabited by European Beech opens the possibility of an evaluation of provenances at a species-wide scale. This is of great value and provides the means to observe and document the growth and other adaptive or economically important traits of provenances originating from most regions, on sites in most of the regions of European Beech occurrence. The trial-data will show, how well populations are adapted to certain site-inherent environmental features, e.g. high and low temperature extremes, late frost occurrence, drought, acidic or calcareous soils, wet snow, storms etc. and how non-adapted populations react to such situations and how capable they are to adapt to them. This is significant for the identification of evaluation criteria to assess the value of a given population with respect to conserving genetic resources of European Beech. It is also important for optional investigations, e.g. predicting the future distribution range of the species in face of atmospheric warming.

Acknowledgements

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Table 1: Number of Provenances in the Trial Series established 1986, ‘87, ‘88, ‘95 and ’98 and the Institution in Charge

Country	Institution	1986	1987	1988	1995	1998
		Series 1	Series 2	Series 3	Series 4	Series 5
Austria	Federal Forest Research Centre, Vienna				49	
Belgium	Station de Recherches Forestières, Gembloux			73		34
Bulgaria	Forest Committee, Sofia				49	
Croatia	Forest Research Institute, Jastrebarsko				51	36
Czech Republic	Forestry and Game Research Institute, Jíloviště - Strnady				49	31
Denmark	Ministry of Environment and Energy, Hørsholm	48			49	42
France	INRA, Avignon/Orléans		17	58	50	
Germany BW	Institute for Forest Genetics, Grosshansdorf		29	33		20
Germany BY	Centre for Tree Improvement, Teisendorf, Bavaria				57	
Germany MV	Institute for Forest Genetics, Grosshansdorf					17
Germany HE	Institute for Forest Genetics, Grosshansdorf	48		58		
Germany NW	Forest Gene Bank, Arnsberg, Northrhine-Westfalia				116	
Germany NW	Institute for Forest Genetics, Grosshansdorf	54	28			
Germany RP	Institute for Forest Genetics, Grosshansdorf					25
Germany SN	Saxonian State Centre for Forestry, Graupa, Saxony				104	40
Germany SH	Institute for Forest Genetics, Grosshansdorf		48	31/68*	147	45 18**
Germany ST	Institute for Forest Genetics, Grosshansdorf				49	33 13**
Hungary	University of West Hungary, Sopron					33
Luxembourg	Administration for Water and Forests, Luxembourg				49	17
Ireland	COILLTE Research Laboratory, Newtownmountkennedy				49	34
Italy	Faculty of Forestry, University, Florence				49	
The Netherlands	Institute for Forestry and Nature, ALTERRA, Wageningen		32	70		30
Poland	Forest Dept., Akademia Rolnicza, Poznan				71	34
Poland	Forest Research Institute, Warsaw				49	
Romania	Academy of Agriculture and Silviculture, Bucharest				27 44**	32 32**
Sweden	Forest Research Institute, Ekebo				36	33
Slovakia	University of Forestry and Wood Technology, Zvolen				100	32
Slovenia	University of Forestry and Wood Technology, Ljubljana					32
Spain	State Forest Service, Navarra, Pamplona				100	

Spain	State Forest Service, Castilla y León, Burgos					36
Spain	State Forest Service, La Rioja, Logrono					32
United Kingdom	Northern Research Station, Roslin, Midlothian				53	25
Ukraine	Institute of Forestry and Wood Technology, Lvov				70	40
Number of trials per series		3	5	7	23	26

*There are two parallel trials at this location. **There are parallel trials in the respective country resp. Bundesland.

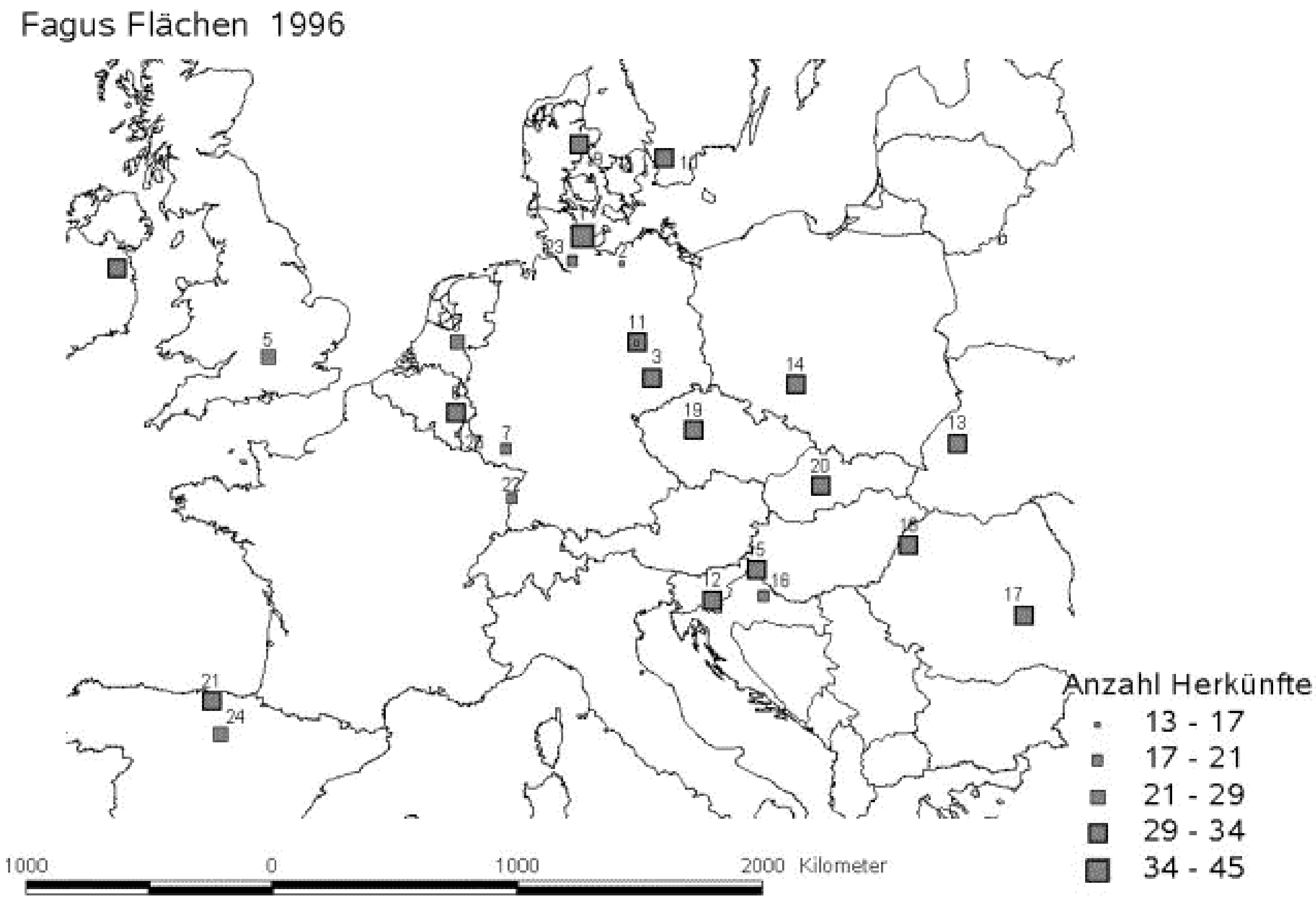

Figure 1: Location of the 26 trial sites in 17 countries of Series 5, seeded 1996 and planted 1998

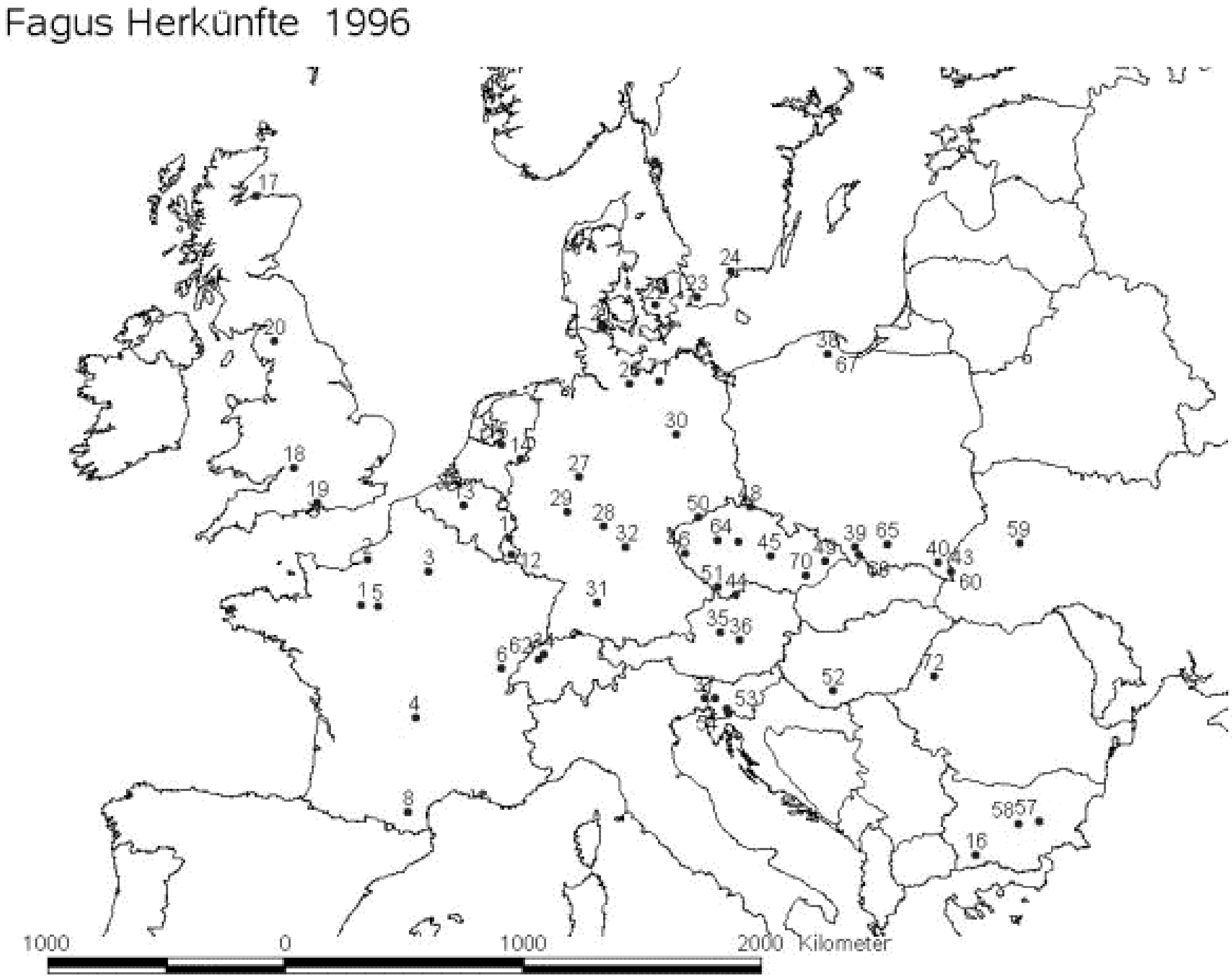

Figure 2: Location of the mother stands of the 61 provenances included in trials of Series 5

Fagus orientalis and *Fagus sylvatica* differ in Nuclear Markers (AFLPs), Chloroplast Microsatellites, and Leaf Morphology

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Abstract

F. orientalis Lipsky of different sites in north Turkey as well as *F. sylvatica* L. originating from Germany and Greece were analysed by chloroplast microsatellites and AFLP markers. In addition, leaf morphology was studied in a part of the material. AFLP markers were applied that had shown differential amplifications in preliminary analyses. UPGMA basing on AFLP data distinguished two *F. orientalis* groups, one from Turkey and another of botanical gardens as well as one *F. sylvatica* group. Low structuring in the neighbourjoining analysis and the lack of diagnostic bands suggests a recent differentiation between *F. orientalis* and *sylvatica*. High bootstrap values were only found for *F. orientalis* from two botanical gardens, four of which have a unique chloroplast type and are very similar, most likely due to clonal replication. *F. orientalis* from Turkey showed several chloroplast types even within provenances. In contrast, only two different chloroplast types could be detected for *F. sylvatica*, indicating a genetic bottleneck before postglacial recolonisation of west-central Europe. Comparison of leaf morphology of one provenance each of the two taxa growing at a common provenance trial site showed distinct differences in length, area, and weight of the leaves, petiole length, angle between nerves and central axis as well as distance between leaf bottom and widest part of the leaf.

Keywords: *Fagus orientalis*, *Fagus sylvatica*, AFLP, cpDNA, leaf morphology

1 Introduction

Both, *Fagus orientalis* Lipsky *and F. sylvatica* L. are wide-spread and dominant tree species occupying similar ecological habitats. However, each species has a distinct distribution range, *F. orientalis* in Turkey, in the Caucasus Mountains, and the Iranian Caspian mountain ranges and *F. sylvatica* in western Europe reaching from southern Scandinavia southward into the Mediterranean peninsulas. The two distribution ranges overlap in a limited area, mainly in south-east Bulgaria. However, even in this area the two species do not come into direct contact because *F. orientalis* inhabits low elevations, whereas *F. sylvatica* occupies high elevations above 1000 m a.s.l. In *F. sylvatica* most west-central European populations are genetically uniform in maternally inherited chloroplast markers suggesting a single common source that has passed a genetic bottleneck before the time of postglacial recolonisation from one refuge in south-eastern Europe (Demesure *et al*., 1996). In accordance with this finding are cpDNA, allozyme, and fossil pollen data (Goemoery *et al*., 1999, Huntley and Birks, 1983). Cluster analysis of morphological characters (leaf and fruit characters) distinguished two morphotypes corresponding to European beech (*F. sylvatica* L. and *F. sylvatica* var. *moesiaca* Maly (synonymous to *F. moesiaca* (Maly) Czeczott)) and western Asian beech (*F. orientalis* Lipsky = *F. sylvatica* ssp. *orientalis* (Lipsky) Greuter and Burdet; Denk *et al*., 2002). Clinal variation of morphological characters and low resolution of ITS (Internal Transcribed Spacer) cladograms suggested that *F. orientalis, F. sylvatica*, and morphologically intermediate *F. moesiaca* can be regarded as a single species (Denk *et al*., 2002). However, due to the small contact zone, only a limited gene flow between taxa was possible (Goemoery *et al*., 1999). In the present study, AFLPs (Vos *et al*., 1995) and chloroplast microsatellites (Weising and Gardner, 1999) are applied to reveal the relationship between *F. orientalis* from northern Turkey and *F. sylvatica* from Greece and Germany. The marker system is also applied in *F. orientalis* individuals of two botanical gardens. Additionally, leaf morphological characters of one *F. orientalis* and one *F. sylvatica* provenance of a common site in a provenance trial are compared. Two questions are addressed: (1) Are *F. orientalis* and *F. sylvatica* two distinct (allopatric) species or is there evidence for gene exchange suggested by the clinal variation of morphological characters (Denk *et al*., 2002)? (2) Is the marker system applicable for the identification of plant material from unknown origin (for example, from botanical gardens)?

