Czech University of Life Sciences Prague

Faculty of Forestry and Wood Sciences

Department of Silviculture

STRUCTURE, GROWTH AND INCREMENT OF THE FOREST STAND UNDER TRANSFORMATION TO UNEVEN-AGED FOREST STAND

Diploma Thesis

RESEARCH PROJECT BY: **Irene Guerra Avalos**

RESEARCH PROJECT´S DIRECTOR: **Ing. Jiří Remeš, Ph.D.**

RESEARCH PROJECT´S TUTOR FROM E.T.S.I. MONTES MADRID (SPAIN):

Ing. Ignacio García-Amorena Gómez del Moral, Ph.D.

Prague 2008.

Statutory declaration

I hereby certify that I have elaborated my thesis independently, only with the expert guidance of my thesis director Ing. Jiří Remeš, PhD. and thesis tutor from E.T.S.I. Montes Madrid (Spain) Ing. Ignacio García-Amorena Gómez del Moral, Ph.D.

I further declare that all data and information I have used in my thesis are stated in the reference.

In Prague …………. ....……...……………………………….

Signature: Irene Guerra Avalos

Acknowledgements

I want to thank to Ing. Jiří Remeš, Ph.D., director of this thesis, for his patience and help. I am also grateful to my coleague Irena Fajkusová for helping me with the measurements in the forest.

I would like to express my sincere gratitude to Ing. Ignacio García-Amorena Gómez del Moral, Ph.D., who was supervising this work as tutor from E.T.S.I. Montes in Madrid (Spain), for his advocacy and comprehension as well as for his help with the writting of this work.

Further more I want to thank to my friends to support me in the difficult moments, especially to Jitka Krausová, who helped me with the translation from Czech documents, and to Ana Andreu for her work on the format of this thesis.

Last but not least, I would like to thank to my family for their support during the last to years, to be by my side encouraging me and sharing the happiness of the achievement.

Abstract

Even-aged forest stands transformation to uneven-aged irregular stands is a flourishing tendency in last decades. Efforts are being done on practical work in Czech Republic and another countries like Canada and U.S.A., Finland, Sweden, Germany and others of central Europe.

This paper deals with the transformation process which is taking place in the forest complex of Hetlín. Forest Range Hetlín (Forest District Opatovice) started the transformation process to a mixed uneven-aged forest with the group and single-tree selection silvicultural system on January 1st 1938. Since that moment progressive thinnings have been done and new species have been introduced. The positive consequences of harvestings can be observed in current volume increment but some of the introduced species find problems for their well development due to the natural characteristics of the stand, specially because of soil conditions.

For successful achievement of transformation process goals a lot of interventions are necessary to be made. It will take lot of time so we will have to wait for final results.

Keywords: uneven-aged forest stands; close-to-nature silviculture; conversion process; transformation process; stand structure; selection principles; silviculture; forest management.

INDEX

1. INTRODUCTION **1**

2. OBJETIVES **3**

3. LITERATURE REVIEW **5**

3.1 GENERAL FRAME OF FORESTS IN CZECH REPUBLIC 5

3.1.1 Geographical situation 5

3.1.2 Climate 6

3.1.3 Soil 8

3.1.4 Vegetation and tree species composition 11

3.1.4.1 Vegetation tiers in forests in Czech Republic 14

3.1.4.2 Conversion from broadleaves to conifers 19

3.1.5 Forest evolution in the last 10000 years. The Norway spruce 21

3.1.5.1 Occurrence, origin and distribution of Norway spruce forests 21

3.1.5.2 Threats to Norway spruce genetic resources, their management and protection 23

3.1.5.3 The most urgent needs in Norway spruce conservation 24

3.2 HISTORY OF FOREST MANAGEMENT IN CZECH REPUBLIC 26

3.3 ACTUAL SITUATION OF THE FORESTS AND FOREST POLICY IN CZECH REPUBLIC 28

3.3.1 Present forest management in Czech Republic. "Principles of state policy in Czech Republic" 28

3.3.2 Forest management under state supervision. Forest Act 30

3.3.3 The most important common needs to solve in Czech forestry and recommended measures 34

3.3.4 Main forest regeneration systems 38

3.4 UNEVEN-AGED MANAGEMENT 41

3.4.1 Uneven-aged harvest and regeneration methods 42

3.4.2 Uneven-aged tending methods 43

3.4.3 Management rules for transformation 44

3.4.4 Differences between broadleaved trees and conifers for the selection system 45

3.4.5 Biodiversity & ecological stability 46

3.4.6 Economical features 47

4. MATERIAL. DESCRIPTION OF HETLÍN FOREST 49
4.1 LOCATION 49
4.2 NATURAL CONDITIONS 49
4.2.1 Geological and soil conditions 49
4.2.2 Climate conditions 49
4.2.3 Tree species composition 50
4.3 FOREST MANAGEMENT 50
4.3.1 The beginning of transformation process 50
4.3.2 Felling 51
4.3.3 Planting 51

5 .METHODS 53
5.1 THE EXPERIMENTAL PLOTS 53
5.2 MEASUREMENTS: POSITION, H, DBH, G, VOLUME 53
5.3 EVALUATION (STATISTICAL PROCESSES) 54

6 RESULTS AND DISCUSSION 55
6.1 GLOBAL EVALUATION (ALL PLOTS TOGETHER) 55
6.1.1 Species percentage 55
6.1.2 Statistical analysis and results for the main species 57
6.1.3 Dbh distribution for the totality of the species 59
6.1.4 Volume, basal area, mean dbh (dg) and number of trees per hectare values and increment values 61
6.2 EVALUATION ACCORDING EACH PLOT 65
6.2.1 Percentage of species for each plot 65
6.2.2 Volume, basal area, mean dbh (dg) and number of trees per hectare values and increment values 66

7 RECOMMENDATIONS 69
8 CONCLUSION 75
9 REFERENCES 77
10 ANNEXES 81

ANNEX 1. MAPS AND PICTURES OF HETLÍN COMPLEX 82
ANNEX 2. LOCATION MAPS FOR THE LOTS 88
ANNEX 3. TABLES FOR TOTAL PERCENTAGE OF SPECIES 92
ANNEX 4. GRAPHICS OF CORRELATION ANALYSIS & TABLES FOR STATISTICAL ANALYSIS FOR THE TOTALITY OF THE SPECIES IN ALL PLOTS TOGETHER 94
ANNEX 5. GRAPHICS FOR DBH DISTRIBUTION OF THE TOTALITY OF SPECIES IN ALL PLOTS TOGETHER 100
ANNEX 6. GRAPHICS OF VOLUME ON DBH DISTRIBUTION FOR THE TOTALITY OF THE SPECIES IN ALL PLOTS TOGETHER 103
ANNEX 7. GRAPHICS OF PERCENTAGE OF SPECIES IN EACH PLOT 106
ANNEX 8. DBH DISTRIBUTION FOR NORWAY SPRUCE, EUROPEAN LARCH AND SCOTS PINE IN RECTANGULAR PLOT I & II 109

1. INTRODUCTION

The concept of close-to-nature silviculture was developed by Karl Gayer at the end of the last century, and has been applied for more than a hundred years mainly in Central Europe (Gayer 1886, Schütz, 1999). The combination of the development of the tractor yarding, which technology became available in the 1930s, the economic depression (1928-1929), and the public and professional sentiment against clear cutting led to harvesting treatments that removed only the largest trees in the stands (Reynolds et al., 1984). The history of uneven-aged silviculture reveals that the popularity of these practices has flourished among managers and researchers.

The natural state of the different forest ecosystems is linked with dissimilar temporal and spatial scales of irregularity. This can either be understood from a purely temporal or structural point of view, or from a more complete sense as a genuine and unique silvicultural system. The well known silvicultural concept of plenter (or selection) system, the most closely associated with the uneven-aged forests, has been applied successfully for more than 120 years (e.g. Franche-Comté in France, the Black Forest in South-Western Germany and the Val-de-Travers and Emmenta valleys in Switzerland (Schütz, 2002)). However large differences rose on Central Europe about getting to uneven-aged structure, as other approaches which focus more on natural processes or structural characteristics of irregularity were proposed (Schütz, 2002). Nevertheless, emerging concepts about succession and climax plant communities also contribute to both the desire of an uneven-aged forestry and the view that selection silviculture was the most natural means of managing forests.

Transformation from a regular forest to an irregular one is a long and difficult task which needs time and frequent intervention. The countries where forests have been over the centuries managed with an even-aged silviculture face serious difficulties in their attempts to turn to uneven-aged forests. Large monospecific extensions, with lack of seed bank make really difficult the natural regeneration. In addition, the fact that most of the plantations were done with coniferous species led to an acidification of soil which complicate the establishment of new species. Also to treat the forest like a whole system, taking into account the soil, climate, water cycle, biodiversity and mankind is needed.

Transformation from even-aged forests to uneven-aged forest problems, faced by several regions (e.g. a Great Britain, Finland and Central Europe), are extensible to the Czech Republic due to the similar geoclimatic conditions, species composition of forest and same historical land exploitation. Economy, policy and forest ecology concepts are related with silviculture and forest management. Actually all the articles and reports about transformation studies are strongly focused on achieving environmental equilibrium and the use of forest products in the most sustainable way according with Forest Act.

2. OBJETIVES

The aim of this thesis is to compare the particular silvicultural systems from different points of view: production, economical, ecological as well as environmental. The growing interest about biodiversity preservation, avoidment of pollution and soil erosion (According to scientists, the simplification of forest stands in the Czech Republic was one of the reasons for the dramatic flood situations in 1999 and 2002) and the conservation of the habitats favored the emergence of studies related with this topic.

The research is carried out in Central Bohemia (Czech Republic), in site conditions representing large areas of Central Europe. The study is done in Hetlín forest range at the Municipal Forest of Kutná Hora Town. In different plots with a whole area of 1,754 hectares various parameters were measured. Based on Dbh and height measurements growth and production values were obtained, both currently and retrospectively. Also tree species composition was taken into account with the aim of evaluate the ecological situation of the stand in terms of study if the transformation process is reaching the goal of forming mixed stands.

This thesis will be focused on the evaluation and analyses of stand structure, growth and increment of the selected forest stands under transformation to uneven-aged systems (selective forest).

By comparing the current stand structure, growth and increment of selected forest stands under transformation to uneven-aged forest stands with data from 2000. The following specific objectives will be pursued:

I. To see if volume stock experiments an increment after the interventions.
II. To get some conclusions about wood production potential (basal area, volume stock).
III. To find out what advantages for the stands are given by the admixture with other species.

IV. To check which of those species are better fitted to the natural characteristics of the stand.

V. To study the static stability of the stands, taking into account the different species which compose them.

Some results about the development of the stand will be found. In last term this results will lead to some recommendations dealing with the proper development and based on human intervention.

3. LITERATURE REVIEW

3.1 GENERAL FRAME OF FORESTS IN CZECH REPUBLIC

3.1.1 Geographical situation

The Czech Republic is located in the “heart” of Europe. The borders in the northern part and in the western part on the mountains of Bohemia, integrated by the Ore Mountains rising in the northwest from the Paleozoic rock hill ranges while the wooded hills of the Bohemian forest lie to the southwest. The basin of Bohemia and the highlands of Bohemia and Moravia include the central part of the country. Towards the southeast the gentle uplands of the Moravian Hills separate Bohemia from the plains of Moravia. The low Moravian lands spread in the east part. Moravia which is the eastern lowland area that lies southeast of Czech Republic. The lowland plains of Moravia separate the Bohemian region from the Carpathian Mountains of Slovakia and have formed a narrow corridor between the plains of Poland and the Danube Valley. The rivers Moldava (in Czech Vltava), Ohře, Elba (in Czech *Labe*), Orava, Lužnice, Jihlava, Sázava, Svratka, Beca, Odra, Opava and Morava are among the principal ones of the country.

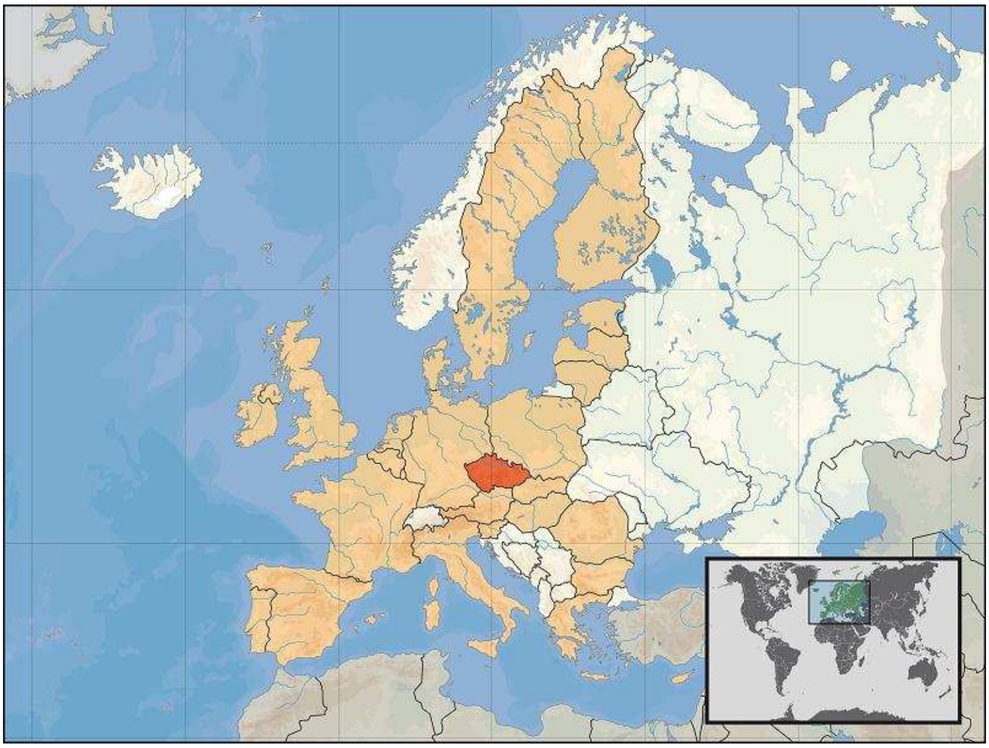


Figure 1. Situation of Czech Republic in the World.

Figure 2. Topographic map of Czech Republic. Source: The Times Atlas of the World. *Philippe Rekacewicz, Emmanuelle Bournay, UNEP/GRID-Arendal.* July 97

3.1.2 Climate

Due to the geographical localization of this country the climate in Czech Republic ranges from oceanic climate in the West to continental climate in the East.

Moderating oceanic influences diminish from west to east, so we can consider the west part closer to the temperate climate. The humid continental climate that concerns most of the territory is the responsible of the gentle summers with intermittent soakers, of the cold covered with snow winters and, in general, of the changeable conditions. Climatic conditions are mainly connected with changes of elevation above see level (in the Czech Republic 115-1602 m a.s.l.). July is the hottest month in the whole country, and the coldest is January. Average temperature is in range from 10°C to 0°C, relief of terrain is from plane to severe slopes. From December to February, the temperatures descend below 0ºC even in the low lands, and are chill in the mountains. In fact, a dry locality does not exist. Mean annual precipitation is fluctuating between 350- 1600 mm/year. The long, sunny and calm periods tend to be alternated in summer with strong and sudden storms. The winter makes possible that the snow remains in the soil from 40 to 100 days (approximately 130 in the mountains) and provokes in addition the appearance of fog in the low lands.

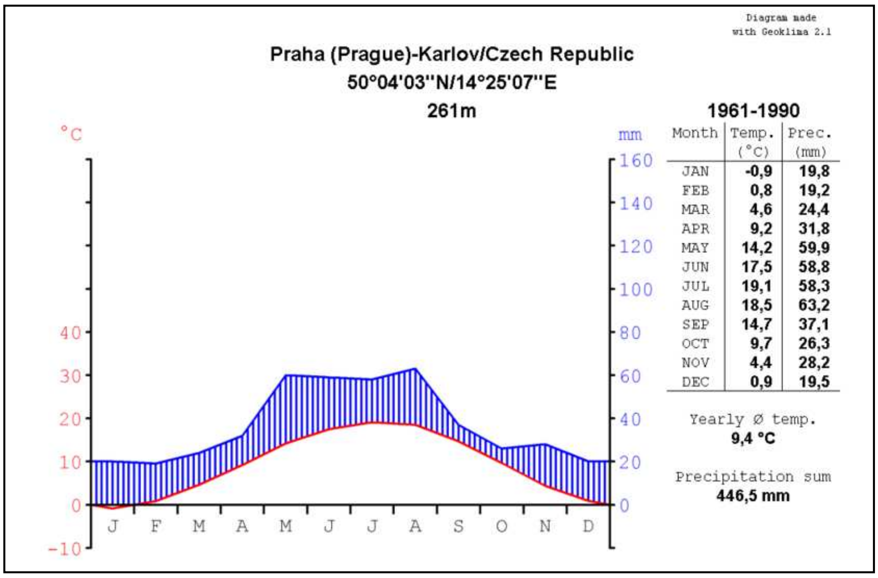


Figure 3. Climatic diagram from Prague (West of Czech Rep.) Source: CHMI Climatology section. Jörg M.