2 Material and Methods

2.1 Plant material

The seed samples of *F. orientalis* for the International Beech Provenance Trial were collected during October 1983 in Turkey and sent to the Institute at Groshansdorf for rearing of plants. In spring 1987 the trial was established near Eutin, North Germany, with three-year old seedlings (von Wuehlisch *et al.*, 1998; von Wuehlisch, 2004). During an inspection of the field trial by Prof. L. Paule, morphological characters of most of the trees of provenance *Devrek* originating from Tefen-Kirkdere, forest district Devrek, Turkey, were found to resemble *F. sylvatica* rather than *F. orientalis*. Also, the analysis of isozyme gene loci of this provenance showed allele frequencies to resemble those of *F. sylvatica* rather than those of *F. orientalis* (Goemoery, pers. communication). However, the morphology of the other seven provenances originating from Turkey appeared to be typical for *F. orientalis*. The geographic origin of *F. orientalis* populations is shown in Figure 1.

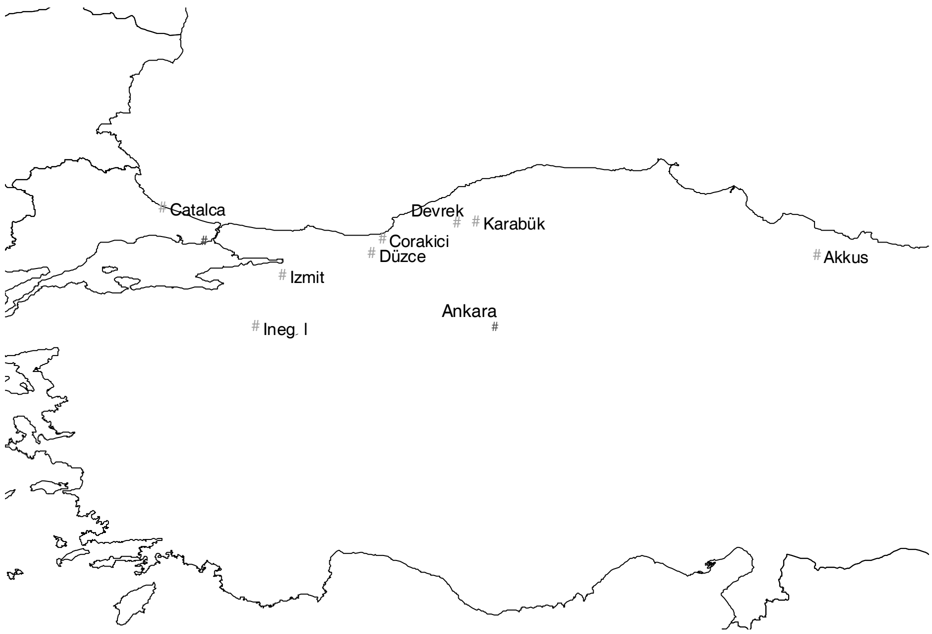


Figure 1. Location of the eight Turkish provenances analysed

Plant material that had been collected from *F. orientalis* trees from botanical gardens was verified as *F. orientalis* by their morphology (fruit and leaves). The trees from the botanical garden Goettingen are about 35 years *(orient3*), 20 years (*orient1*) and about 10 years old (*orient4, 5*). The three *F. orientalis* trees from the botanical garden at Hann. Muenden have an estimated age of about 80 years (*orient7, 8, 9*).

2.2 Molecular markers

DNA was extracted from buds using the Dneasy™ Plant Minikit (Qiagen, Hilden, Germany). DNA amount was tested on a 0.8% agarose gel after staining with ethidium bromide.

AFLP reactions were carried out according to the protocol of Vos *et al.* (1995) with slight modifications. Genomic DNA was restricted with *Eco*RI and *Mse*I. A preselective amplification was performed with the primer combination E01/M03 (nomenclature according to Keygene, http://wheat.pw.usda.gov/ggpages/keygeneAFLPs.html) with the following PCR profile: a first step of 2 min at 72 °C followed by 20 cycles of 10 s at 94 °C, 30 s at 56 °C, 2 min at 72 °C and an extension step for 30 min at 60 °C. Four ml of the preselective amplification product were used in the selective reaction with the primer combinations E38/M64 and E37/M68. The PCR profile was a denaturation at 94 °C for 2 min followed by nine cycles of 10 s at 94 °C, a 30 s annealing step at 65 °C and 2 min at 72 °C. The initial annealing temperature of 65 °C was reduced in each cycle by 1 °C. The last 24 cycles were performed with an annealing temperature of 56 °C ending with 30 min at 60 °C. The selective PCR reactions were carried out with *Eco*RI primers that were labelled with the fluorescent dyes 6-FAM and HEX. All PCR reactions were performed in the Peltier Thermal Cycler (PTC-0200 version 4.0, MJ Research). Fragments were separated on the ABI Genetic Analyser 3100 jointly with the internal size standard GS 500 ROX (fluorescent dye ROX) from Applied Biosystems. The size of the AFLP fragments was determined with the software packages Genescan 3.7 and Genotyper 3.7 (Applied Biosystems). Absence and presence of fragments of specific sizes were recognised and transformed into a 0/1 matrix (script for Genotyper 3.7 was kindly provided by Applied Biosystems). For 14 samples (designated with a resp. b in Figure 2) the AFLP procedure was repeated beginning with the restriction ligation reaction.

Chloroplast microsatellite markers were amplified according to Weising and Gardner (1999) and tested for polymorphisms in *F. sylvatica* and *F. orientalis*. Primer pairs *ccmp4, ccmp7* and *ccmp10* were amplified in the total sample, since they show variation in *F. sylvatica* (Vendramin, personal communication). Only *ccmp7* showed polymorphisms in our samples. Amplification products of *ccmp4*, *ccmp7* and *ccmp10* were separated on a 2 % agarose gel and excised from the gel. Gel extraction was performed with QIAEX II (Qiagen). The sequencing reactions were carried out with the Big Dye Terminator v.3.1 Cycle Sequencing Kit (Applied Biosystems) and run on the ABI 3100 Genetic Analyser. The chloroplast microsatellites were amplified in all 133 samples with one primer (the forward primer) labelled with the fluorescent dyes 6-FAM or HEX. In addition, reproducibility of the method was tested by the application of a temperature gradient from 40 to 52 °C annealing temperature (T_a) for *ccmp*7 in samples that represented all detected alleles (fragment sizes). Fragments were separated on the ABI 3100 sequencer and analysed as described above.

AFLP data were used to calculate an UPGMA (Unweighted Pair-Group Method Analysis) dendrogram from the mean number of pairwise character differences with the software package PAUP 4.0b10 (Swofford, 1998). Clusters were used to search for markers that are preferentially amplified in the one or in the other cluster. A neighbourjoining dendrogram with 100 bootstrap replicates was calculated.

2.3 Leaf Morphology

Leaves were harvested in the provenance trial mentioned above. From each of the three replications 10 trees were cut down and 10 leaves each were harvested from the lower, the middle, and the upper region of the crown resulting in a total of 900 leaves per provenance (10 leaves x 3 crown regions x 10 trees x 3 replications). *F. orientalis* is represented by the provenance Coracici, north Turkey, *F. sylvatica* by the local provenance of Eutin.

After harvest, the leaves were pressed between sheets of paper until measurement respective scoring of the following characters.

- length, width, area, weight of the leaves
- petiole length, length from bottom to widest leaf part of the leaves (distance)
- no. of nerves, left and right leaf side
- angle between 5th nerve and central axis, angle at leaf tip between leaf border and central axis
- leaf form: leaf in total, base, tip, border, waviness of leaf border

3 Results

3.1 cpDNA Variation

Chloroplast microsatellite *ccmp7* is highly variable even within populations of *F. orientalis* from northern Turkey displaying seven different alleles represented by fragment sizes from 145 bp to 151 bp (Table 2). In *F. orientalis* samples from botanical gardens three alleles could be observed, the most frequent one (152 bp) is absent in the samples from northern Turkey. Chloroplast type1 (common in Germany) was observed in one sample of *F. orientalis* from the botanical garden Goettingen (*orient 1*), in all 10 samples of population Devrek and in 2 out of 8 samples from population Karabuek from northern Turkey. Chloroplast type 4 (148 bp) that is characteristic for the investigated *F. sylvatica* populations from Greece is present in *F. orientalis* populations Duezce, Inegoel, Akkus and Izmit (Table 2). Of all Turkish populations only population Devrek is fixed on one chloroplast type (type1, Table 2).

For *ccmp7,* one single allele (145 bp, type 1) was found in *F. sylvatica* from different locations in Germany (Table 1, 2). Five other *F. sylvatica* samples from Mt. Olymp (Greece) classified as intermediate between *F. orientalis* and *F. sylvatica* (*F. sylvatica* var. *moesiaca*) by leaf morphology showed chloroplast type 1 as well. Three *F. sylvatica* populations from Greece (from Mt. Olymp, Piera Mountains, Gardiki) revealed a different chloroplast type (148 bp = type 4).

Table 1: - Provenances of *Fagus sylvatica* and *F. orientalis.*

taxon descript.	country	region	name	n trees	location	latitude	longitude	alt. (m)
orientalis	Turkey	Corakici	Cora	10	provenance test	41°03'	31°17'	900
orientalis	Turkey	Duezce	Duzce	10	provenance test	40°51'	31°09'	1050
orientalis	Turkey	Akkus	Akkus	10	provenance test	40°50'	37°05'	1250
orientalis	Turkey	Catalca	Catal	10	provenance test	41°28'	28°21'	350
orientalis	Turkey	Inegoel	Ineg	10	provenance test	39°53'	29°36'	1300
orientalis	Turkey	Izmit	Izmit	10	provenance test	40°34'	29°57'	1250
orientalis	Turkey	Karabuek	Kara	10	provenance test	41°17'	32°32'	900
orientalis	Turkey	Devrek	Devre	10	provenance test	41°16'	32°17'	950
orientalis	unknown	bot. garden	orient	7	botanical garden			
sylvatica	Germany		sylnb	13	Goettingen,			
			syln		Solling,			
			syl		Botanical gardens			
sylvatica	Greece		o	5 (10)	Mt. Olymp			
			m	5 (10)	Pieria Mountains			
			g	5 (10)	Gardiki, near Lamia			
var. *moesiaca*	Greece			5	Mt. Olymp			

F. orientalis from Turkey were sampled in the International Beech Provenance Trial 1983/86, Eutin. For *F. sylvatica* from Greece (o,g,m) 30 samples were examined with chloroplast microsatellites, 15 of these samples were analysed with AFLPs.

3.2 AFLP analysis

About 300 fragments were generated using two selective AFLP primer combinations (E38/M64; E37/M68). In a preliminary investigation we screened 8 samples of *F. sylvatica* and 6 samples of *F. orientalis*. We found 39 fragments that were either preferentially amplified in *F. orientalis* or *F. sylvatica,* respectively. The fragments were used in the analysis of all 133 samples. For control, all AFLP reactions were repeated for 14 samples. The UPGMA dendrogram based on the mean number of pairwise character differences revealed three major clusters. Replicated samples always cluster together (Figure 2, samples designated with a and b). Most *F. orientalis* collected from the botanical gardens Goettingen and Hann. Muenden form a separate "upper" group due to many common characters indicating a common origin (see below). The remaining samples from defined origins cluster in two large groups. One group (cluster 1) contains *F. orientalis* samples from northern Turkey and two *F. orientalis* from the botanical garden Goettingen (*orient1, orient5*) plus one sample of *F. sylvatica* from Greece (*o4*). The "lower" cluster (cluster 2) comprises *F. sylvatica* from Germany and Greece, but also nine out of ten samples from population Devrek and two samples from the neighbouring population Karabuek from northern Turkey originally described as *F. orientalis* (Table 1, Figure 2). The mean character difference between cluster 1 and cluster 2 is 25.9 % (Figure 3). In a neighbourjoining analysis with 100 bootstrap replicates only the "upper" *F. orientalis* group from the botanical gardens is well supported (Figure 2). Significant bootstrap values are otherwise only observed for replicated samples and two samples from population Catalca (Figure 2).

3.3 Comparison of cpDNA and nuclear AFLP

In cluster 2 chloroplast type 1 and 4 can be observed. Samples from populations Devrek and Karabuek from northern Turkey that cluster jointly with *F. sylvatica* revealed chloroplast type 1 (145 bp at *ccmp*7) of *F. sylvatica* (*Figure 2*, *Table 2*). Samples described as *F. sylvatica* var. *moesiaca* from Mt. Olymp (Greece) also have chloroplast type 1. The remaining *F. sylvatica* samples from Greece show chloroplast type 4 (Figure 2, dark grey).

In cluster 1 (*F. orientalis* cluster) *ccmp7* is highly variable with seven alleles (Table 2). Chloroplast type 1 is present in two samples (*Devrek50*, *orient1,* shaded in pale grey). These samples also cluster in the AFLP dendrogram. Chloroplast type 4 is present in 18 samples of the *F. orientalis* cluster (dark grey shades).

The “upper” cluster comprises *F. orientalis* from the botanical gardens Goettingen and Hann. Muenden with chloroplast type 8 (152 bp, *orient 3, 4, 7 ,9*) and one sample (*orient 8*) with chloroplast type 1 of *F. sylvatica*. Sample *orient* 8 clusters with this group based on 15 common AFLP bands (bootstrap value 71, Figure 2) but can be distinguished from all other samples of the “upper” cluster by 8 AFLP bands. Five of these fragments show a significantly higher frequency (33% to 73% higher) in the *F. sylvatica* cluster than in *F. orientalis* cluster 1. The remaining three AFLP bands show no pronounced differences between clusters (less than 10%). *Orient8* possesses AFLP fragment E37/M68 –130 bp that is otherwise absent in *F. orientalis* cluster 1 and in the “upper” *F. orientalis* cluster 3.

Table 2: – Frequencies of chloroplast types in *ccmp7* (fragment size in base pairs, bp) and differential amplification of AFLP E37/M68-130 bp.

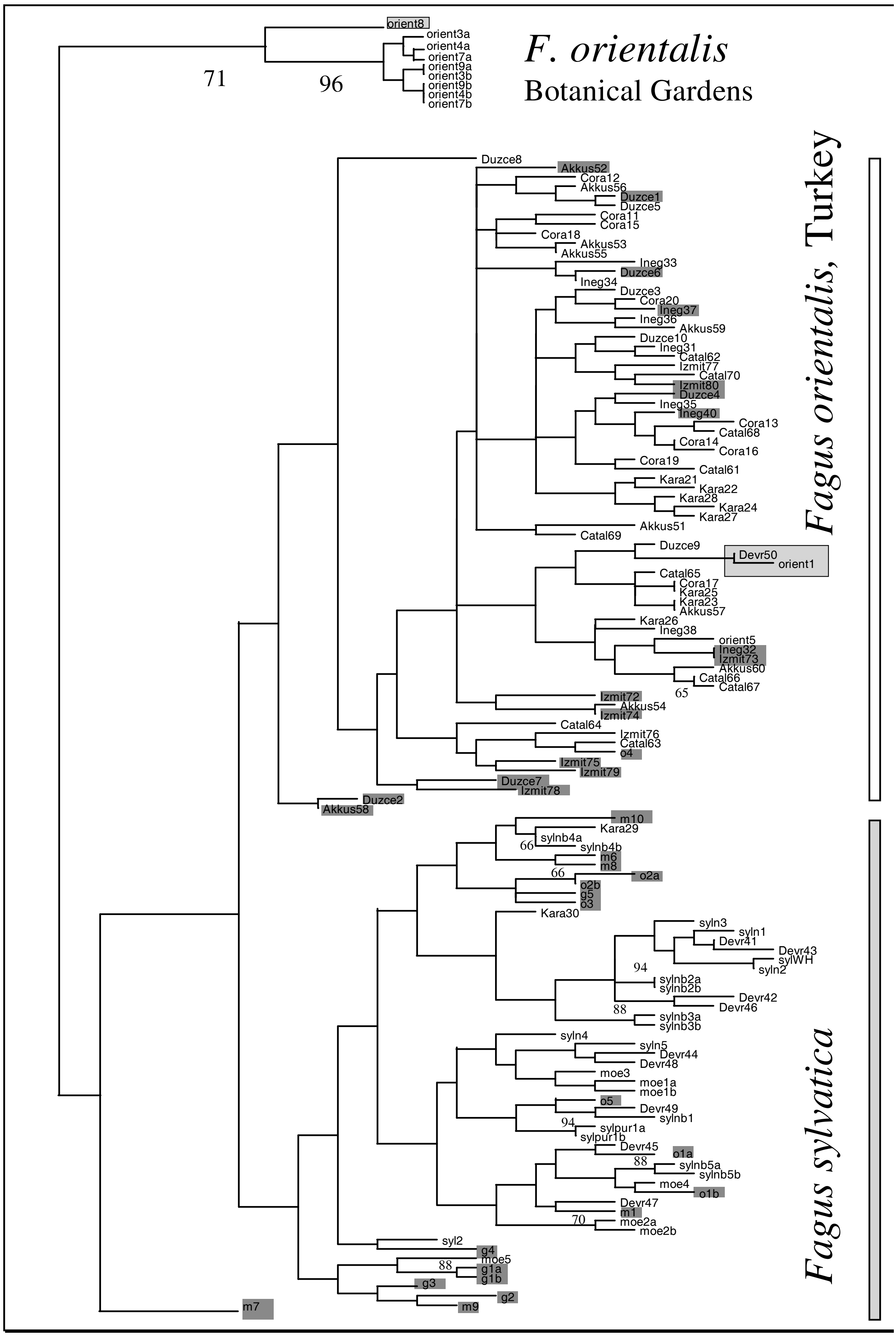
region	name	taxon	chloroplast type								AFLP130	
			1	2	3	4	5	6	7	8		
			145	146	147	148	149	150	151	152	present	absent
			bp	bp	bp	bp	bp	bp	bp	bp		
Duezce	Duezce	*orient.*				5	2		3		0	10
Corakici	Cora	*orient.*			1		5				0	10
Karabuek	Kara	*orient.*	2	6							2	8
Inegoel	Ineg	*orient.*				4	2	4			0	10
Devrek	Devre	*orient.*	10								4	6
Akkus	Akkus	*orient.*				2	1	4			0	10
Catalca	Catal	*orient.*					3	3			0	10
Izmit	Izmit	*orient.*			2	6					0	10
Bot. Garden	orient	*orient.*	1		1					4	1	5
Lower Saxony	*syl*	*sylv.*	13								11	2
Greece	o,m,g	*sylv.*				30					3	11
Olymp	*moe.*	*moe-siaca*	5								3	2

3.4 AFLP bands differing between cluster 1 and 2

AFLP fragments were sorted according to the degree of differentiation between clusters 1 and 2. Frequencies of amplification products in cluster 1 (*F. orientalis* from northern Turkey) and cluster 2 (*F. sylvatica* cluster) are shown for all 39 AFLP fragments in Figure 3 (middle and lower part). The difference in frequencies between cluster 1 and cluster 2 (Figure 3, upper part) is a measure for the utility of the AFLP marker for the distinction of these clusters. Amplification products that show the strongest differences in frequencies between clusters (above 60%) show high frequencies in the *F. sylvatica* cluster (above 70 %) and very low frequencies in the *F. orientalis* cluster (Figure 3, upper part). Fragments with high frequencies in the *F. orientalis* cluster also show relatively high frequencies in the *F. sylvatica* cluster (Figure 3, right side). None of the bands was diagnostic for the *F. sylvatica* or *F. orientalis* cluster. Thirteen markers show either no amplification product in the *F. orientalis* or in the *F. sylvatica* cluster (Figure 3). One of the fragments (E37/M68-130bp) that is absent in the *F. orientalis* cluster and in 11 out of 14 *F. sylvatica* with chloroplast type 4 from Greece is present in 11 out of 13 *F. sylvatica* samples from Germany (Table 2). The fragment is also amplified in the two samples from provenance Karabuek that cluster with *F. sylvatica*. In population Devrek and in *F. sylvatica* var. *moesiaca* presence and absence of the band is evenly distributed (Table 2).

3.5 F. orientalis from botanical gardens

Two *F. orientalis* from the botanical garden Goettingen (*orient1*, *orient5*) cluster with *F. orientalis* from northern Turkey. One has chloroplast type 1 (*orient1*), the other has a chloroplast type observed once in population Corakici and twice in population Izmit (147 bp, Table 2). *Orient1* clusters with one sample from population Devrek (*Devrek50*), northern Turkey, with the same chloroplast type 1. The “upper” cluster of *F. orientalis* from botanical gardens Goettingen and Hann.Muenden differs distinctly from all samples of northern Turkey. These samples are very similar (bootstrap value 96, 35 out of 37 AFLP fragments have an identical amplification pattern) and differ clearly from all other samples in the AFLP analysis and by a unique chloroplast type (152 bp).



F. orientalis
Botanical Gardens
orient8
orient3a
orient4a
orient7a
orient9a
orient3b
orient9b
orient4b
orient7b
71
96
Fagus orientalis, Turkey
Duzce8
Akkus52
Cora12
Akkus56
Duzce1
Duzce5
Cora11
Cora15
Cora18
Akkus53
Akkus55
Ineg33
Duzce6
Ineg34
Duzce3
Cora20
Ineg37
Ineg36
Akkus59
Duzce10
Ineg31
Catal62
Izmit77
Catal70
Izmit80
Duzce4
Ineg35
Ineg40
Cora13
Catal68
Cora14
Cora16
Cora19
Catal61
Kara21
Kara22
Kara28
Kara24
Kara27
Akkus51
Catal69
Duzce9
Devr50
orient1
Catal65
Cora17
Kara25
Kara23
Akkus57
Kara26
Ineg38
orient5
Ineg32
Izmit73
Akkus60
Catal66
65
Catal67
Izmit72
Akkus54
Izmit74
Catal64
Izmit76
Catal63
o4
Izmit75
Izmit79
Duzce7
Izmit78
Duzce2
Akkus58
Fagus sylvatica
m10
Kara29
sylnb4a
66
sylnb4b
m6
m8
66
o2a
o2b
g5
o3
Kara30
syln3
syln1
Devr41
Devr43
sylWH
syln2
94
sylnb2a
sylnb2b
Devr42
Devr46
88
sylnb3a
sylnb3b
syln4
syln5
Devr44
Devr48
moe3
moe1a
moe1b
o5
Devr49
sylnb1
94
sylpur1a
sylpur1b
Devr45
o1a
88
sylnb5a
sylnb5b
moe4
o1b
Devr47
m1
70
moe2a
moe2b
syl2
g4
moe5
88
g1a
g1b
g3
g2
m9
m7

Figure 2 (previous page): UPGMA dendrogram from AFLP data based on the mean number of pairwise character differences calculated by Paup (Swofford, 1998). One "*F. orientalis"* and one "*F. sylvatica"* cluster can be distinguished. *F. orientalis* from the botanical gardens Goettingen and Hann.Muenden form a separate group. Chloroplast type 1 of *F. sylvatica* from Germany (pale gray shades, framed) and chloroplast type 4 of *F. sylvatica* from Greece (dark grey shades) are plotted on the dendrogram (see *Table 2*). In the *F. sylvatica* cluster all untagged samples have chloroplast type 1 (pale grey bulk). Bootstrap values higher than 50% (100 replicates) are indicated for a neighbourjoining analysis.

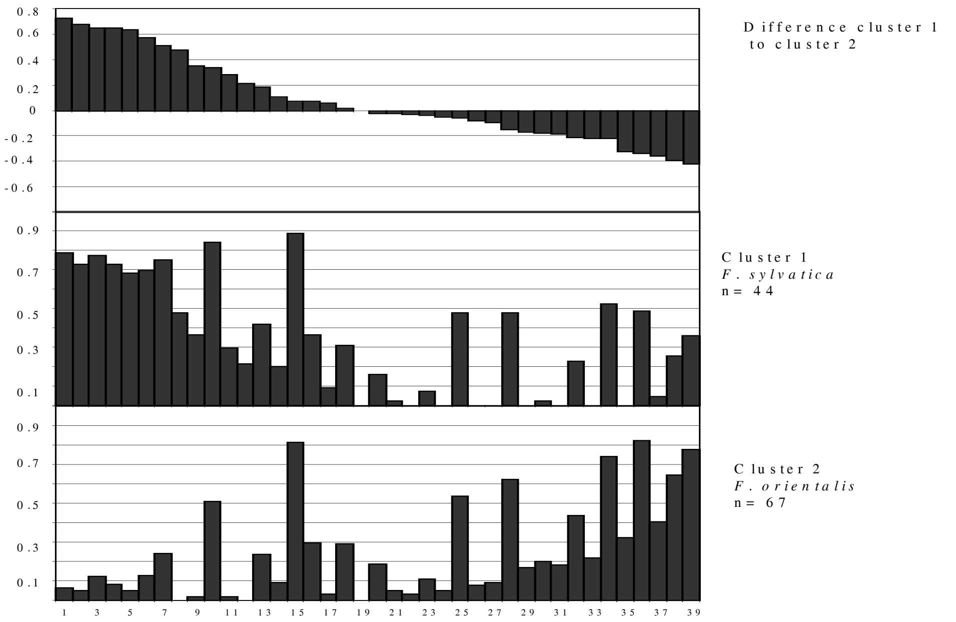


Figure 3. Differences in the frequencies of AFLP bands in samples of cluster 1 (*F. orientalis* cluster) and cluster 2 (*F. sylvatica* cluster) are shown for all 39 AFLP fragments (upper part). The corresponding relative frequencies of AFLP bands in samples of *F. sylvatica* cluster 1 and *F. orientalis* cluster 2 are displayed in the middle and lower part of the Figure.

3.6 Leaf morphology

The total variation within provenances and even in a tree, depending whether the leaf was from the top or lower part of the crown was large. The two provenances studied, Coracici for F. *orientalis* and Eutin for F. *sylvatica* proved to differ significantly for length, area, and weight of the leaf, petiole length and angle of the nerves as compared to the central axis and the distance between leaf base and the widest part of the leaf (distance). The number of nerves, the width and the shape of the leaf proved not to have a high discriminatory power for distinction of the two provenances representing the species.

Leaf characters	F. orientalis	F. sylvatica	Leaf shape types %	F. orientalis	F. sylvatica
Length* mm	88.4	77.3	Ovate elliptical	27.6	29.6
Width¯ mm	51.6	49.1	Wide ovate elliptical	33.8	50.5
Area* cm²	34.2	28.8	Oblong	11.3	11.3
Weight* mg	201.7	120.4	Spatulate elliptical	16.4	6.6
Distance* mm	47.8 (54%)	40.1 (52%)	Wide spatulate elliptical	8.2	2.2
Petiole length* mm	7.6	10.4	Rectangular	2.7	0
No. nerves¯	9.2	8.2			
Nerve angle*	40.0°	37.5°			

4 Discussion and Conclusions

4.1 Chloroplast microsatellites

The occurrence of only one chloroplast type in *F. sylvatica* in Germany is in accordance with earlier studies that show no variation in chloroplast markers for *F. sylvatica* of west-central Europe indicating a genetic bottleneck at the time of postglacial recolonisation. Results obtained from chloroplast markers and allozymes indicate a postglacial recolonisation of west-central Europe from one or few sources (Demesure et al., 1996, Dounavi, 2000, Goemoery et al., 1999). In the aforementioned studies no samples from Greece or northern Turkey were included.

The high variation of chloroplast types at *ccmp7* in *F. orientalis* of northern Turkey indicates a glacial refuge in this region. The occurrence of chloroplast type 1 and chloroplast type 4 points to the possibility that one source for postglacial recolonisation of west-central Europe was located in northern Turkey. Distant populations might have received only a subset of the original diversity of chloroplast types. The observation of only two chloroplast types in Greece - chloroplast type1 for *F. sylvatica var. moesiaca* from Mt. Olymp, chloroplast type 4 for *F. sylvatica* populations Mt. Olymp, Piera Mountains and Gardiki - supports this hypothesis.

Because of presumably high mutation rates in chloroplast microsatellites there is certainly a possibility that the same repeat number has evolved independently in different lineages (homoplasy). However, the conformity with other studies based on cpDNA, ITS and allozymes (Demesure et al., 1996, Denk et al., 2002, Dounavi, 2000, Goemoery et al., 1999) suggests that chloroplast type 1 of *F. sylvatica* from west-central Europe has evolved only once and can be traced back to one or a few populations.

4.2 AFLP markers

The absence of diagnostic markers for *F. sylvatica* and *F. orientalis* from northern Turkey, respectively, and low structuring in the neighbourjoining analysis points to a relatively recent differentiation of *Fagus* in western Asia and Europe presumably during the cold phases of the Pleistocene (Denk et al., 2002). The UPGMA dendrogram revealed one cluster including all *F. sylvatica* samples and one cluster with exclusively *F. orientalis* from northern Turkey. Samples from Greece (Mt. Olymp, material supplied by V. Meng) that were regarded as intermediate between *F. orientalis* and *F. sylvatica* by morphological criteria (*F. sylvatica* var. *moesiaca*) could not be distinguished from *F. sylvatica* by AFLPs or by chloroplast markers (see above). The nine samples from population Devrek and two samples from Karabuek in northern Turkey that cluster with *F. sylvatica* could be characterised as *F. sylvatica* by morphological characters. Additional investigations should clarify the possibility of anthropogenic transfer of *F. sylvatica* into this region. In accordance with our results, clustering of several morphological characters distinguished two morphotypes, one comprised *F. sylvatica* and *F. sylvatica* var. *moesiaca*, the other *F. orientalis* from western Asia (Denk et al., 2002).

Only one sample of *F. sylvatica* (*o4*) from Greece (Mt. Olymp) clusters with *F. orientalis* from Turkey. Genetic and morphological examinations in this region may reveal a transition zone ("hybrid zone") between *F. sylvatica* and *F. orientalis* in Greece.

A QTL mapping study of character differences between *F. orientalis* and *F. sylvatica* (for example, differences in leaf and cupule morphology) could yield information about the mode of character evolution that resulted in different morphotypes. Genetic markers that are highly correlated with character differences between *F. sylvatica* and *F. orientalis* might also allow for differentiation between populations of the two taxa.