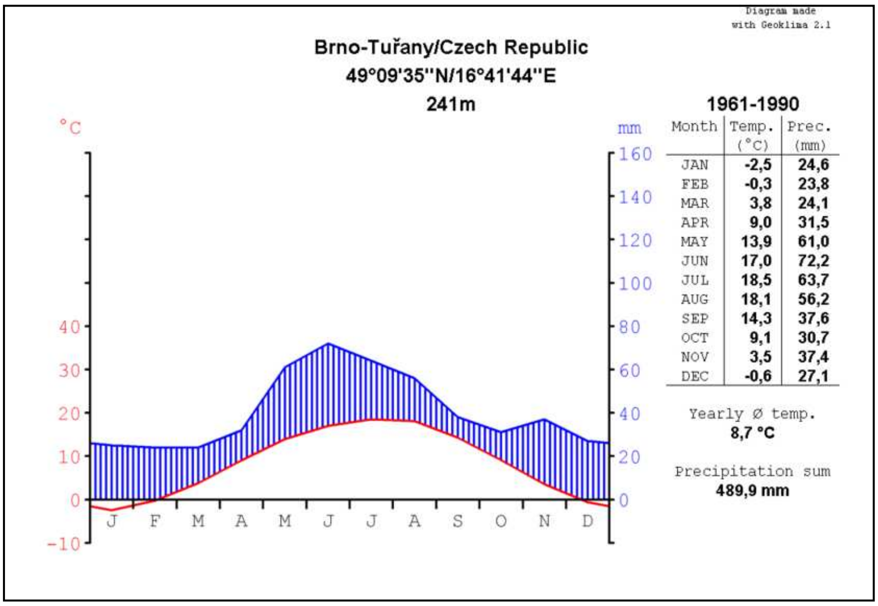


Figure 4. Climatic diagram from Brno (East of Czech Rep.) Source: CHMI Climatology section. Jörg M.

Climatic conditions are also modified by vertical surface diversity resulting in vertical zonality of the climate that shows in the varied character and abundance of biota. Three climatic altitudinal regions can be distinguished in Czech Republic (Quitt E., 1971):

- The warm region (T) at the lowest and driest levels, with two subunits:

T4 with a very long, warm and dry summer, warm spring and autumn, and a short, moderately warm and very dry winter with a very short period of snow cover.

T2 with a shorter, less warm and less dry summer and with a moderately warm spring and autumn.

- The moderate warm region (MT), occupying most of the Czech Republic. It forms a transition between the warm and cold climatic regions, it has no marked characteristics

- The cold climatic regions (CH), to which belong mostly mountain to alpine zones of the mountains. This region is characterized by a very short, moderately cold and humid summer, and moderately cold spring and autumn. The winter is very long and cold, humid and with a very long lasting snow cover.

Table 1. Selected meteorological data. Average data from Czech Republic. Source Remeš J. & Podrázsky V.

	Average temperature ºC	Average precipitation mm	Lang's rain factor
Normality	7.3	673	88.9
2000	9.3	691	72.74
2001	7.9	812	97.83
2002	8.9	829	90.11

The normality data come from a normal curve distribution, these are the most frequent observations in the measuring stations, in this table data from 2000, 2001 and 2002 can be compared with those.

3.1.3 Soil

The soils change very much from one place to another. The chemical composition and the physical structure of the soil in a given place are determined by the type of geological material from which it is originated, for the vegetable cover, for how long the meteorization has been taking place, for the topography and for the artificial resultant changes of the human activities.

The geological structure of the Czech Republic is characterized by two basic units: the Bohemian Massif, which forms the whole of Bohemia and the north-western part of Moravia and Silesia, and the Western Carpathians in the remaining part of Moravia.

The Bohemian Massif is formed from crystalline Proterozoic and older Paleozoic rocks. The crystalline rocks are mostly acidic metamorphic substrates, principally various types of gneiss, phyllites, mica-slates and granulites. As a whole it represents an area with poor, mostly acidic substrates and as a result it has a relatively low diversity of flora and vegetation.

During the Tertiary period the poor, sandy and clay sediments of the larger basins were formed, and vulcanites were deposited in northern and north-western Bohemia. These areas now form centers of a rich flora and diverse vegetation. The Moravian Western Carpathians are mostly formed by Tertiary flysh, which is characterized by alternating bands of sandstones, slates and clay stones, rarely of marls.

The most frequent soil types from the mountain to the planar levels are brown forest soils. In the warmest areas of the country various types of cambisols prevail, depending on the mineral content of the substrates. On the basaltic volcanites of the northern and north-western Bohemian mountains eutrophic cambisols are typical. On terraces and sand dunes in the lowlands arenic cambisols occur and at lower, warmer and drier levels, cambisols are replaced by leptosols and luvisols on eolic loesses. At higher elevations acidic cambisols prevail. Haplic (mountain) podzols occur in the highest supramontane to sub alpine tiers. Arenic podzols can be found on sandy substrates at lower levels. The chernozems are typical in dry lowland areas to colline levels (Neuhäuslová, 1998).

Gleys are frequent in the South Bohemian basins, on heavy, waterlogged substrates.

The overview of highest taxa at the reference classes and soil types levels is displayed in the Table 2 . The overview comes from Němeček J. & Kozák J. (2001) and is based on previous approaches: the WRB (1998), Soil Taxonomy (1999), Référentiel pédologique (1998) and Systematik der Böden Deutschlands (1998).

Table 2. Němeček J. & Kozák J. (2001): The Czech taxonomic soil classification system and the harmonization of soil maps.

Reference classes	Soil types
LEPTOSOLS	Litozem (LI) Ranker (RN) Renzina (RZ) Pararenzina (PR)
REGOSOLS	Regozem (RG)
FLUVISOLS	Fluvizem (FL) Koluvizem (KO)
VERTISOLS	Smonice (SM)
ANDOSOLS	Andozem (AD)
CHERNOSOLS	černozem (CE) černice (CC)
LUVISOLS	šedozem (SE) hnědozem (HN) luvizem(LU)
CAMBISOLS	kambizem (KA) pelozem (PE)
PODZOLS	kryptopodzol (KP) podzol (PZ)
STAGNOSOLS	pseudoglej (PG) stagnoglej (SG)
GLEYSOLS	glej (GL)
ORGANOSOLS	organozem (OR)
SALISOLS	solončak (SK)
SODISOLS	solonec (SC)
ANTHROPOSOLS	kultizem (KT) anthrozem (AN)

Taking into account both Reference Classes and Soil types, Subtypes, Varieties, Sub varieties, ecological and degradation phases and soil forms 11 great soil regions have been defined in the Czech Republic (Němeček J. & Kozák J.,2001).

3.1.4 Vegetation and Tree Species Composition

Most of the fertile lands of the country are in the low plains and in the wavy hills of the central basin and of the north of Bohemia, and in the low lands of Moravia. In spite of centuries and centuries of shelter and clear cuttings of forests to practice the agriculture (42,5 % of the Czech territory is cultivated), these continue covering approximately a third part of the Czech territory, around 34% of the national territory is covered by forests, this means about 2.640 million hectares. Many of the wooded virgin areas which have survived are situated in uncultivable zones of mountain.

Although this change in the land use for cultivation and for timber, woodlands remain a characteristic feature of the Czech landscape. Altitude and type of terrain are very important factors, which have dominant role in the forest vegetation forming.

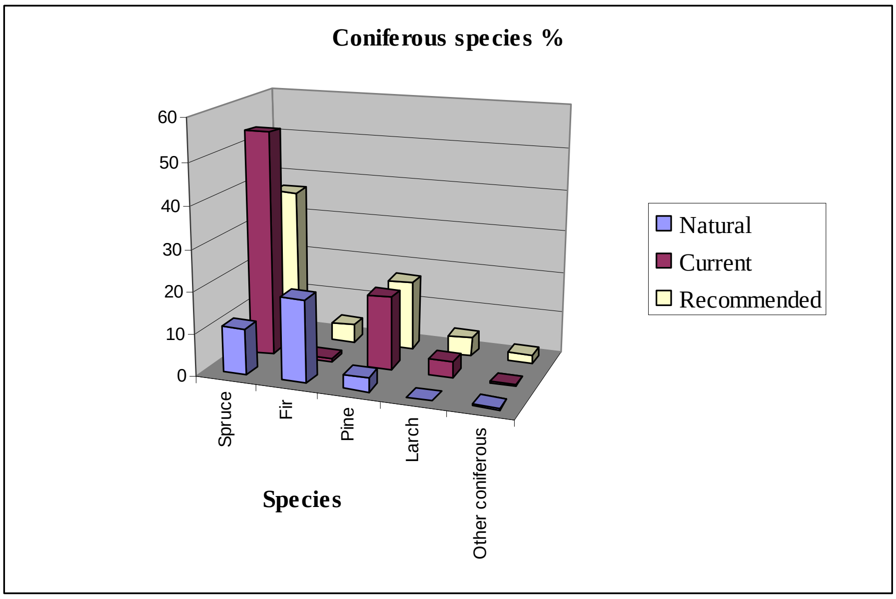
Most of Czech forests are coniferous forests, though some broadleaves species are also present (Fig.7). Oak species, European beech, and Norway spruce dominate the forest zones in ascending order of elevation. In the highest reaches can be found taiga and tundra vegetation characteristic of more-northerly or more-elevated regions elsewhere in Europe.