4.3 cpDNA and AFLPs

In the AFLP dendrogram a *F. orientalis* cluster comprising samples from northern Turkey, a *F. sylvatica* cluster and one "upper" cluster with *F. orientalis* from the botanical gardens Goettingen and Hann. Muenden could be distinguished. The *F. sylvatica* cluster contains *F. sylvatica* from Germany and *F. sylvatica* from different locations in Greece but also two samples of population Karabuek and nine samples of population Devrek from northern Turkey. At chloroplast microsatellite *ccmp7* these samples show chloroplast type 1 as *F. sylvatica* from Germany. The congruence of AFLP and chloroplast data suggests that genetic variants (morphotypes) similar to *F. sylvatica* are present in the two nearby populations Devrek and Karabuek in northern Turkey (see *Table 2*) and might support the hypothesis that one refuge, from which postglacial recolonisation of west-central Europe started, was in northern Turkey. Also reinvestigation of morphological characters showed that these samples from northern Turkey are very similar to *F. sylvatica* (unpublished data). However, it can not be excluded that seeds of *F. sylvatica* had been transported by humans to northern Turkey across the Black Sea, although we do not have any evidence for this rather unlikely transfer.

One sample from population Devrek (*Devrek50*) with chloroplast type 1 clusters with *F. orientalis* (cluster 1) in the AFLP dendrogram pointing to gene flow between nearby populations that are composed of genetic variants similar to *F. sylvatica* or *F. orientalis*, respectively. Also clinal variation of morphological characters from Asia minor to Europe (Denk et al., 2002) suggests gene flow between the taxa. Additional studies especially in the contact zones of *F. orientalis* and *F. sylvatica* are necessary to determine possible gene exchange.

4.4 Individuals from botanical gardens

Two *F. orientalis* individuals from the botanical garden Goettingen (*orient1*, *orient5*) group together with *F. orientalis* from northern Turkey pointing to an origin in this region. *Orient1* clusters with *Devrek50* from northern Turkey in the AFLP dendrogram and possesses the same chloroplast type 1 of *F. sylvatica.* These examples illustrate that additional data on *F. orientalis* populations may allow to locate the geographical origin of samples from unknown sources (for example, from botanical gardens).

The “upper” group of *F. orientalis* (bootstrap value 96) comprises individuals from the botanical gardens Goettingen and Hann. Muenden. Since they are genetically very similar, it could not be excluded that the seed material originated from a single tree or closely related trees. Closer investigation revealed that *F. orientalis* from Hann. Muenden was grafted onto rootstocks of *F. sylvatica* in the botanical garden Goettingen in 1968 (V. Meng, pers. comm.). Thus *orient3*, *orient4* from Goettingen and *orient7*, *orient8* from Hann. Muenden are most likely one clone. The estimated age of 35 years of *orient3* supports this interpretation.

F. orientalis from the botanical garden Hann. Muenden (*orient8*) clusters with the “upper” *F. orientalis* in the AFLP analysis, but possesses chloroplast type 1 of *F. sylvatica* from Germany and one AFLP fragment that is not found in *F. orientalis* clusters (E37/M68-130 bp). Five out of eight AFLP bands that distinguish *orient8* from the other samples in the “upper” cluster show significantly higher frequencies in the *F. sylvatica* cluster than in *F. orientalis* cluster 1, suggesting that *orient8* might be a hybrid between *F. orientalis* (“upper” cluster) and *F. sylvatica*.

4.5 Leaf Morphology

The investigation of leaf characters was performed on 20 year old trees that have been raised under identical site conditions (spatially and temporally). Care was taken to eliminate differences due to exposition to sunlight by comparing only leaves of the same crown strata. The differences found are thus not confounded with biasing site, age, or shade effects. Numerous characters were found showing distinct differences. They principally confirm earlier findings of taxonomists. The discriminatory power of morphological characters seems to allow clear distinction between the two species. However, representative investigations should be carried out to verify this conclusion.

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Dynamics of oriental Beech stands in Fandoghlu forest, Ardebil/Iran

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Abstract

Fandoghlu forest with 4378 hectares area located at the end of Western Alborz Mountain Chains. For maintenance, restoration and development of forest resources, dynamical studies of vegetation cover is essential. Five stands (404 hectares) of oriental Beech (*Fagus orientalis* Lipsky) silviculturaly were surveyed. To achieve this beside structural menstruation (in 134 plots), some existing historical records also came into consideration.

After determining of 5 main forest types, the structural characteristics along with historical evidences was used to identify the current dynamical position of each stand and therefore the final climatic climax forest of location namely; high uneven-aged mixed multilayer ***Fagus*** and ***Quercus*** forest.

Key words: Fandoghlu, Dynamics, Stand, Oriental Beech, Climax

1 Introduction

There are two basic types of succession (Oksanen, 2002)**;** a) Primary Succession that occurs in completely new habitat such as substrates, glacier retreat or bay, volcanic eruption and b) Secondary Succession that occurs in the former ecosystem that has previously been occupied and is now abondened such as organic substrates, fire, logging and cultivation.

Also there are some points of views about the succession and the most acceptable one is demonstrated by Clemets which is known as a Integrated, Holistic view (Clements, 1928). This view supposes;

- Community as an entity, a unified functioning unit
- having integrated members
- showing Characteristics assemblages (deserts, ponds, forests)
- introducing some Evidences such as; Predictable succession pattern, Repeatable assemblages (Beech – Maple forest) and Presence of sp1 depends on sp2

As a rule of succession in a bare area having essential characteristics to grow plants at the three stages this kind of plants settle (Blumenshine, 2002)

- Pioneer ;
  - Annual Herbs, Grass (*Carex, Graminae*,…)
  - Shrubs (*Coryllus, Crataegus, Evonymus*,…)
  - Trees (*Salix ,Cerasus, Malus*,…)
- Intermediate ;
  - Transitional species (*Carpinus, Acer, Sorbus*,…)
- Climax;
  - Final species (*Quercus, Fagus*)

There are some studies about forests, in particular about the succession of Beech stands. Thomasius in 1987 have published an article titled “The ecology of Beech and some consequences in the case of a climatic change”. Stoyko (1992) have studied the Coenotic structure of climax and polydominant Beech forests in Ukraine. Also Buckley (1994) have published a book about the “Ecology and management of coppice woodlands” and disccussed some patterns of succession in woodlands of England. Oksanen (2002) have showed that there is some evidences to formation of soils in different stages of succession.

2 Materials and Methods

Fandoghlu is a unique forest with 4378 hectars area (Anon., 1984), located at the end of Western Elburz Mountain Chains in Ardebil Province. The area has smooth topography and climatically sub humid (Anon., 2002). It has also foggy forest with the exploited brown soil (Azimi, 2003). Most destruction are caused by man inventions during last 5 decades due to different traditional living needs of around 11 villages or trade of some valuable products to near large cities. So because of the long history of logging and other human disturbances it has been severely exploited and now most present-day woodlands are only consisted of coppice trees and shrubs (Sabeti, 1976) of some species mostly famous as pioneers such as common Hazel (Shaqaqi Afzal and Delfan Abazari, 1996). In a disturbed 913 hectars forest area seperately six main forest types of mixed Hazel-Beech (Anon., 1984) existed. Also some species heve not ability to survive and mostly or completely eliminated. This problem have caused that foresters think that the site is potentialy Hazel forest (Shaqaqi Afzal and Delfan Abazari, 1996), as its current name Fandoghlu says (Fandoghlu is a turkish name = the area mostly dominated by Hazel). But pioneer species can not be dominant at climax vegetation of forest resources, so we managed to study the succession of this forest to determine reasons of current stands composition, late stands composition and forcasting the future of stands composition (Buckly, 1996).

Studying the suuccession of these utilizations in Fandoghlu forest will help us to find the main reasons of forest stands degradation and to manage towards natural planning of man inventionsin this uniqe area. To study the succession there are some known methods but some of them are not applicable in most cases, therefore we tried to benefit 2 or 3 of these as a complementary evidences to admit our received results (David,1992).

The more known methods of study are:

- Direct observation
- Space for time substitution
- Inference from population structure
- Historical records
- Micro & Macro fossil deposits

We have organized a sampling to derive structural information of some quantitative and qualitative characteristics. Our Stand measurement was a kind of Systematic – Random sampling (Zobeiri, 1994). With the Sampling grid of 150*200 meters and the Plot area of 0.01 ha and the measurement of structural characteristics was done to get information on species, origin of sp., quality of sp., collar diameter, hight, canopy layers, canopy cover, regeneration, slope, aspect and altitude.

3 Results

The results of these measurements is illustrated in the table 1 and shows that how differnt are the measured stands.The studied stands in comparison together have similar quality or quantity in some cases, but also different in other cases for example; *Fagus,Corylus* and *Corylus - Fagus* are the same in diversity of woody species and collar average, but quietly different in other characteristics due to the structural difrences (Table 1).

Table 1. Qualitative and quantitative characteristics of different forest types.

Foret type Characteristics	*Fagus, Coryllus*	*Fagus,Coryllus* with *Carpinus*	*Coryllus,Carpinus* with *Quercus*	*Coryllus – Fagus*	Mixed *Coryllus*
Diversity of woody species	12	17	15	12	10
Two storied structure (%)	51	53	51	32	0
Number of woody species (n/ha)	2398	2972	2954	3821	3900
Averrage of collar diameter (mm)	50	45	52	51	5
Averrage of woody species height (m)	7.62	7.7	7.6	8	5.85
Species quality (%)	82	78	70	77	70
Canopy cover (%)	70	77	73	81	77
Regeneration (seed origin, %)	13.5	17	37	33.5	12
Number of saplings (n/ha)	8845	5621	6600	9514	8131
Frequency of *Corylus* (%)	25.5	30	24.7	52.5	60
Frequency of *Fagus* (%)	45.5	28.3	18	13	7

4 Discution and Conclusion

According to all Structural information and statistical analysis, the studied 5 stands are in different stages of ecological succession as below:

Fagus, Coryllus *Fagus, Coryllus* with *Carpinus*

Coryllus – Fagus *Coryllus, Carpinus* with *Quercus*

Mixed *Coryllus*

Also historical information derived from some books ”Ardebil through time” , local old and aware people (derived from 29 interviews) and the ground flora (presence of *Ilex*, *Asperula* and *Galium*) all together are the signs to admit that Fandoghlu was belong to high and productive forests of Beech and Oak. Also one can conclude that the current stands are developing towards "mixed multilayer uneven-aged standard forests of Oak and Beech".

But wich one is correct; *Fagetum*? or *Quercetum*? “It needs some more studies in the near future.”

This result is similar to some studies of Beech forests by other scientists in other places (Thomasius, 1987). Even some years ago virgin-like stocking of the flat and hilly country were regarded as natural oak mixed forests in many places, silvicultural experts unveiled that in most cases these were potential sites of beech forests. A beech forest as a mountainous, stenothermic and moist loving species is widespread in the humid climate of the Carpathias and partially spread in the semihumid climate of the Podolien (Stoyko, 1992). At the final stages of succession in coppice forests of Britain some trees such as *Fagus, Tilia, Fraxinus* and *Quercus* are dominant with a less existing pioneer species such as *Coryllus* and *Salix* (Buckly, 1994). In temperate humid climates, beeches will finally be the dominant species (Oksanen, 2002).

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Spatial variability of Carbon Sequestration in ectorganic and endorganic soil layers at two different forest types

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Abstract

All natural forests store C in phytomass, forest floor and soils. The capacity of natural forests to sequester CO_2 and store C emitted as a waste product of our industrial activities. Forest soil is important in sequestering atmospheric CO_2 and emitting trace gases that are active and enhance the greenhouse effect. Land use changes and predicted global warming, through their effects on net primary productivity, forest type and soil conditions, may have important influence on size of organic matter pool in the soil and direct affect on atmospheric concentration of trace gases. Soil organic matter is a key component of any terrestrial ecosystem, and any variation in its amount and composition has important effects on many of the processes that occur within the system. The loss of organic matter from soils following disturbance is an important source of CO_2 for the atmosphere. The consequences of doubling the global atmospheric CO_2 concentration may be seen in different ranges of spatial scale. Investigations of heterogeneity in natural systems have indicated substantial variability, even at scales of less than one meter. In fact, the values of a variable at sites that are close together are more similar than those further apart. In the present study, a spatial estimation theory known as geostatistics was applied by variogram and kriging interpolation for analysing soil carbon at two different forest types. The spatial analysis of carbon sequestration indicated a well defined structure of the variogram for all soil depths. According to ordinary kriging interpolation, carbon accumulation in forest floor of oak-beech forest type was 22.6 ton ha^{-1}, while in ash forest type was only 0.26 ton ha^{-1}. The storage of mineral carbon to a depth of 100 cm at the ash forest was 141.5 ton ha^{-1}, whereas at the oak-beech forest stand, was 99.3 ton ha^{-1}. An increase of carbon storage rate in soil mineral layers at the ash forest stand, created favorable soil conditions for rich vegetation species. The impact of tree species and soil properties were the most important factors influencing the spatial variability of carbon sequestration in the forest floor and mineral soil layers within two stands.

Keywords: Spatial variability, Carbon sequestration, Variogram, Kriging, Forest type

1 Introduction

It is well known that soil organic matter is the most important component of forest ecosystems, and any variability in its amount and chemical properties may affect many processes that occur within the system. The organic matter content in soil depends on the soil conditions, the vegetation cover (type and composition), topography, hydrological conditions, elevation and management practices. So these are the main factors of the organic matter variability (Garrett and Cox, 1973; Buringh, 1984). The total carbon pool contributed the greatest percentage of the organic matter content (more than 50 %) in comparison to other chemical elements (Buringh, 1984). Total carbon in soils, defined as the sum of both the organic and carbonate carbon, is estimated to be 2300×10^{15} g of C for the upper 100 cm of world soils (Sombroek *et al.*, 1993).

Carbon in forest ecosystems is cycled between the vegetation, litter, humus pools and atmosphere. Carbon compounds are the vital storage that plants store and use to build their structure and maintain their physiological processes. Land use changes and predicted global warming, through their effects on net primary productivity, forest type and soil conditions, may have important influence on the size of organic matter pool in the soil and direct effect atmospheric concentration of trace gases. The consequences of a doubling of the global atmospheric CO_2 Concentration may be seen in different ranges of the spatial scale heterogeneity in carbon sequestration at forest soils. Soil depth and soil type affect the amount of carbon sequestration. It is necessary to determine the soil carbon by deep sampling (> 50 cm depth), especially in old deep-rooting systems like forest ecosystem, for evaluating the amount of carbon in the soil.

Soil carbon accumulation was investigated in two different forest types. The purpose of this study was to evaluate the importance of forest soil as reservoir of sequestered carbon at two different vegetation types. The variability of carbon concentration was studied at soil ectorganic and endorganic layers.

2 Materials and Methods

2.1 Materials

The investigated zone covers an area of 2 ha. The elevation of the study area ranges from 18.5 up to 21 meters above sea level. This area is located at East-Flanders Forest of Belgium. Soil and vegetation conditions of the highest and the lowest parts of the study area differ considerably. Two main forest types were selected: oak-beech and ash stands with 75 years old. The oak-beech forest type on the slope side of the study area (1.2 ha) is a typical thin Quaternary deposit of the sandy loam texture on a shallow impermeable clay and sand complex of the Tertiary formation. The ash forest type on flat side of the study area (0.8 ha) is an alluvial deposit with thick Quaternary of the loamy texture, where the impermeable layer ceases and the Tertiary origin cannot be found at least at 4 m depth (Zahedi, 1998).

2.2 Methods

The organic carbon was determined in two ways: by loss ignition after heating at 375°C for 24 h, and by the method of Walkley & Black. In most studies, soil carbon content has been calculated to a depth of 100 cm, except for shallow Lithosols (Batges, 1996). Large amounts of soil organic carbon lie below 100 cm in both mineral and organic soils (Sombroek *et al.*, 1993). The objective of this study was to analyze the carbon sequestration of the different soil depths for the two forest types.

The carbon content (g/m^2) was obtained from the multiplication of the biomass (g/m^2) with the carbon percentage for each ectorganic horizons. The value of the bulk density was used for each separated mineral depth to estimate the carbon content for the soil mineral layers. It is well known that the bulk density is critical for converting the total carbon percentage by weight to content by volume (e.g. kg/m^2 to a certain soil depth), but it varies with soil structure. In general, bulk density is determined by a core sampling which is comparable with values obtained by the clod method (Vogel, 1994). The following formula was used to calculate the carbon accumulation (g/m^2) at different depths of mineral soil (Vandendriessche et al, 1993):

$$Cc\ (g/m^2) = 10000 \times C\ (\%) \times Bd\ (g/cm^3) \times e\ (cm)$$

Where the **Cc** (g/m^2) is the carbon sequestration at the mineral layer, **C** (%) is the carbon concentration, the **Bd** is the bulk density (g/m^3) and **e** is also the thickness of the mineral layers (cm).

In this research, the basic method of the vegetation analysis is based on the two-way indicator species analysis (TWINSPAN). Forest classification was carried out using herbal species and main dominated trees. Classical statistics and the geostatistical analysis were used by, GEO-EAS and GEOPACK software. For the monitoring of the spatial interpolation, we applied the GIS application IDRISIWIN.

3 Results

There is a significant carbon accumulation both as un-decomposed litter on the soil surface and as organic matter in the surface mineral layers. The highest and lowest mean total carbon percentage was found in the litter and sub-mineral (50 - 100 cm depth) layers respectively (table 1). Figure1 illustrates the mean sampling depth. The error bars in this figure show standard error of the mean values. The mean value decreases as the soil depth increase, whereas the coefficient of variation increases with soil depth. The carbon percentage at the sub-mineral layer indicated that the relative variability increases with soil depth, however the absolute values decrease strongly. The oak-beech and ash stands have a different spatial distribution of the carbon accumulation, partly reflecting the soil and humus conditions of the tree species. The soil conditions are also quite different, particularly with respect to their drainage and organic matter content. Several studies found also a negative correlation between total carbon percentage with soil depth. Buringh (1984) in a study of soils, in which soil carbon has been determined to a depth of 1 m, found that the total carbon content is less than 0.2 %. Soil surface (0- 20 cm depth) layers seldom contained more than 5 % carbon. The H layer showed more variability among ectorganic horizons. As discussed earlier, it may be related to the differences in potential of carbon storage between the two stands. In order to reveal the possible spatial structure of the observations, semivariograms were computed for the carbon concentration at different soil depths. The structure of the semivariograms was found to be the same in different directions. Therefore, the variograms were considered to be isotropic. As illustrated in Figure 2, all variograms indicate a well-defined structure. A definite rise of the curves in this figure as a function of distance was sufficient proof of the spatial dependence. The parameters of the fitted models of the experimental variograms are given in Table 2. The variograms of the carbon concentration of the L and the mineral soil at 0-5 cm depth were fitted by a spherical model. The F, H and 5-15 cm layers were fitted by an exponential model. All variograms indicate no relative nugget effects (between 0 - 1 %). This confirms that the sampling interval of the carbon percentage data was selected well for the spatial estimation in the study area. With increasing lag distance, the semivariogram function also increased and reached a maximum value.

Table 1. Statistical parameters of carbon concentration (%) at different soil depths.

Statistical parameters	L	F	H	0-5 cm	5-15 cm	15-50 cm	50-100 cm
Number of samples	102	76	76	118	118	118	118
Mean	46.11	41.24	26.3	5.30	2.42	0.91	0.27
Std. Dev	1.07	3.84	6.35	1.71	0.88	0.37	0.153
% C.V.	2.33	9.32	24.13	32.3	36.4	41	57

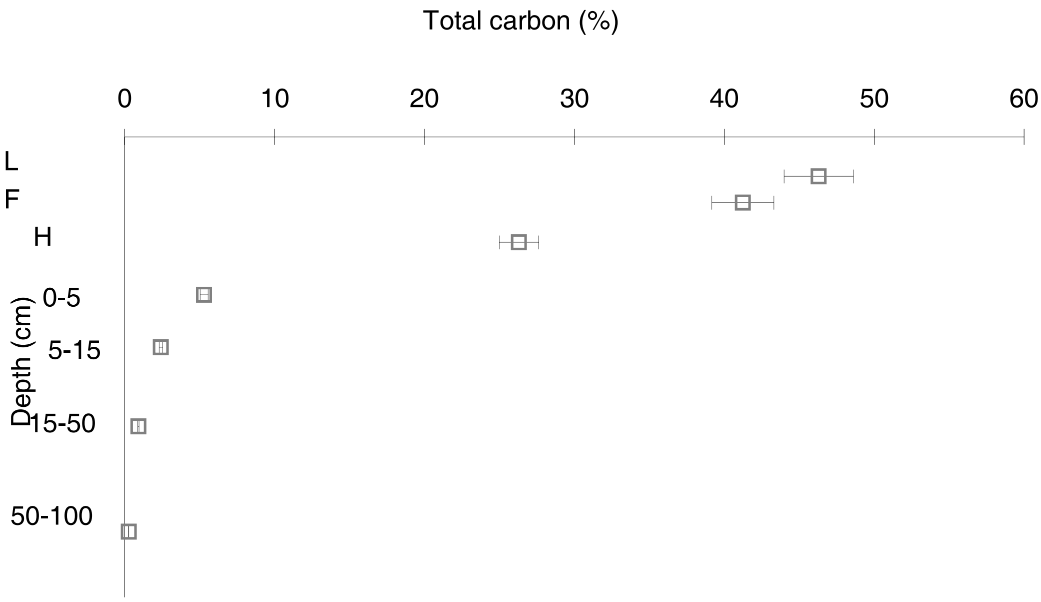


Figure 1. Average carbon concentration at different soil depths of the study area. The horizontal bar represents the standard error of mean carbon at each depth

The distance over where there was spatial dependence for the carbon percentage varied between different depths. The range for the L, F and H horizons was calculated to 45, 32 and 38 m, respectively. Whereas, the range of variogram for the top-mineral layers was 18 m. Therefore, on average, samples separated by 18 m or more were not correlated to each other for the top-mineral layers.

Ordinary kriging with blocks of 2×2 m was used for the interpolation carbon percentage at different soil depths within the two forest types. The kriged maps of the total carbon within the ectorganic horizons showed that the L layer covers a carbon percentage ranged between 46 and 47 over half of the interpolated area within the oak-beech stand. While, for the ash stand the estimated map of total carbon at the L layer indicated that only 16 % of the interpolated area showed a carbon percentage within this range. Therefore, the oak-beech stand represented a higher percentage of the carbon storage in the litter layer than the ash stand. The objective of this part was to analyze the carbon sequestration of the different soil depths for the two forest types. In this study, three depths of the organic horizons and four depths of the mineral layers were used to estimate carbon content separately.

Table 2. Parameter of the models fitted to experimental variograms of the soil carbon concentration at the ectorganic and mineral layers

Depth	Model	Nugget	Relative nugget (%)	C	Sill	Structured part = C/sill ×100 (%)	Range (m)
L	Spherical	0.01	1	0.79	0.80	99	45
F	Exponential	0.00	0	9.1	9.1	100	32
H	Exponential	0.00	0	36	36	100	38
0-5 cm	Spherical	0.00	0	2.33	2.33	100	18
5-15 cm	Exponential	0.00	0	0.70	0.70	100	18

Table 3 presents the bulk density of the study area, on the basis of humus types within different mineral layers, which was used in this research. The following formula was used to calculate the carbon accumulation (g/m^2) at different depths of mineral soil:

$$Cc\ (g/m^2) = 10000 \times C\ (\%) \times Bd\ (g/cm^3) \times e\ (cm)$$

Where the **Cc** (g/m^2) is the carbon sequestration at the mineral layer, **C** (%) is the carbon concentration, the **Bd** is the bulk density (g/m^3) and **e** is also the thickness of the mineral layers (cm).

Table 3. Bulk density at different soil depths in the study area

Soil depth (cm)	Bulk density (gm^3) Oak-Beech stand (moder)	Ash stand (mull)
0 – 5	1.169	1.144
5 - 15	1.311	1.164
15 - 50	1.347	1.184
50 - 100	1.052	1.612

Table 4 presents the carbon storage amount at different soil depths within the two stands. The average carbon amount on the forest floor was markedly lower than in the mineral layers because of low bulk density and limited thickness.

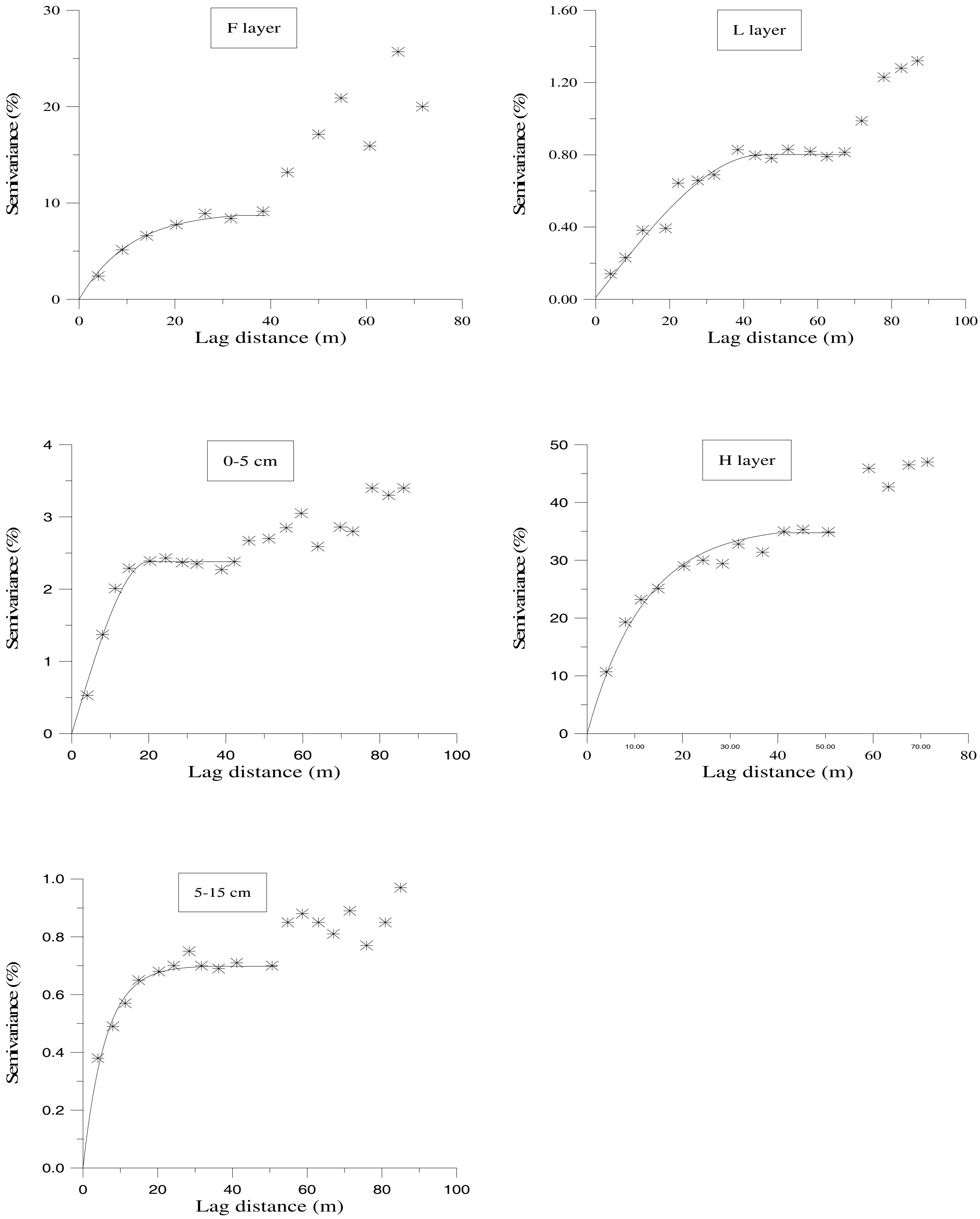


Figure 2. Experimental variograms (points) and spherical fitted models (lines) of carbon concentration at L and 0 - 5 cm layers and exponential model (line) for the F, H and 5 - 15 cm layers.

The carbon contents of the oak-beech stand floor were considerably higher than the ash stand. In contrast, in the mineral layer up to a depth of 100 cm, it was lower. Carbon content was estimated 163 ton ha^{-1} at depth of 100 cm in the ash stand, whereas for the oak-beech stand it was 135 ton ha^{-1}. Accumulation of carbon contents at the forest floor within the oak-beech stand (33 ton ha^{-1}) was higher than the ash stand (0.05 ton ha^{-1}). According to our data, the carbon accumulation in the ectorganic horizons was estimated to be 22.6 ton ha^{-1} within oak-beech stand, whereas in the ash stand it was calculated to be 0.26 ton ha^{-1}. The carbon storage to a depth of 100 cm was computed to 141.5 ton ha^{-1}, while for the oak-beech stand was estimated to 99.3 ton ha^{-1}. Comparing the mean value of the total carbon content between the two stands showed that the oak-beech stand with a higher sequestration of organic carbon in the forest floor than in the ash stand, due to a decreases decomposition rate (higher C/N ratio) and a lower pH value. The ash stand with a higher mineral carbon pool in the deeper soil layers and fast decomposition of the organic matter, accelerates the microbial processes and finally produces a humus with active mull characteristics.

Table 4. Total carbon content different soil depths within two forest types.

Soil depth	Oak-Beech stand Mean (g/m^2)	Oak-Beech stand Std. Error (g/m^2)	Ash stand Mean (g/m^2)	Ash stand Std. Error (g/m^2)
L	47	7.2	18	1.8
F	1512	203	1.1	022
H	706	84	7.5	2.8
LFH	2260	240	203	37
0 - 5 cm	2740	160	3290	220
5 - 15 cm	2770	220	3300	190
15 - 50 cm	3320	190	4740	170
50 - 100 cm	1100	90	2820	200
0 - 100 cm	9930	460	14150	520

Estimated maps of the L layer showed that about 83 % of the interpolated area of the oak-beech stand covers higher carbon content than the ash stand ranges between 20 and 40 g/m^2 (table 5 and fig 4). The interpolated maps of the F and H layers within the oak-beech stand indicated also a higher content of the total carbon than the ash stand (fig3). The average of the interpolated maps for the ectorganic layers was estimated to be 0.3 ton ha^{-1} and 25 ton ha^{-1} respectively for the ash and oak-beech stands. The interpolated maps of the top-mineral layers showed that about 61 and 68 % of the estimated areas of the ash stand show a higher carbon content than the oak-beech stand respectively in the 0 - 5 and 5 - 15 cm soil depths between range 6 - 10 kg/m^2. The estimated maps at sub-mineral layers within the ash stand indicated also a higher mineral carbon pool than the oak-beech stand (fig4). The rate of carbon content accumulation on the basis of the interpolated areas within ash was averaged to 169 ton ha^{-1} for a depth of 0 - 100 cm for the mineral layers, while for the oak-beech stand it was calculated to be 116 ton ha^{-1} (table 5).