The present anthrophic activities are main reasons of the totally tree species compositions change.

<u>Species composition of forests</u>:

Table 3.Coniferous species. Source Remeš J. & Podrázsky V.

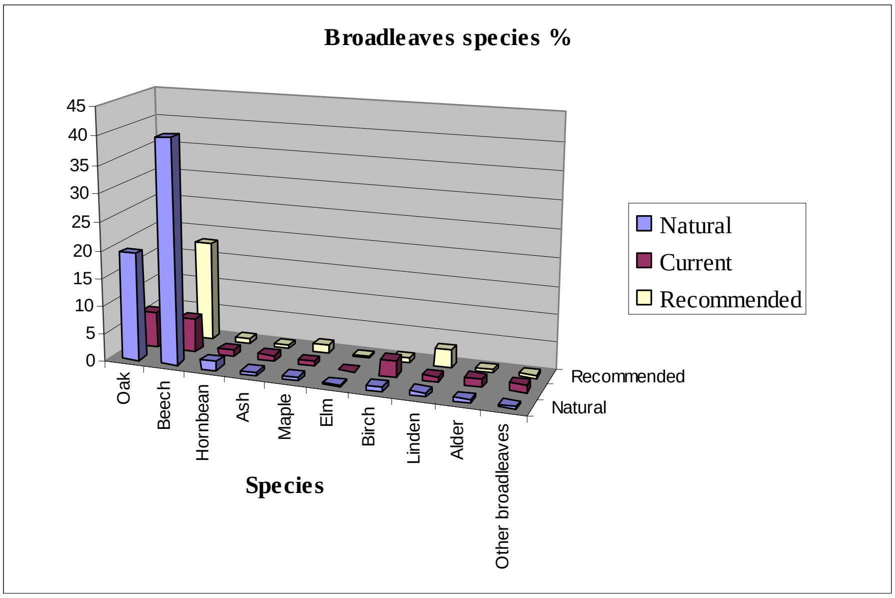
	Natural	Current	Recommended
Spruce (*Picea abies* (L.) Karst.)	11,2	53,9	36,5
Fir (*Abies alba* Mill.)	19,8	0,9	4,4
Pine (*Pinus sylvestris* L.)	3,4	17,5	16,8
Larch (*Larix decidua* Mill.)	0	3,8	4,5
Other coniferous	0,3	0,2	2,2
Total coniferous	34,7	76,3	64,4



Graph 1. Coniferous species in Czech forests (data from Table 3)

Table 4. Broadleaved species. Source Remeš J. & Podrázsky V.

	Natural	Current	Recommended
Oak (*Quercus petraea* (Matt.) Liebl; *Quercus robur* L.)	19.4	6.4	9.0
Beech (*Fagus sylvatica* L.)	40.2	6.1	18.0
Hornbean (*Carpinus betulus* L.)	1.6	1.2	0.9
Ash (*Fraxinus angustifolia* Vahl.)	0.6	1.1	0.7
Maple (*Acer pseudoplatanus* L.; *Acer platanoides* L.)	0.7	0.9	1.5
Elm (*Ulmus glabra* Huds.; *Ulmus laevis* Pall.; *Ulmus carpinifolia* Gled.)	0.3	0	0.3
Birch (*Betula pendula* Roth.)	0.8	2.9	0.8
Linden (*Tilia cordata* Mill.; *Tilia platyphylos* Scop.)	0.8	1	3.2
Alder (*Alnus glutinosa* L.)	0.6	1.5	0.6
Other broadleaves	0.3	1.5	0.6
Total broasleaves	65.3	22.5	35.6



Graph 2. Broadleaved species in Czech forests (data from Table 4).

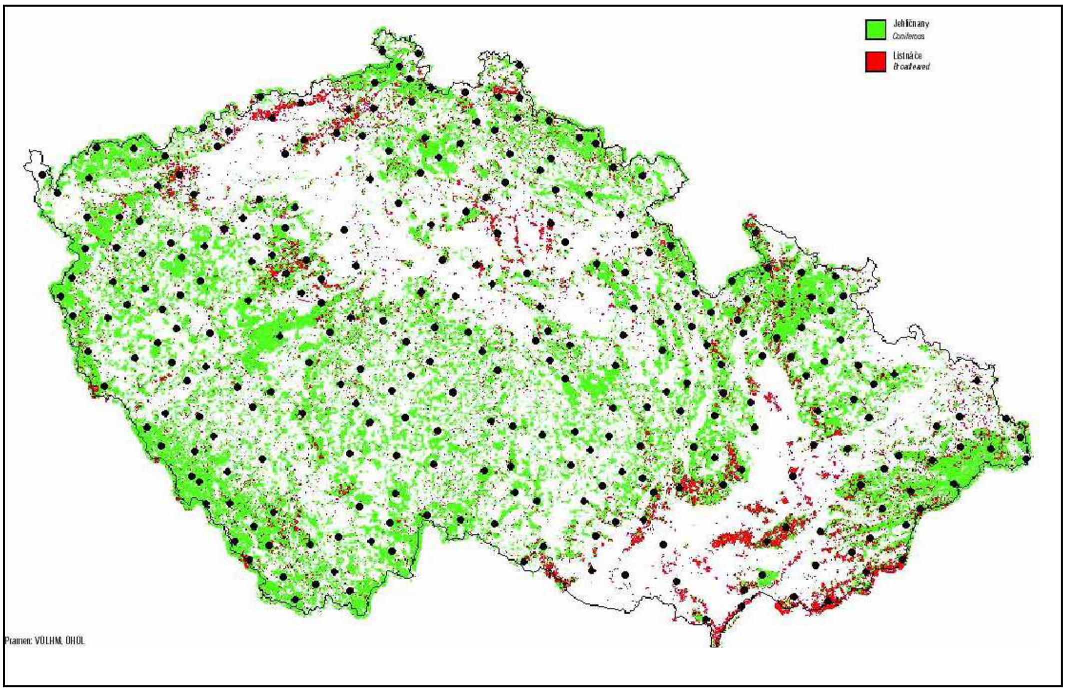


Figure 5. Coniferous (green) and Broadleaves (red). Source Remeš J. & Podrázsky V.

3.1.4.1 Vegetation tiers in forests of Czech Republic

The timberline runs at about 1,400 meters above sea level. At these higher elevations, as in the Giant Mountains, the tree cover over the timberline consists of little more than dwarf pine. The Alpine zone supports grasses and low-growing bushes.

The plant communities have a kind of natural order according to a changing ecological factor, like temperature, moisture, topography... The tier classification refers to the distribution of vegetation in zones in order to the changing temperature in relation with the altitude.

Vegetation tiers in forests in Czech Republic, named according prevailing species:

1st.- Oak Vegetation Tier.

It is located in the warmest and driest regions in the Czech Republic. It occurs in lowlands, hilly lands and in the warmest parts of articulated highlands usually at the altitude of 300 m a.s.l. with some exceptions being found at about 500 m a.s.l.

Climate character is sub-continentally warm, with larger amplitude of temperatures and frequent incidence of dry periods. Mean annual temperature ranges about 8 °C. Mean annual precipitation total is very low, usually under 600mm. Growing period is very long, longer than 165 days.

Tree species leaders are oaks, most frequently sessile oak *Quercus petraea* as the dominant climax specie. Indicator of the tier are the pubescent oak *Quercus pubescens* and *Quercus cerris*. *Fraxinus angustifolia* is often abundant and *Fagus sylvatica* is absent or rare in wet habitats. This zone includes warm and water-deficient sites, with the exception of deep sands soil localities dominated by *Pinus sylvestris* and floodplains. The Oak zone covers 8.3 % of the forested area in Czech Republic.

2nd.- Beech-Oak vegetation tier

This vegetation tier occurs continually in warm dry up to slightly humid regions and it is characterized by a common representation of some thermophilous species.

Lowlands, uplands and hilly lands of this vegetation tier are usually situated at altitudes ranging from 350 to 400 m a.s.l.

This tier is linked to warm climatic regions with mean annual temperatures around 7,5-8 °C. Mean annual precipitation is 600 to 650 mm. Growing period is about 160 to 165 days.

Dominating tree species are sessile oak (*Quercus petraea*) with European beech (*Fagus sylvatica*) admixed in segments of normal hydric range. Other important tree species are European hornbeam (*Carpinus betulus*) in coppice stand, where *Fagus sylvatica* and *Quercus petraea* were eliminated by coppicing.

The Beach-Oak zone covers 14.9 % of the forested area in Czech Republic.

3rd.- Oak-Beech vegetation tier

This vegetation tier show a clear predominance of the species of Central-European deciduous forest with the last traces of thermophillous species of lower vegetation altitudinal zones and with an exceptional occurrence of some sub-montane species.

It develops in hilly lands and uplands, most usually at altitudes between 400 and 550 m a.s.l., on warm expositions (SW and S dominantly) even beyond 600 m

Mean annual temperatures range about 6,5 to 7,5 °C, growing period length is 150 - 160 days. Mean annual precipitation is 650 - 700 mm.