Table5. Mean value of the observation points and the estimated carbon sequestration in two different stands

Soil depth	Oak-Beech stand Observation	Oak-Beech stand Estimation	Ash stand Observation	Ash stand Estimation
LFH	22.6 ton ha^{-1}	25 ton ha^{-1}	0.26 ton ha^{-1}	0.3 ton ha^{-1}
0 - 100 cm	99.3 ton ha^{-1}	116 ton ha^{-1}	141.5 ton ha^{-1}	169 ton ha^{-1}

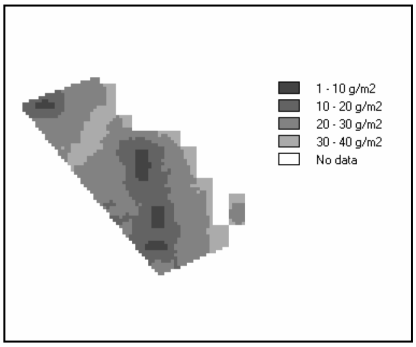
4 Discussion and Conclusion

The oak-beech stand is characterized by a marked organic matter accumulation in soil layer surface with moder humus type, a typical thin Quaternary deposit, shallow impermeable clay and sand complexes of the Tertiary formation. Whereas, the ash stand can be characterized by quick litter decomposition and high earthworm concentrations with mull humus characteristics on the alluvial deposit. Comparison between a beech (*Fagus sylvatica*) forest under similar conditions of climate and soil with an ash (*Fraxinus excelsior*) forest with mull humus type appears to have a supposedly faster mineralization. However, it may have a comparable quantity of carbon stored in the soil, because rapid decay of high quality litter (e.g., ash) does not necessarily mean that the carbon is rapidly mineralized (Schlesinger, 1977), and since the humus formed has a greater longevity and is more profoundly mixed with the deeper soil layers due to earthworm activity (Muys and Lust, 1992). In addition, under these conditions, the oak-beech stand affects the amount of the carbon accumulation in the ectorganic layers. Soil conditions in turn are most influenced by the soil moisture and temperature regimes, although the biological and mineralogical aspects are also important (Buringh, 1984). During the growth season, the litter layer can develop to more than 10 cm depth. So the accumulation of the organic carbon is usually considerable. The litter layer tends to decline in the later stages of decomposition, due to very slow biological activities. Therefore, this stand has with a large amount of the carbon accumulation in the forest floor. On the contrary, the ash stand is associated with a higher decomposition rate, the suitable conditions for microbial activities resulting considerable mineral carbon storage in the A1 and Bw horizons.

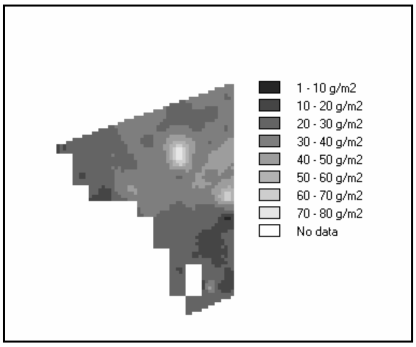
It was concluded that the mean value of carbon concentration decreases as the soil depth increases, while the coefficient of variation increases with soil depth. The sub-mineral layer (50 - 100 cm) showed the higher variability in comparison with all other layers. We concluded that the soil conditions and forest vegetation type were the most important factors, affecting to this variability. The carbon concentration in the L and F layers indicated a low variability among vegetation types. There is a significant difference between ectorganic and mineral layers in respect to carbon sequestration.

The spatial analysis of the carbon percentage indicated a well defined structure of the variogram of soil organic matter for all soil depths. It is also concluded that the sampling interval for the carbon percentage was chosen well for the spatial estimation in the study area. The minimum and maximum distance over which there was spatial dependence varied from 18 m to 45 m for the L and 5 - 15 cm layers respectively. The ordinary kriging interpolation showed that the oak-beech stand has a higher accumulation of carbon percentage in the ectorganic layers than the ash stand, whereas the ash stand stores higher carbon storage in the mineral soil layers than the oak-beech stand. Carbon content at the ectorganic layers and mineral soil to a depth of 100 cm indicated different carbon content accumulation within the two forest types. It was concluded that the oak-beech stand shows a higher organic carbon content in the forest floor than the ash stand, while the ash stand at 0 - 100 cm soil depth contains a larger mineral carbon pool than the oak-beech stand. The carbon accumulation in the forest floor within the oak-beech stand was estimated to be 22.6 ton ha^{-1}, while in the ash stand it was calculated to be only 0.26 ton ha^{-1}. The storage of mineral carbon to a depth of 100 cm within the ash stand was calculated to be 141.5 ton ha^{-1}, whereas for the oak-beech stand it was estimated to be 99.3 ton ha^{-1}.

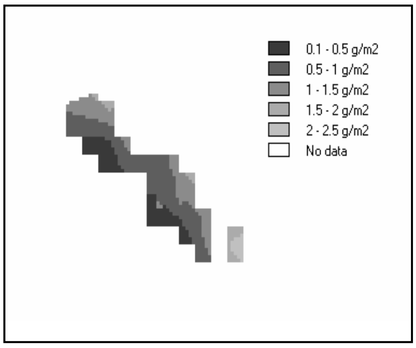
It is concluded that the impact of plant species (oak, beech and ash trees) and soil characteristics (alluvium and Quaternary/Tertiary materials) are the most important factors influencing the carbon sequestration in the forest floor and in the mineral soil layers.



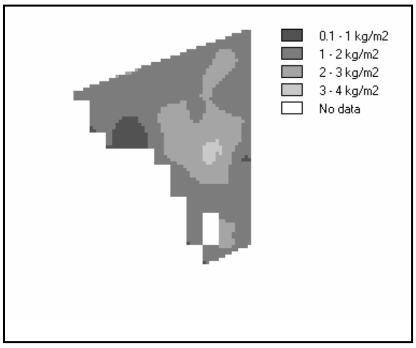
Ash stand (L layer)



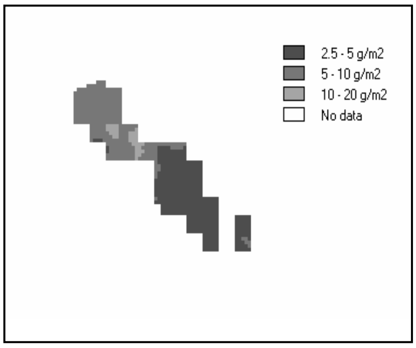
Oak-Beech stand (L layer)



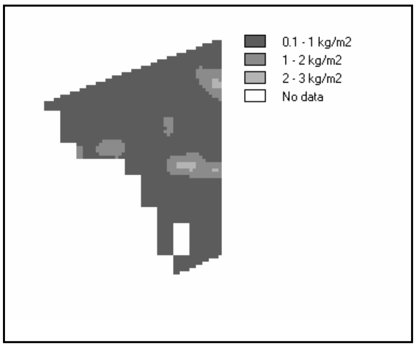
Ash stand (F layer)



Oak-Beech stand (F layer)



Ash stand (H layer)



Oak-Beech stand (H layer)

Figure 3. Carbon sequestration maps of two different forest stands at ectorganic horizons.

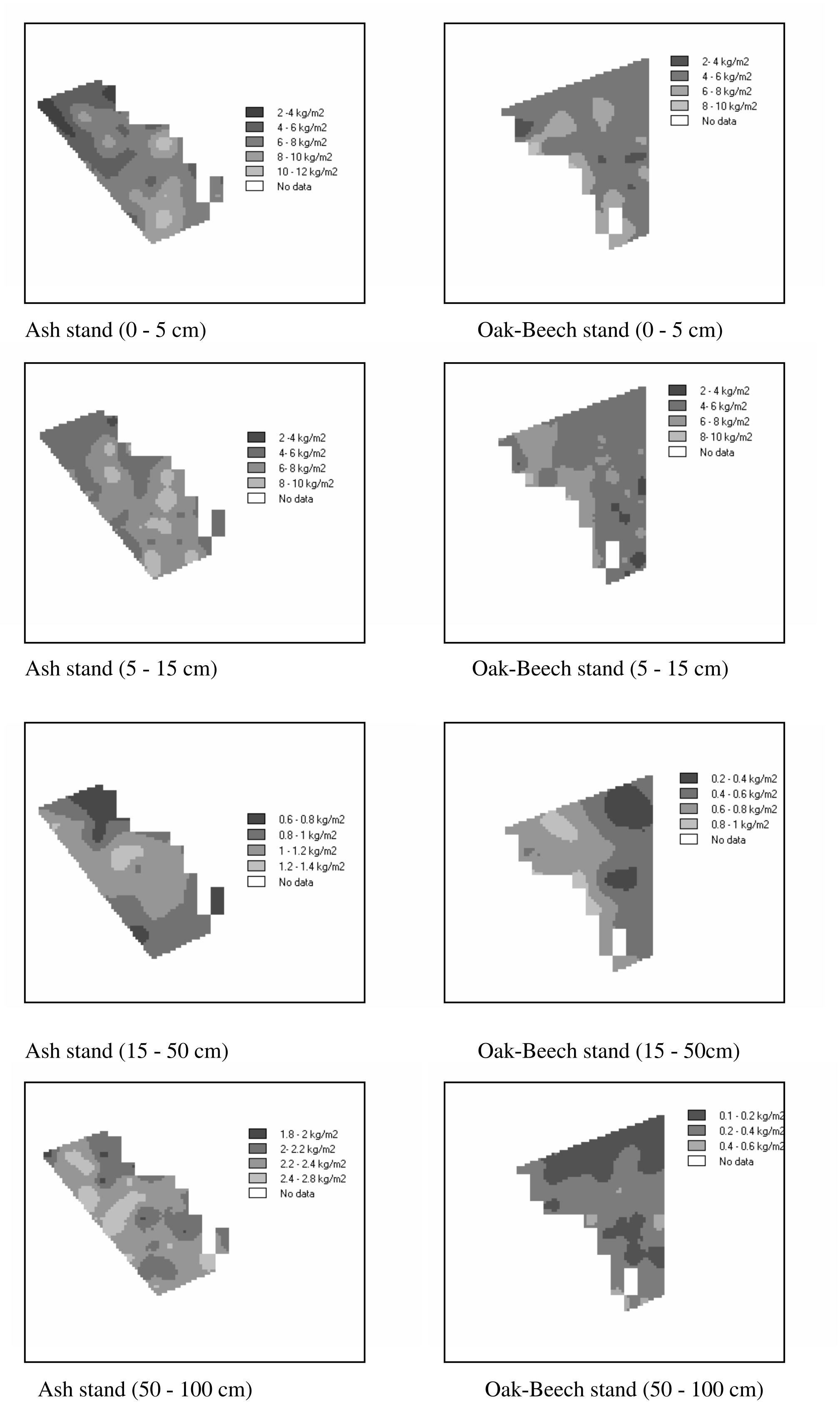


Figure 4. Carbon sequestration maps of two different forest types at the mineral soil layer.

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Thinning and Stem Quality in Pure and Mixed Beech (*Fagus sylvatica* L.) Stands

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Abstract

The production of high quality beech timber is necessary for a multifunctional management of beech forests. The influence of thinning on the stem quality is analysed on the basis of 28 permanent long-term growth and yield research plots in pure beech (*Fagus sylvatica* L.) stands and in mixed species stands which include beech. Heavy thinning results in a higher proportion of high quality stem timber, but also slightly reduce total production. An even horizontal distribution of the stems and, in mixed stands, beech in groups results in better quality conditions.

Keywords: Thinning, *Fagus sylvatica* L., Stem quality, Pure stands, Mixed stands

1 Introduction

Beech (*Fagus sylvatica* L.) is one of the important tree species in Switzerland. It occurs in both pure and mixed stands. Forest growth and yield research at the Swiss Federal Institute for Forest, Snow and Landscape Research WSL in Birmensdorf, Switzerland, has been monitoring research plots in pure beech stands as well as in mixed stands for more than 100 years. It is possible to compare and to interpret the data and the results because the same silvicultural methods are applied in both stand types.

Discussions on various silvicultural systems are often based on personal experience and observations only. However, such discussions often lack an objective and representative basis. This demonstrates the enormous importance of long-term growth and yield research experiments. Questions concerning *thinning quantity and stem quality in pure and mixed beech stands* can only be answered to a certain extent by long-term monitoring series on research plots, even if the observation periods available (several decades) are short when compared to entire stand development cycles.

There are statements in old publications about this subject which are probably still valid today. In Switzerland, among others, Flury (1931) and later on Burger (1941) showed the possibilities and limitations of beech in mixed stands. They did this on the basis of results from various research plots. Badoux (1939) analyzed the growth in beech thinning experiments. Leibundgut et al. (1971) was able to show with thinning experiments established by Schädelin that with the application of a heavy Swiss selective thinning according to Schädelin (1934) clearly better results can be achieved than with weaker variants. Bryndum (1987) showed in Danish beech experiments that the highest value performances were achieved with a “common strong” (C-degree, definition of thinning degrees see table 1) and a “very strong thinning” (D-degree) as well as with a staged B-C-thinning. Compared to the Swiss experiments where thinning is controlled by the social position of the trees according to Kraft (cited according to Assmann 1961), the Danish experiments are driven by basal area guiding curves. Bachmann (1990) shows in a convincing way that silvicultural activities have to concentrate on the value performance of the stands. Spellmann and Nagel (1996) emphasize that today value performance is more important than volume performance. Since the data series on which the studies of Flury (1931), Badoux (1939) and Burger (1941) are based are much longer today, an update of their results and of those of Zingg and Ramp (1997) could yield new insights. Therefore, this study deals with the growth of beech as influenced by thinning and mixture. A special look will be taken at the stem quality visible from the outside. Finally the following questions are asked:

Table 1. Definition of thinning degrees

A	No thinning: only dead or dying trees are removed
B	Weak thinning from below: removal of trees of the social class 4 (suppressed)
C	Moderate thinning from below: the same as B, additionally some trees of the social class 3 (dominated) are removed
D	Heavy thinning from below: the same as C, additionally most of the trees of the social class 2 (co-dominant) are removed
H	Thinning from above: favouring selected elite-trees

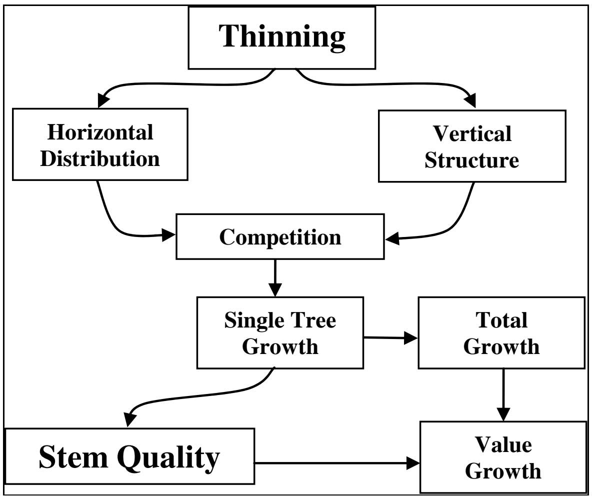


Figure 1: Conceptual model of the impact of thinning on stand structure, growth and stem quality

How does thinning influence

- growth,
- stem quality and therefore
- the value performance?

The various thinning methods have an influence on the horizontal distribution of the stems and, in mixed stands, on the mixture type within time (Fig. 1). Therefore it is a question to what extent the stand structure, e.g. the pattern of the horizontal distribution of the stems or the mixture type influence the quality of the stems. The hypothesis system concerning the effects of thinning is shown in figure 1.

Table 2. Mixed and pure beech research plots with thinning trials

Plot	Altitude	slope	aspect	Plot size	species composition					site index h_{dom}*		Last survey	Age at last survey
	m a.s.l.	%		ha	beech	spruce/fir	other coniferous	oak, ash, maple	other broadleaves	m			
Murten C	520	10	N	0.3	35	56	8	2		21.5		1990	113
Murten D	530	10	NW	0.3	49	43	8	2		22.6		1990	115
Murten H	530	10	NW	0.5	43	46	8	3		22.5	***	1990	111
Biel-Bienne B	670	30	NW	0.5	59	41		1	0	21		1992	101
Biel-Bienne H	670	30	NW	0.5	49	51		0	0	20.5	***	1992	101
Frinvillier B	570	40	N	0.2	76	19		5	0	18.1		1992	116
Frinvillier C	570	50	N	0.2	80	4	11	5		19.4		1992	116
Frinvillier H	570	60	N	0.5	55	41	3	0	0	19		1973	96
Horgen A	630	10	N	0.2	85	2	9	4		27.9		1989	100
Horgen C	650	20	N	0.25	81	10	0	8	1	25.4		1989	103
Horgen H	650	20	N	0.5	76	20		3	1	25.4		1989	101
Embrach C	590	10	W	0.25	99			1	0	19	***	1991	142
Embrach B	585	10	W	0.17	97			5		18.5	***	1991	142
Embrach H	585	10	W	0.25	98			2	0	17.5	***	1991	142
Zofingen, Mühlethal B	510	50	NW	0.25	99			1		19		1997	130
Zofingen, Mühlethal C	470	40	NW	0.2	99			1	0	20.4		1981	109
Zofingen, Mühlethal D	490	30	NW	0.2	100			0		20.3		1997	125
Zofingen, Mühlethal H	510	40	NW	0.25	95			5	0	20.2		1997	126
Zofingen, Baan C	560	10	W	0.25	95	0		6	0	20	***	1991	130
Zofingen, Baan B/H	560	10	W	0.25	99			1	0	19	***	1991	130
Zofingen, Baan D	580	0	none	0.2	100					18	***	1972	117
Aarburg B/H	475	20	S	0.25	100			1		21	***	1994	139
Aarburg C	485	20	S	0.25	99			1		20.5	***	1978	125
Aarburg B	485	10	W	0.25	100			0	0	21	***	1994	141
Concise B	530	10	E	0.25	83			17		18	***	1950	87
Concise C	530	20	SE	0.2	86			14		18.5	***	1950	87
Concise D	560	10	SE	0.2	92			8		19	***	1950	91
Concise H	560	10	E	0.25	91			9		15.5	***	1950	97

* Dominant height h_{dom50} (average height of the 100 thickest trees per ha at the age of 50) interpolated or extrapolated (values with ***) on the basis of measurements

2 Materials and Methods

2.1 Materials

Pure beech stands and mixed stands in which the basal area proportion of other tree species was larger than 20% were considered for this analysis. The experimental plots used are described in table 2. 17 beech stand thinning plots from 5 sites and 11 mixed stand thinning plots from 4 sites situated in the Swiss Mittelland were selected. The experimental areas differ in site and stand age. In addition to this, the sites of the mixed stands differ in respect of the proportion of beech: In *Murten* and *Biel/Bienne*, the proportion of conifers was at least at the beginning of the experiment higher than that of broadleaved trees whereas the contrary was true in *Frinvillier* and *Horgen*. All experimental plots were established between 1890 and 1910 and stand development was surveyed and observed at least until 1950. Some of these plots continue to be studied.

2.1 Methods

At first, indices were calculated for every plot to assess the spatial distribution of the trees on the plots and the mixture ratio in the mixed stand plots. The aggregation index R according to Clark and Evans (1954) was used for the distribution and the segregation index of Pielou (1977) was applied to the description of the mixture. Both indices were recommended by Pretzsch (1996). In total there are four surveys for all plots with tree co-ordinates and for these plots indices can be calculated. Edge corrections according to Donnelly (1978) were made for the aggregation index.

The growth performances of the stands were assessed by means of the standard instruments of forest growth science. Since the performance differences between pure and mixed stands are well known and have already been described (Flury 1931, Burger 1941), only the comparison of the total growth performance of basal area and the dominant diameter, i.e. the mean diameter of the 100 thickest trees per hectare, as a value performance indicator will be presented in this study.

Table 3. Estimation of the stem quality, definition of the Forest Growth and Yield Research Group of the Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Switzerland

Code	*Definition*
1	Excellent, stem fault-free up to the crown base, several logs of 2-5 m length
2	Two logs fault-free (approx. 10 m)
3	One log fault-free (approx. 5 m) or two logs with normal or good quality
4	Sawlogs of poor quality
5	No sawlog quality

The stem quality is determined by an expert on the standing tree according to the definitions in table 3. In this study the assessed stem quality is quantified corresponding to the basal area proportion of stem quality codes 1 and 2 (G% 1+2) to avoid the incorrect conclusion of volume-wise quality proportions. Flury (1931) and Burger (1941) conducted this analysis on the basis of stem numbers. It is, however, also meaningful to weight tree size through the basal area. A direct link to the composition of the assortment of the stands or the single tree and the marketable quality of the wood is not given with this definition of stem quality.

Six models were calculated using a General Linear Model (software SYSTAT 10) to estimate the proportion of the total production of stem quality, defined as basal area of stems with quality 1 or 2 (G% 1+2), calculated stepwise backward and forward using the variables listed in table 4. In these models we did not consider the fact that the data origin partly from neighbouring plots and time series from these plots.

3 Results

3.1 Horizontal distributions of trees and stem quality

The Aggregation Index R according to Clark and Evans (1954) gives information about the spatial pattern of the trees on the plot (figure 2). The values are below 1 only on the A-degree plot in *Horgen* which means that there is a tendency to clumping. On all other plots and treatment variants, the average R-values are above 1. R-values do not change much in the course of time. Both natural mortality as well as thinning cause random distribution patterns to emerge but on different levels: the R-values of the A-degree plots are lowest whereas those of the D-degree plots (heavy thinning from below) are the highest with values around 1.3. The R-values of the B-, C- and H-degree are close together and in an indistinct

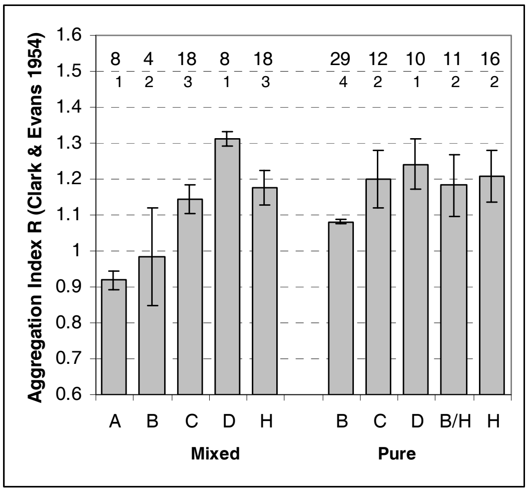


Figure 2. Aggregation Index (Clark und Evans 1954) in relation to the thinning degree, means and standard deviation. Top line = number of measurement, second line = number of plots.

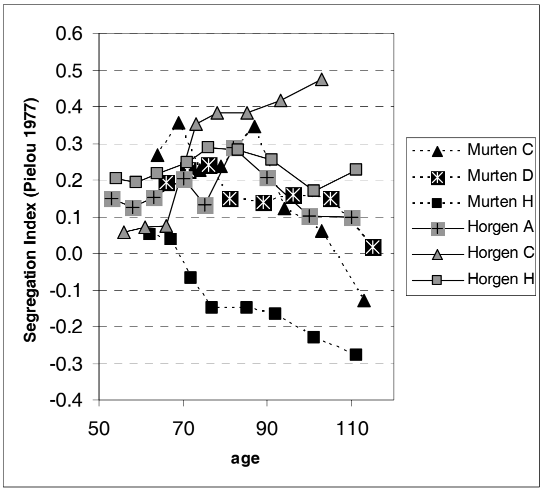


Figure 3. Development of the Segregation Index according to Pielou (1977) on two sites with different proportions of beech admixture and with different treatments

sequence between 1.1 and 1.2. R-values in mixed and pure beech plots are similar, but it seems that heavy thinning from below has a stronger influence on the distribution than thinning in the upper storey. In these latter plots selective thinning has been practised since the time of Flury and Burger (approx. since the 1920's).

The Aggregation Index R is only weakly negatively correlated with the total production (G; Pearson correlation, r=-0.091, n=117) and with the stem quality (% of G with quality 1 or 2) r=0.113, n=117.

3.2 Species mixture and stem quality

The Segregation Index S according to Pielou (1977) describes the mixture of the tree species. In figure 3 the development of S in two stands is shown. There are two different patterns: in *Murten* a clear development from a group mixture to a single tree mixture can be observed whereas this is not the case in the experimental plots in the *Horgen*. *Murten* had from the beginning less than 50 % beech (G), while *Horgen* had more than 80%.

The Segregation Index is slightly positively correlated with the stem quality G% 1+2 (r=0.213, n=52), with negatively with the total production (G; r=-0.334, n=52), and positively with the proportion of beech in G (r=0.353, n=52).

3.3 Total production

The differences of total production of basal area G (figure 4 and 5) between the thinning intensities show not a clear picture. It seems that in the mixed stands with a high proportion of beech as well as in the pure beech stands thinning from above (H) result in slightly lower total production of beech but this is not true for the two cases where thinning from above was applied only later during the trial (*Aarburg* B/H and *Zofingen, Baan* B/H).

Total basal area growth of all species is positively correlated with the stem quality G% 1+2 of beech (r=0.606, n=366) and with the total basal area growth of beech (r=0.669, n=366).

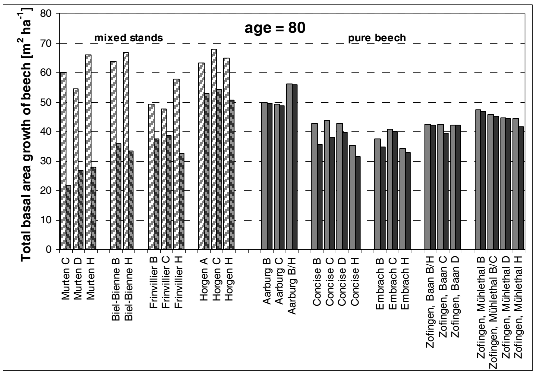


Figure 4. Total growth (basal area) of the stand (left column) and of beech (right column) at the age of 80.

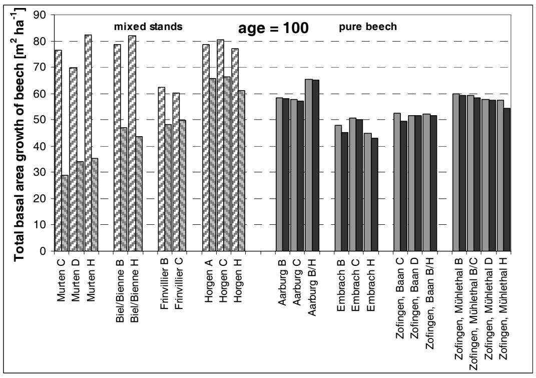
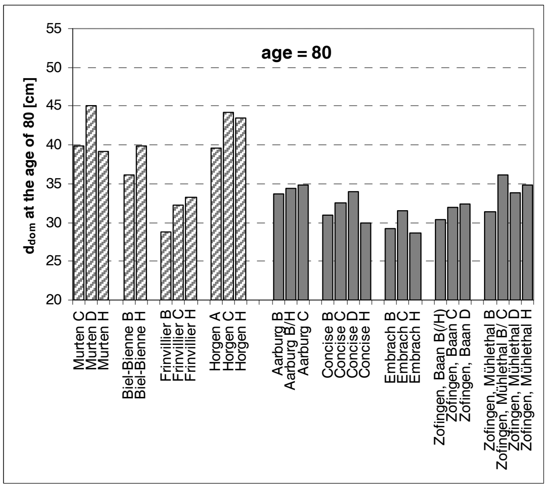
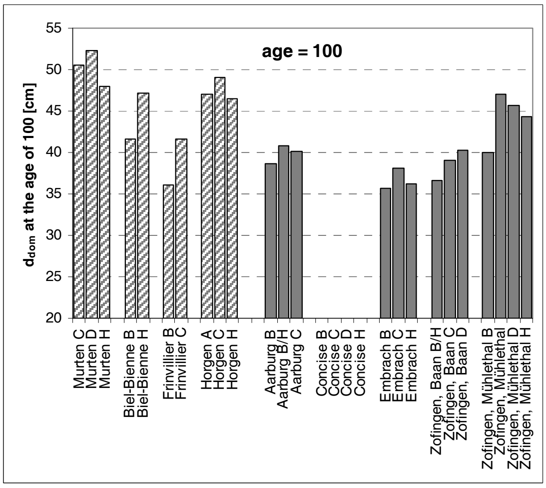


Figure 5. Total growth (basal area) of the stand (left column) and of beech (right column) at the age of 100.

3.4 Dominant diameter d_{dom}

There dominant diameter of beech does not clearly depend on thinning intensity (fig. 6–8). In most cases d_{dom} is larger on plots with C, D or H degree thinning than in those with B degree thinning. In contrast, H degree thinning does not necessarily result in a larger d_{dom} than C or D degree thinning. The dominant diameter d_{dom} is highly correlated with the total production of basal area G ($r=0.884$, $n=366$), but less with the stem quality (G% 1+2) ($r=0.550$, $n=366$).