Fagus sylvatica dominates grassy-like communities. The co-dominating *Quercus petraea* and *Carpinus betulus* have a production optimum in this zone. Under a coppice silvicultural system, *Fagus sylvatica* and *Quercus petraea* are repressed by *Carpinus betulus*. *Quercus robur* and *Abies alba* are common on permanent water influenced nutrient medium or poor soils. *Pinus sylvestris* is associated with nutrient-poor sites. The Oak-Beech zone covers 18.4 % of the forested area in Czech Republic.

4th.-Beech Vegetation Tier

It occurs at altitudes between 550 - 600m, reaching above 800 m a.s.l. in the Carpathian part of Moravia.

Mean annual temperature is about 6 to 6,5 °C, mean annual precipitation amounts to about 700 to 800 mm, growing season lasts 140 - 150 days.

This zone, representing the climatic optimum for *Fagus sylvatica*, featured a large area of pure beech stands, which occur now in the Carpathian area. *Quercus petraea* and *Abies alba* may be minor associates in the lower tree layer. In the Hercynicum area, localities with stagnic soils (sites with a strongly fluctuating water table) and wet (gley) soils within the Beech zone, are substituted by the Oak-Coniferous zone. As these edaphic conditions are not tolerated by *Fagus sylvatica*, *Abies alba* and *Quercus robur* dominate on such sites. The Beech zone covers 5.7 % of the forested area in Czech Republic.

This tier is the most extensive altitudinal zone and takes up 36 % of the Czech territory.

Forest stands of this vegetation tier can be generally referred to as the most altered ones. The majority of remaining beech stands is reserved in particularly protected areas. More extensive beech stands have survived in the Carpathian part of Moravia, especially in the northern part of White Carpathians where European beech has its Central-European optimum.

5th.-Fir-Beech Vegetation tier

It can be considered the first montane altitudinal vegetation (cold climatic zone) tier. It takes an altitude of 600 - 700 m a.s.l.

Mean annual temperature is about 5,5 to 6 °C, mean annual precipitation total ranges from 800 to 900 mm. Growing period length does not exceed 140 days.

Main stand-forming tree species are European beech (*Fagus sylvatica*) and Silver fir (*Abies alba*) with Norway spruce (*Picea abies*), while *Quercus petraea* is absent. *Abies alba* occurs more frequently on fine-textured soils and ridges where beech litter does not accumulate. *Picea abies* is also present, albeit to a much greater extent than in the past, is *Picea abies* which reaches a production optimum in the Fir-Beech zone. Throughout the zone, *Fagus sylvatica* is accompanied by several understory species considered to be diagnostic of the zone and faithful companions of the tree species. Tree species of water-influenced sites from the lower zones ascend to this zone; similarly, some sub alpine plant species descend to cool sites. The Fir-Beech zone covers 30 % of the forested area in Czech Republic.

6th.- Space-Beech vegetation tier

This vegetation tier already starts to be dominated by montane species.

Its presence concentrates in higher altitudes of hilly lands, usually at elevations ranging from 700 - 900m.

In climatic terms, this vegetation tier can be found in mountain regions with mean annual temperature about 4,5 to 5,5 °C and mean annual total precipitation of 900 - 1 050 mm. Climate humidity is considerably contributed to by horizontal precipitation originated from fog and icing. Growing period is relatively short (115 - 130 days).

Natural tree species composition of sites with normal hydrological regime shows a common occurrence of European beech (*Fagus sylvatica*), Silver fir (*Abies alba*) and

Norway spruce (*Picea abies*) like the main stand forming tree species and are referred to as a 'hercynian mixture'. Several understory species considered to be companions of *Picea abies* occur sporadically the in herb layer, such as *Prenanthes purpurea* L. (ascended from relatively wetter sites in the Fir-Beech zone and yet wetter in the Beech zone to relatively drier sites in this zone), *Polygonatum verticillatum* (L.) All., and *Festuca altissima* All.. *Calamagrostis villosa* (Chaix ex Vill.) is the understory dominant and *Pinus sylvestris* is a co dominant on nutrient-poor sites. *Doronicum austriacum* Jacq. (the Carpathian geoelement ranging eastwards to Orlické and Šumava Mts.), *Homogyne alpina* (L.) Cass., and *Luzula sylvatica* (Huds.) Gaudin are additional species. The Spruce-Beech zone covers 12 % of the forested area in Czech Republic.

7.- Spruce vegetation tier

The vegetation of this tier is concentrated in the highest altitudes of hilly lands at 900-1050 m a.s.l. The climate is cold with mean annual temperature from 4 to 4,5 °C, precipitation is high and its mean annual is about 1050 to 1200 mm. Snow cover period is quite long this is why the growing period is very short (100-115 days).

Fagus sylvatica retreats to lower tree layer in the 'Hercynian' tree species mixture, however, as krummholz; it forms occasionally the upper timberline in the Carpathians. Haplic Podzols (mountain) are the typical soils throughout the zone. A significant proportion of the understory species considered being companions of *Picea abies*, such as *Homogyne alpina* L., *Doronicum austriacum* Jacq., *Luzula sylvatica* Huds., and *Poa chaixii* Vill., are present in the herb layer. The Beech-Spruce zone covers 5 % of the forested area in Czech Republic.

8th.- Spruce vegetation tier

This vegetation zone is characterized by a mean annual temperature from 2.5 to 4.0 °C; mean annual precipitation 1200 to 1500 mm and growing season around 60 to 100 days.

Spruce vegetation tier occurs at an altitude of 1050 to 1350 m a.s.l.

Picea abies is nearly an absolute dominant, while *Fagus sylvatica* and *Abies alba* are either absent or growing as scrub. A mid-sized *Acer pseudoplatanus* is restricted to nutrient-rich soils. At the relatively narrow, upper timberline the forest grades into discontinuous clumps (cohorts, tree islands) of *Picea abies* mixed with the clumps of *Pinus mugo* Turra. The same understory species as in the Beech-Spruce zone are present in the herb layer, however, *Calamagrostis villosa* and *Avenella flexuosa* (L.) Parl. often dominate on acid habitats and nutrient-poor soils. The Spruce zone covers 1.7 % of the forested area in Czech Republic.

9th.- Dwarf pine tier

It occurs at an altitude over 1350 m. The mean annual temperature is 2.5 to 4.0 °C and the mean annual precipitation exceed 1500 mm. The growing season is really short not overriding 60 days.

This zone, occupying localities above the timberline, is characterized by shrub communities of *Pinus mugo*, scattered krummholz of *Picea abies*, and the shrub growth form of other species such as *Sorbus aucuparia spp. glabrata* (Wimmer & Grab.) Cajander, *Salix silesiaca* Willd., *Betula pubescens* L., and *Betula carpatica* Waldst. & Kit. ex Willd.. The Dwarf pine zone occupies a small area of Krokonoše and Jeseníky Mts.

0.- Pine zone (with a minor exception, including only Pinus sylvestris)

This special zone combines natural stands of pine (predominantly *Pinus sylvestris* and in some areas also with *Pinus rotundata* Link.) which occurrence is limited not by altitudinal but soil conditions. *Quercus petraea* and *Fagus sylvatica* (rarely *Picea abies*) are the principal associates. *Abies alba, Betula pubescens, B. pendula* and *Picea abies* associate pine on water-influenced habitats. *Pinus sylvestris* dominates or it is one of the major species only in special edaphic conditions, e.g., deep sands, serpentine, limestone rocks, peats, and acidic (base-poor) rock outcrops (relict pine stands). These edaphic conditions override the climatic influence and make the zone apparently climate-independent.

Table 5. The survey of the forest vegetation tiers (FVT) & characteristics. Source Remeš J. Podrázsky V.

n.	Name	%	Altitude m a. s. l.	Average temperature	Annual precipitation	Growing season
0	Pine	3,73				
1	Oak	8,31	< 350 m	> 8 °C	< 600 mm	> 165 days
2	Beech-Oak	14,89	350-400	7,5-8 °C	600-650 mm	160-165
3	Oak-Beech	18,41	400-550	6,5-7,5 °C	650-700 mm	150-160
4	Beech	5,69	550-600	6,0-6,5 °C	700-800 mm	140-150
5	Fir-Beech	30,04	600-700	5,5-6,0 °C	800-900 mm	130-140
6	Spruce-Beech	11,95	700-900	4,5-5,5 °C	900-1050 mm	115-130
7	Beech-Spruce	5,00	900-1050	4,0-4,5 °C	1050-1200 mm	100-115
8	Spruce	1,69	1050-1350	2,5-4,0 °C	1200-1500	60-100
9	Mountain Pine	0,29	> 1350	< 2,5 °C	> 1500 mm	< 60

3.1.4.2 Conversion from broadleaved to secondary conifers forest

In the European forests the proportion of fast growing coniferous forests is much higher than expected from natural conditions. The reason is that the conversion of sites covered with pure or mixed broadleaved forests into coniferous forests (mainly spruce and pine) was based on results of plots focusing on optimizing timber production. The findings suggested that on such sites coniferous trees grow much faster than broadleaves and they also reach a higher total merchantable timber volume (Pressler 1880; Hönlinger 1909). Most foresters of the period were convinced that forest management must help to increase the volume production regardless of the natural species distribution (Hasenauer H., 2004).