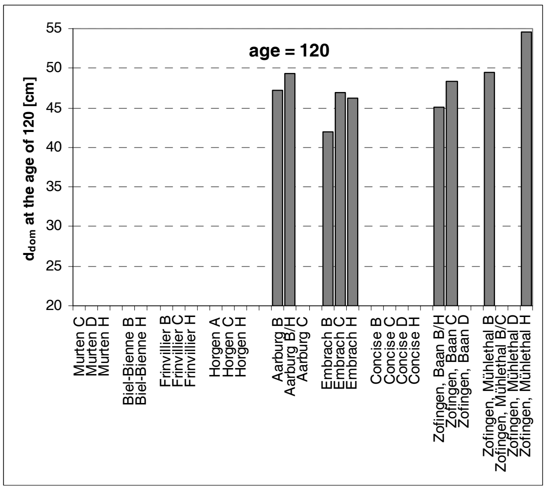
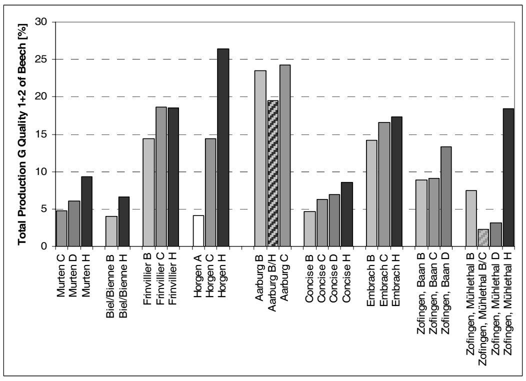
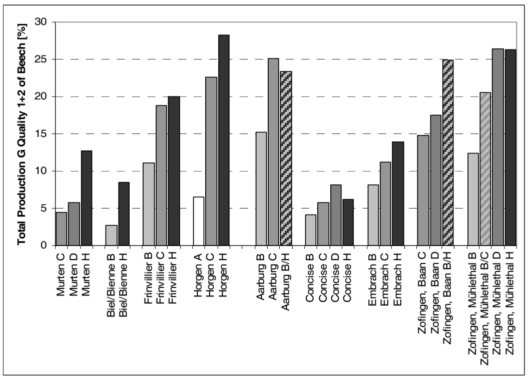


Figure 6–8. Dominant diameter of beech at the age of 80, 100, and 120.

3.5 Thinning and stem quality





Figures 9 and 10. Total growth of basal area of stems with quality 1 or 2 at the age of 80 (left) and at the last survey (right). The influence of the various thinning degrees is evident: heavier thinning, e.g. degree D or H enhances the proportion of high quality stems

The proportion of the total growth of the basal area of stems with quality 1 or 2 of beech (G% 1+2) is most cases higher in stands treated with a more intensive thinning (figure 9). In general G% 1+2 is higher in C-degrees than in B-degrees, higher in D-degrees than in C-degrees and higher in H-degrees than in D-degrees. It is important to mention that in these values of total production the remaining stand as well as all the total harvest up to the stand age is included. In the mixed stands the result is most clear in the case of the plots in *Horgen* where the H-degree can be compared with an untreated A-degree.

3.6 Modelling stem quality

The total data set includes 366 points in time in the various research plots. Missing data points for R (aggregation) and for tree mixture (Segregation index S) reduce the data set significantly to 117 and 56, respectively. Therefore six models were calculated: Model 1b (stepwise backward exclusion of variables) and 1f (variables taken stepwise forward into the model) without the indices R and S, with the same procedure models 2b and 2f using the index R and the models 3b and 3f using both indices R and S. Using the data without the indices R and S, i.e. 366 data points, the model 1b explains approx. 67% of the variation, including the index R (117 data points) the model explains 71%. The best model explains more than 92% of the variation but takes into account only 52 points in time of the data set. These three models are presented in tables 5 to 7.

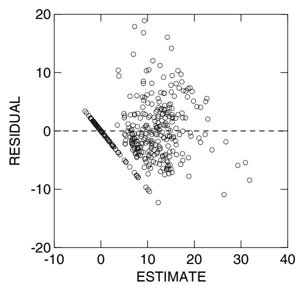
Table 4. Variables used to model stem quality G% 1+2.

Dependent variable		Mod 1b	Mod 1f	Mod 2b	Mod 2f	Mod 3b	Mod 3f
PR_Q12_TP_G = Proportion of quality 1 and 2 of the total production of basal area G		R^2					
		0.668	0.665	0.713	0.697	0.919	0.597
Independent variables	N ⇨	366		117		52	117
AGE	Stand age		x	x	x	x	x
MASL	Altitude m a.s.l.	x	x			x	
TP_G_TOT	Total production of basal area G of the stand		x	x	x		x
TP_TOT	Total production of volume of the stand		x	x		x	
TP_G_BEECH	Total production of basal area G of beech			x			
	Total production of volume of beech	x		x		x	
PR_TP_BEECH	Proportion of beech of the total production of basal area G	x		x		x	
TP_E_TOT	Total harvest				x		
TP_E_BEECH	Total harvest of beech	x	x		x	x	x
G_TOT	Basal area of the stand	x					
G_BEECH	Basal area of beech	x					
PR_G_E_PER	Thinning intensity: harvested basal area in percent of total basal area before harvest					x	
PR_G_BEECH	Proportion of basal area of beech		x			x	
HDOM	Dominant height h_{dom}: Average height of the 100 thickest trees per hectare	x	x	x	x	x	
DDOM_BEECH	Dominant diameter d_{dom}: Average diameter of the beech belonging to the 100 thickest trees per hectare	x	x			x	
DG_BEECH	Diameter corresponding to the mean basal area of beech in the stand			x	x	x	
SDI	Stand density index (SDI) according to Daniel and Sterba (1980)	x		x	x		
SDI_DIFF	Reduction of the SDI after thinning (thinning intensity)	x	x	x	x		
R_CE	Aggregation Index R according to Clark & Evans (1954)			x	x	x	x
SEGR	Segregation according to Pielou (1977)					x	

Table 5. Modelling the proportion of the total production, expressed as basal area, of stem quality 1 or 2 in pure and mixed stands without the indices R (horizontal distribution) and S (mixture)
Dep Var: PR_Q12_TP_G N: 366 Multiple R: 0.818 Squared multiple R: 0.668
Adjusted squared multiple R: 0.659 Standard error of estimate: 4.665

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2 Tail)
CONSTANT	15.890	4.537	0.000		3.502	0.001
MASL	-0.015	0.005	-0.112	0.749	-3.177	0.002
TP_BEECH	-0.027	0.006	-0.915	0.021	-4.339	0.000
PR_TP_BEECH	-0.057	0.035	-0.147	0.118	-1.651	0.100
TP_E_BEECH	0.914	0.086	1.428	0.052	10.686	0.000
G_TOT	-0.392	0.172	-0.495	0.020	-2.276	0.023
G_BEECH	0.409	0.143	0.472	0.034	2.859	0.004
HDOM	0.465	0.049	0.761	0.147	9.532	0.000
DDOM_BEECH	-0.319	0.059	-0.530	0.098	-5.421	0.000
SDI	0.016	0.008	0.355	0.031	2.049	0.041
SDI_DIFF	0.022	0.005	0.175	0.519	4.135	0.000

Plot of Residuals against Predicted Values



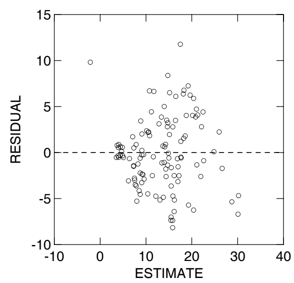
Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Regression	15571.262	10	1557.126	71.560	0.000
Residual	7724.679	355	21.760		

Table 6. Modelling the proportion of the total production, expressed as basal area, of stem quality 1 or 2 in pure and mixed stands, including the index R (horizontal distribution).
Dep Var: PR_Q12_TP_G N: 117 Multiple R: 0.844 Squared multiple R: 0.713
Adjusted squared multiple R: 0.683 Standard error of estimate: 4.128

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2 Tail)
CONSTANT	24.627	10.500	0.000		2.345	0.021
AGE	-0.127	0.037	-0.392	0.210	-3.427	0.001
TP_G_TOT	-0.566	0.323	-1.055	0.008	-1.755	0.082
TP_TOT	0.039	0.019	1.306	0.007	2.056	0.042
TP_G_BEECH	1.560	0.449	3.548	0.003	3.471	0.001
TP_BEECH	-0.069	0.025	-2.393	0.004	-2.764	0.007
PR_TP_BEECH	-0.187	0.112	-0.556	0.025	-1.676	0.097
HDOM	0.314	0.148	0.229	0.236	2.126	0.036
DG_BEECH	-0.301	0.143	-0.381	0.084	-2.104	0.038
SDI	-0.032	0.006	-0.605	0.235	-5.607	0.000
SDI_DIFF	0.015	0.008	0.177	0.330	1.947	0.054
R_CE	6.218	3.124	0.147	0.499	1.991	0.049

Plot of Residuals against Predicted Values



Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Regression	4437.572	11	403.416	23.677	0.000
Residual	1789.033	105	17.038		

4 Discussion and Conclusion

The quality of the trees in a managed forest depends on the one hand on genetic factors and on the other on site conditions and on neighbourly relations. The latter are modified by silvicultural interventions. The stem quality and the wood quality can be influenced by steering the growth through silvicultural interventions. The stem quality is, especially in beech, significant for the economic results. It is for this reason that the question to the interrelationship between silviculture and stem quality has a great importance.

The results concerning total growth of basal area in relation to the various thinning degrees are not as clear as in the Danish beech thinning trials (Bryndum 1987, Bastien 1995). This may be the case because the thinning degrees in the Swiss plots were defined only by the social position of the trees to harvest whereas in the Danish trials the thinning was controlled by predefined basal area developments. In addition to this the very heavy thinning E and F in the Danish trials were not part of the trials in Switzerland. Nonetheless the Swiss results presented here suggest the same trend than the Danish studies, i.e. lower total production with higher thinning intensity.

As greater the diameter as greater the economic value of beech of a good quality. One reason to apply thinning to beech in a stand is to concentrate growth on qualitatively good trees and let them grow as large as possible. As well as for the results concerning total production of basal area the results concerning the dominant diameter d_{dom} in relation to the thinning degree is not very clear. Here again this may be the case because the thinning intensity is not as clearly defined by the thinning degree as it is by basal area development curves in the Danish experiments where the effect of thinning on the dominant diameter can be clearly seen.

The proportion of the quality 1 and 2 of beech (G% 1+2) in the mixed stands is higher in the research plots such as in *Horgen* or *Frinvillier* which are rich in beech than in the stands of *Murten* or *Biel/Bienne* which had more conifers. This corresponds to the observations made by Flury (1931) and Burger (1941). Beech admixed with conifers shows inferior qualities than beech from pure stands and than beech from mixed stands rich in beech. The development of the mixture from a group mixture to the single tree mixture – see figure 3 – may have strengthened this development: the majority of the beech compete directly with other tree species. The best results obtained were on the H-degree area in *Murten* where trees with quality 1 and 2 were on the increase. The best quality proportions in the *Horgen* were also on the H degree plots. These observations are supported by the result of the model 3b, where the segregation index S remains in the model with a positive coefficient (Table 7).

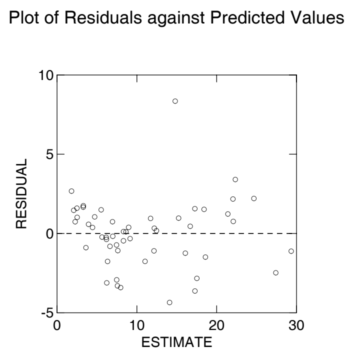
In the pure beech stands the proportion of trees with quality 1 and 2 with a weak thinning from below treatment is in most cases lower than in the pure beech stands intensely thinned from below and thinned from above. At least in the H-degrees this is not surprising because in a Swiss selective thinning according to Schädelin (1934) or Leibundgut (1966) trees to remain in the stand are selected also according to their quality and their strongest competitors, usually of lower quality, are removed.

None of the simple correlations can explain the proportion of stems of good quality but the models using several variables seem to be able to give better results. None of the independent variables is used in all the six models. Stand age which is of course correlated with the various variables representing the total production, but also with dominant diameter or with dominant height, is retained in most of the models. Site, here as altitude in m a.s.l. which correlates only weakly with other variables is present in three models and may be represented in the other cases with the total production. Of course it is to expect that the total production of beech is used as well somehow to estimate the proportion of quality of beech. In both models of pure and mixed stands (1b and 2b) the stand density index SDI (Daniel and Sterba 1980) and the reduction of the SDI through thinning, i.e. a thinning intensity was used. The horizontal distribution expressed with the aggregation index R and the mixture type expressed with segregation index S seem to play a quite important role concerning the total production of stems of good quality (total production of basal area of trees with stem quality 1 or 2). If the stems are distributed randomly or even we can expect a higher proportion of good quality stems and the higher the segregation index – i.e. as less intensive beech is mixed with other species - the higher the proportion of good quality can be expected.

The fact that the models using these indices result in a better explanation of the variance may not only be due to this. To calculate these indices we need the coordinates of the tree positions. In the data presented here coordinates in mixed stands were available only from the last survey, i.e. in old stands. The chance to find stems of good quality in olds stands of course is higher than in young stands. For the calculation of the index describing the horizontal distribution data were available since the thirties, e.g. also in stands between 50 and 70 years old.

Table 7. Modelling the proportion of the total production, expressed as basal area, of stem quality 1 or 2 in mixed stand, including the indices R and S
Dep Var: PR_Q12_TP_G N: 52 Multiple R: 0.959 Squared multiple R: 0.919
Adjusted squared multiple R: 0.892 Standard error of estimate: 2.443

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2 Tail)
CONSTANT	-17.469	15.530	0.000	.	-1.125	0.268
AGE	-0.263	0.093	-0.630	0.043	-2.842	0.007
MASL	-0.071	0.021	-0.568	0.075	-3.379	0.002
TP_TOT	0.046	0.010	1.400	0.024	4.715	0.000
TP_BEECH	-0.055	0.011	-1.509	0.024	-5.125	0.000
PR_TP_BEECH	0.301	0.146	0.767	0.015	2.066	0.046
TP_E_BEECH	1.095	0.114	1.398	0.101	9.645	0.000
PR_G_E_PER	-0.136	0.085	-0.164	0.200	-1.597	0.119
PR_G_BEECH	0.301	0.125	0.949	0.014	2.413	0.021
HDOM	0.712	0.420	0.598	0.017	1.693	0.099
DDOM_BEECH	-0.553	0.329	-0.661	0.014	-1.681	0.101
DG_BEECH	-0.398	0.167	-0.455	0.058	-2.382	0.022
R_CE	31.205	7.781	0.519	0.127	4.011	0.000
SEGR	10.619	3.723	0.250	0.275	2.852	0.007



Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Regression	2587.963	13	199.074	33.350	0.000
Residual	226.833	38	5.969		

The results of this study show that the growth of stands weakly and moderately thinned from below may be greater than the performance of stands thinned from above. This applies to both pure as well as mixed stands. But it seems to be also clear that stands intensely thinned and thinned from above show better quality conditions than stands with weak thinning or thinning from below. According to Bryndum (1987) substantially higher value performances can be achieved with intensive thinning. Leibundgut et al. (1971) demonstrated that the applied intensive thinning from above can be qualified as "very strong", and despite a lower volume performance resulted in a more valuable stand than the weaker variant. It is also known that the performance is highest with weak thinning, that A-degree thinning has a higher performance than C-degree or H-degree thinning (Assmann 1961, Spellmann und Nagel 1996). Together with the results of the Danish experiment (Bryndum 1987, Bastien 1995) it can be concluded that thinning is a reasonable measure to improve stem quality without loosing growth, i.e. thinning has to be done to improve the value performance of a beech stand. The results of this study confirm that the results of Leibundgut are still valid.

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