Effects of conversion (Johann E. et all, 2004):

- Increase of forest area due to monoculture plantations (Norway spruce and Scots pine mainly).
- Decline of yield. A remarkable reduction of growth became noticeable in those forest stands with a second and third generation of monocultures of spruce growing in the site. The disadvantages of the wide spread of spruce became obvious when soil degraded and the rare broadleaved trees disappeared. In some parts of Europe such as in Denmark, Austria and Germany Norway spruce has shown signs of a declining yield and health. In some cases this may also be due to the origin of seeds (Hauch and Oppermann 1898-1902).
- Lack of stability, high risk. When plantations were created by showing and planting of species of foreign origin such as in the Danish and South Bohemian cases, forest stands suffered extremely from wind, snow damages and diseases. Lack of stability implies a high risk of losing management control of the forest. Because of the increasing risk caused by wind-throw, snow break and bark beetle diseases in some European countries, in Switzerland clear-cutting was stopped at the beginning of 20th century, and the so called “near to nature silviculture” became more important. It entails an increase in deciduous trees species used in artificial regeneration (Bürgi and Schuler in press).
- Alteration of the natural composition of tree species. (Johann E. et all., 2004) The tree species composition prior to intense forest management were:

  - In South Bohemian forest; mixed forest of spruce, fir, beech, at sub-alpine altitude: beech and spruce with some fir at the end of Middle Ages.

- In central part of the Bohemian-Moravian Upland; mixed forest of fir/beech and beech/fir at the 12th century.

The conversion started on 18th century and the result were:

- In South Bohemian forest; the proportion of beech is 40% less of its natural occurrence, fir 10% less of its potential proportion. Spruce is overrepresented to 40%.

- In central part of the Bohemian-Moravian Upland; Norway spruce 80%, other species occur in the following order: Scts pine 11%, European larch 3%, beech, alder and birch 2%, silver fir 1%.

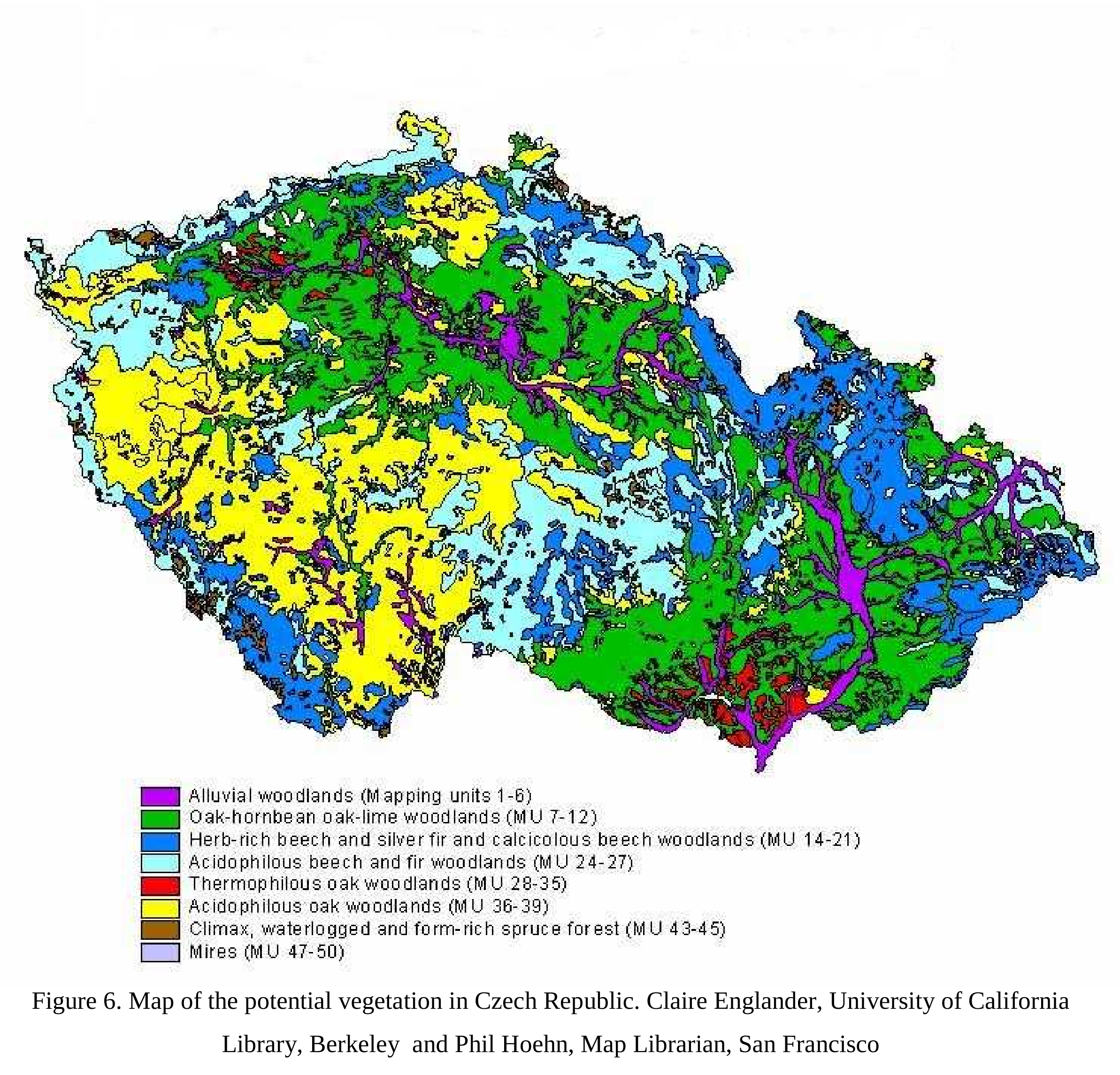
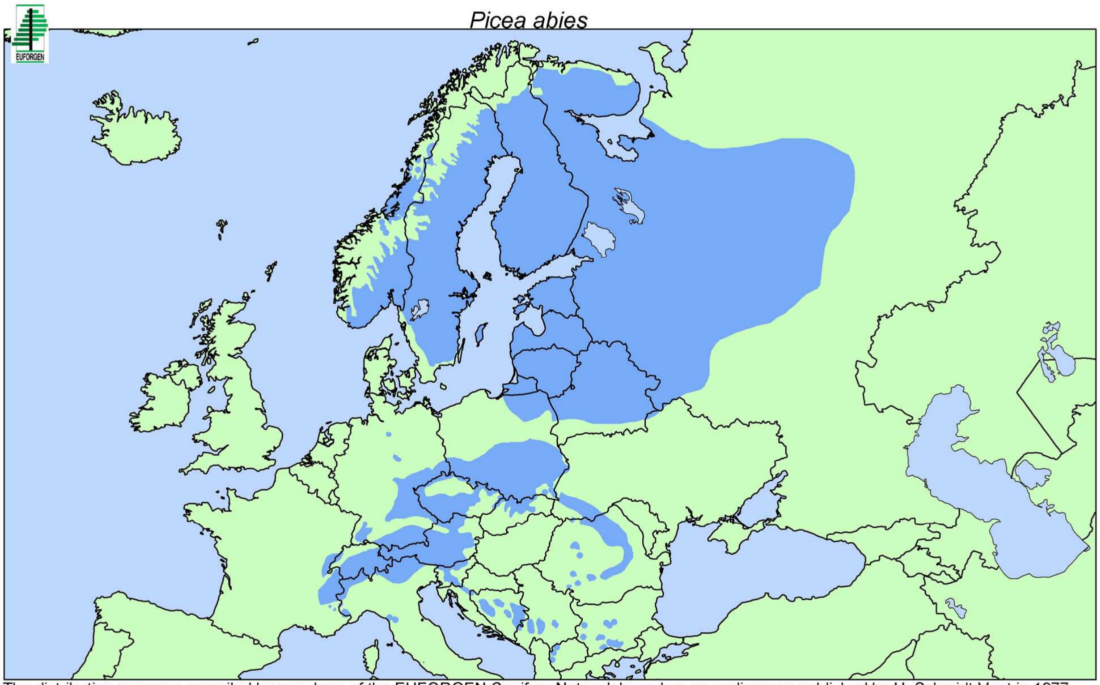


Figure 6. Map of the potential vegetation in Czech Republic. Claire Englander, University of California Library, Berkeley and Phil Hoehn, Map Librarian, San Francisco

3.1.5 Forest evolution during the last 10.000 years. The Norway spruce

3.1.5.1 Occurrence, origin and distribution of Norway spruce forests.

The total natural distribution of *Picea abies* covers 31 degrees of latitude from the Balkan Peninsula (latitude 41°27’N) to its northernmost extension near the Chatanga River, Siberia (latitude 72°15’N). Longitudinal range is from 5°27’E in the French Alps to 154°E at the Sea of Okhotsk in Eastern Siberia. The vertical distribution is from sea level and to altitudes above 2300 m in the Italian Alps.



The distribution map was compiled by members of the EUFORGEN Conifers Network based on an earlier map published by H. Schmidt-Vogt in 1977 (Die Fichte, Verlag Paul Parey, Hamburg and Berlin, p.647).
and was published in:
Skrøppa, T.. 2003. EUFORGEN Technical Guidelines for genetic conservation and use for Norway spruce (Picea abies).
International Plant Genetic Resources Institute, Rome, Italy. 6 pages

Figure 7. European distribution of *Picea abies*. Source: EUFORGEN Conifers Network.

Outside the natural distribution the species has been widely planted, in particular in Central Europe and in Scandinavia.

The natural European range of Picea abies can be divided into three major regions as the result of postglacial re-colonization: the Nordic-Baltic-Russian, the Hercyno-Carpathian and Alpine regions.

During the Pleistocene-Late glacial (12.000-8.300 BC) the climate was Sub artic, characterized by really low temperatures and low precipitations. The dominating vegetation formations were mainly composed by tundra forest and cold steppe with artic wastelands. Around 10000 BC the warmer stage took place. Nevertheless, the vegetation was not able to react so quickly and its character did not change very much. There were a retreat of steppe and successive changes of forest steppe and forest tundra formations: pine and birch species started to be distributed, more closed stands were located in Carpathian region. The pine expansion is not accompanied by other indicators of climatic warming and therefore is considered to be caused by lagged immigration (Gaillard, 1984, 1985). The early pine expansion can be ascribed to the rapid response of *Pinus* populations expanding from locally present glacial refugium shortly after climatic amelioration (Pokorny, 2002).

Norway spruce initiated its expansion through the East Carpathian region with *Pinus cembra* and *Pinus mugo*. In continental parts of Central Europe, *Pinus sylvestris* and possibly some other demanding species might have persisted locally through the entire glacial maximum. Pine is known to tolerate and even reproduce under extremely severe climatic conditions (usually in dwarf forms), either dry, windy, or cold (Pokorny, 2002). *Pinus* expansion may indicate increasingly severe conditions, particularly in winter, i.e. an increase in continentality (Walker, 1995).

Norway spruce probably spread in Czech territory in two main streams: Carpathian-Sudeten and Hercynian. The contact of both streams occurred in the Ore Mountains region in the Atlantic period (7500- 4500 BC) and in the Sub boreal (4500- 2500 BC) the maximum extent of spruce occurred. The areas of montane deciduous forest with elms, maples, and ash were invaded by *Picea abies*, which became a dominant tree over much of the uplands. European beech and Silver fir started to invade Norway spruce forests at the end of this period, leading to the named Hercynian mixture (*Picea abies, Abies alba, Fagus sylvatica*).

The human impact on the natural vegetation is evident from the beginning. Local deforestation, cultivation and grazing were the major types of human impact in early ages.

The extensive selection-felling of European beech, even at the highest altitudes, together with the climatic deterioration during the Little Ice Age (1680-1850), contributed to the conversion of mixed mountain forest into Norway spruce stands. At present these spruce communities are considered to be the natural climax vegetation only at the highest elevations.

Secondary distribution began in the 18th century, as a result of the Czech Directive for Forest and Timber (1754) which recommended cultivation of conifers mainly.

Fast growing tree species such as Norway spruce and Scots pine were promoted in large areas both within and beyond their natural range in order to increase the growth of commercial timber (Güde 1960). These secondary coniferous stands turned out to be easily damaged by environmental stress factors such as air pollution and climatic change (Hasenauer H., 2004).

Forest ecosystems have a certain buffer to resist environmental stress factors. If we reduce this buffer as a result of management (e.g. planting trees beyond their natural range), we increase the risk of damage. We have to enhance the natural resilience of the forest ecosystems, particularly of those forests which are growing beyond the natural potential vegetation range such as secondary coniferous forests growing in areas typically covered with broadleaved forests (Führer 1994).

Residues of natural forests were preserved only in inaccessible localities. Planting of Norway spruce monocultures outside its natural range resulted in increasing wood production, but forest calamities of various origins became more and more frequent. Unsuitable spruce ecotypes, repeated planting of the same species resulting in deprivation of forest soil (mainly by changing of humus layer), and spruce stands on labile soils affected by underground water are the main reasons for considerable problems.

3.1.5.2 Threats to Norway spruce genetic resources, their management and protection

The genetic variability in *Picea abies* has been studied in provenance and progeny trials, often planted at several sites, and by genetic markers such as isozymes and DNA markers. The neutral markers reveal a great genetic variability within populations. Some differentiation occurs between populations derived from different glacial refugium, and appears to reflect their post-glacial evolutionary history. Central European provenances appear to have somewhat reduced genetic diversity compared with those from Eastern Europe and Scandinavia.

The most pronounced adaptive patterns that have been demonstrated in provenance trials relate the population responses to the climatic conditions. In northern Europe these patterns of variability often can be related to latitude and longitude, and with degree of continentality, and will sometimes vary clinally. They are expressed by variation in the timing and duration of the annual growth period and the corresponding release and development of frost-hardiness in spring and autumn, respectively. These annual growth patterns have implications for frost-hardiness, growth potential and wood quality traits, and are important for proper choice of reforestation materials.

Mainly around developing industrial agglomerations the symptoms of emission impact are visible. Usually higher elevations have been damaged heavily and local spruce populations in some regions are seriously threatened. The areas most affected by industrial pollution are in the northern part of the country, in the Ore Mountains.

In some areas where maladapted provenances of Norway spruce have been planted, damage and reduced yield have occurred. During the last two decades the species has suffered severely with the forest decline in Central Europe, resulting in stands with high percentages of trees with needle loss, or completely destroyed stands. The health problems of the Central European spruce forest and the reduced possibilities for recreation in young spruce stands have reduced its popularity in reforestation, in particular outside its natural range. Fragmentation of former continuous forest areas is another threat for the genetic diversity of the species.

Weakened forest stands and changing climatic conditions (winters without frosts, dry and hot springs and summers) are serious causes of the increasing trend of various damaging insects. The most serious biotic threats to Picea abies are root rot (*Heterobasidion annosum*) and bark beetles (*Ips typographus*).

As reintroduction of the Norway spruce local populations is possible only after a substantial change in the current ecological conditions, an ex situ breeding program was started 10 years ago. Where seed collection was still possible, cultivated seedlings were used as hortet for the next cutting propagation. From so-called `resistant trees', grafts were prepared; about 150 clones are available. Considering the insufficiency of spruce seeds in the highest areas, part of the planting stock is grown vegetatively, usually through cuttings.

3.1.5.3 The most urgent needs in Norway spruce conservation

Genetic conservation of *Picea abies* is done by proper use of reforestation materials and by specific in situ and ex situ conservation activities:

Ex-situ conservation means literally, "off-site conservation". It is the process of protecting endangered specie by removing part of the population from a threatened habitat and placing it in a new location.

In-situ conservation means "on-site conservation". It is the process of protecting endangered specie in its natural habitat. The benefit to in-situ conservation is that it maintains recovering populations in the surrounding where they have developed their distinctive properties.

In reforestation, the minimum requirement should be that the origin of the reproductive material is known, and its adaptive properties should be appropriate for the ecological conditions at the regeneration site. A system for the control of reproductive materials should be established and recommendations for proper use of different materials should be developed.

The *P. abies* seed samples of recommended seed lots for practical reforestation should be harvested in years with abundant flowering and seed production and be stored in sufficient amounts in seed banks. Experiences by others suggest that for Norway spruce the storage period should be 30-40 year. A seed bank with deep freezers is probably the best method.

In situ conservation of *P. abies* is often successfully done in protected areas. In several countries, however, protected areas alone do not fulfill the actual needs and requirements for the conservation of genetic resources of forest trees. There may therefore be a need for gene reserve forests, established in natural stands and managed according to silvicultural practice, such as thinning and harvesting, ensuring the potential for successful regeneration. The objective is to maintain the potential for continuous future evolution of the population. It has been suggested that gene reserve forests should cover areas of at least 100 ha, but smaller areas can also serve the purpose. Such forests may consist of a mixture of different species, if that is their natural species composition. In areas where *P. abies* is not a native species, it may be desirable to conserve the genetic variation of well-adapted ones in gene reserve forests. Establishment of ex situ conservation plantations of *P. abies* may be necessary in order to conserve the genetic variability of threatened populations that cannot be maintained at the original site. The objective will be to establish a new population that maintains as much as possible of the original genetic variability and allows for long-term adaptation to the local conditions at the planting site. It can be established by planting of seedlings, but also by direct sowing or vegetative propagules. Sizes of 2–5 ha are generally recommended. Specific genotypes of *P. abies* are conserved ex situ as vegetative propagules, in most cases as grafts, in clone banks or clonal archives. Several replicates should be made of each clone to reduce the risk of loss due to fire and other disasters. Clonal archives are static gene conservation units, with no natural regeneration intended in the plantation. They often contain members of breeding populations that are characterized genetically and are used to provide scions to be grafted in seed orchards or to make controlled crosses. All populations belonging to a breeding program, such as seed orchards and progeny tests, are important gene conservation units as they contain materials with known genetic properties that can be used to generate new populations with known adaptive and wood-production characteristics. Breeding populations organized in a system of multiple populations at different sites have particular value for conserving genetic variability both within and between populations.

The preservation of gene resources and the use of proper genetically suitable seedlings by the new forest owners have to be ensured by continuing education programs.

3.2 HISTORY OF FOREST MANAGEMENT IN THE CZECH REPUBLIC

The forests of Czech Republic have been influenced and transformed by long lasting and changing human interventions. Of particular importance was the medieval colonization with land clearings peaked during the twelfth and thirteenth centuries. Forests in the vicinity of villages were intensively used for local wood supply, food and other forest products, and as part of agricultural production systems. The consequence of this management was the reduction in growing stock volume, forest productivity and genetic forest value. The forest area decreased, on many localities forests were devastated. Some rules were initiated through regulations, which laid the base of Forest Management. Some efforts on improve of forest constitution, (f.e.: Maiestas Carolina – the code of the Czech king and Roman emperor Charles IV. in the 14th century) were evoked response on this state.

There were two options for remedy and appropriate forest management:

1) Safeguarding of sustainability while keeping present selective system of management through suitable control method based on supervising of growing stock volume and its increment.

2) The replacement of silvicultural system for clear-cutting system ensuring sustainability of forest and its yields based on area and age of forest stands.

During the 18th century, especially second half, the silvicultural systems were replaced by the clear-cutting system, which came the most frequently management system in the Czech Republic.

Clear-cutting system of forest management is responsible for totally tree species composition change of forest stands and change of their structure in the middle Europe region.

Czech First forestry act that was good for all territory of the Czech Republic, was adopted in 1754 (for the Czech part) and in 1756 (for the Moravian part). From this time, we can speak about modern systematic sustainable forest management in the Czech Republic.

These fundamental changes in forests by extensive cuttings have brought some positive and some negative effects. The positive effects are that it provided sustainability of management on the basis of the age and the area, deforestation and forest devastation stopped by using of Norway spruce and Scots pine plantations. Change of tree species composition provided desired wood raw material for building and chemical industry. Forest area and forest productivity (growing stock volume) increased and it's still growing at the present time.

On the other hand the negative impacts became manifested namely in the last century mostly due to the effects of salvage felling. There is an important decrease of static and ecological stability of pure even age forest opposite to the forest with more complex stand structure; damages consequence of snow, wind and biotic agents increase. Norway spruce and Scots pine also have some negative influences on the forest soil (podzolization, soil acidification) and nutrient cycles.

After Second World War (1945) the new possibilities for silviculture appeared. With Shelterwood system along with the aim of the ecological and economical reached optimization of forest. It was very popular and it became the main silvicultural system. Shelter wood system was very often used but this period took only till the early 70's when it was another time changed by clear-cutting system. In spite of this the trend in the forest area is favourable – the area enlarged by 439 thousand hectares over last 120 years.

Around 90's resulting of the new role of the forest for society a new interest about close-to-nature forest management and about non-wood-producing functions of forest was born. It's been trying to change even-aged forests into uneven-aged forests, mixing species too. Even it is mainly developed in Europe is a world-wide movement.

3.3 ACTUAL SITUATION OF THE FORESTS AND FOREST POLICY IN CZECH REPUBLIC

3.3.1 The present forest management in the Czech Republic. “Principles of state policy in the Czech Republic”

Fundamental changes in forestry of the Czech Republic were initiated by “Velvet revolution” in 1989.

The State Forest enterprises transformed their organization, ownership relations changed and also, and more important state of forest in the Czech Republic were altered.

These facts all together led to the proposal of a renewal in the forest policy.

Ministry of Agriculture of the Czech Republic has submitted the government

“**Principles of state forest policy in the Czech Republic**”, that have been discussed and accepted at the government session of 25 August, 1993.

The principles are as follows:

- *Forests are a natural resource*. The basic objective of the forest policy is to preserve the forest, in all its expressions. To get this goal is indispensable to arrange the proper strategies for a good development and protection for the benefit of future generations.
- *Sustainable management of forests*. This concept is based in the idea that the stewardship and use of forests should be in a way and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfill now and in the future, relevant ecological, economic and social functions, at local, national and global levels and does not cause damage to other ecosystems.
- *New ecological and social forest functions in the society.* This new view borns like the consequence of the growing social interest about the environmental protection of forests.
- *Forest is a renewable resource.* Forest biomass is a renewable source of energy. Efficient combustion of biomass is a cleaner energy solution than burning fossil fuels. It also reduces demand for coal, oil and natural gas and prevents additional carbon from being released into the atmosphere, reducing green house gases emission.
- *Restore and stabilize forest ecosystems afflicted by air pollution***.** In the 1980’s the air quality in the Czech Republic was one of the worst in Europe.

Democratic changes in the beginning of 90's led to adoption of an environmentally friendly legislation and enforced substantial improvement of environment in Czech Republic. This betterment was caused mostly by decreasing consumption of brown coal with high content of sulphur dioxide. This was used mainly in large power plants. The current situation is comparable with other European countries.

- *Adapt forest tree species composition to the expected development.* Global climate change is finally a real fact and the forest policy should be concerned about the consequences on the ecosystem. Various hypotheses for human-induced climate change have been debated for many years. The biggest factor of present concern is the increase in CO_2 levels due to emissions from fossil fuel combustion, followed by aerosols (particulate matter in the atmosphere), which exert a cooling effect, and cement manufacture. Other factors, including land use, ozone depletion, animal agriculture and deforestation, also affect climate. A lot of present tree species will likely disappear from significant part of forests being destabilized, predominantly broadleaved species. Therefore, it is necessary to make the adaptation of tree species composition in order to reduce the cost of establishment in the future and for the biodiversity conservation.

- *Support of researches focused on a long-term development of forests.* Forest management in the regions under impact of air pollution does not create sufficient sources for necessary reproduction of forests, the support of forest functions, the suppression of the consequences of harmful agents and the support of research focused on a long-term development of these forests. Enhancement of forest conservation needs the establishment of purposeful fund. It will create the prerequisites for funding of these activities.

A change of ownership relations and the state of forest in the Czech Republic require new forest legislation. The forest Act n. 289/1995 respects the equality of the rights in ownership relations, to ensure the balance between interest of the public and the rights of the owners, to protect forests from devastation and to safeguard their multiple functions.

- *Forest management in harmony with forest management plans* will be guaranteed both to the owners and the state through forest professionals with prescribed qualification.

- *The right of common use of forests by citizens* is ensured in the Forest Act, in a spirit of traditions of this country in democracy. Possibility of the use of recreational and hygienic forest functions and pick up of forest crop, is ensured for each citizens, unless the right is being reserved by the owner, on condition that forest protection will be respect and the forest environment will not be disturbed.

- It is necessary to *keep numbers of game on the level not endangering the existence of forest* and enabling its natural regeneration so that nature balance between forest and game management could be restored.

Market economy as management system enables privatization of the part of state forest property. Termination of restitution process is the prerequisite to privatization. With respect to the implementation of principles of state forest policy and other requirements of state, the government will decide the extent and the way of privatization of state forests and the regions where forests should not be privatized.

The importance of forest and forestry development will be supported through an access of forestry to use of finances from the programs and funds of international assistance.

On account of building up the ecologically sound landscape and the utilizations of poorly productive agricultural lands, Ministry of Agriculture will enforce appropriate forest utilization of these areas in agreement with other participated bodies and in harmony with the plans of systems of ecological landscape stability.

3.3.2 Forest management under state supervision. The Forest Act.

Forest management is relatively strict determined by law prescript, namely The Forest Act from 1995 and the Nature and landscape conservation Act from 1992 are dominant role.

The Forest Act, dated on November 3rd 1995, is creating the base framework of forest management in the Czech Republic.

Chapter 289 coll. on forest is valid in Czech Republic. This act is effective as from January 1st, 1996. It contains ten sections:

1) Initial Provisions
2) Preservations of Forest
3) General Use of the Forest
4) Preconditions of Sustainable Forest Management
5) Forest Management
6) Licensing
7) Promotion of Forest Management
8) State Forest Administration
9) Sanctions
10) Transitory and Common Provisions

The main principles of forest management according to the Forest Act are follows:

- Sustainable management of forests as a base of forest utilization

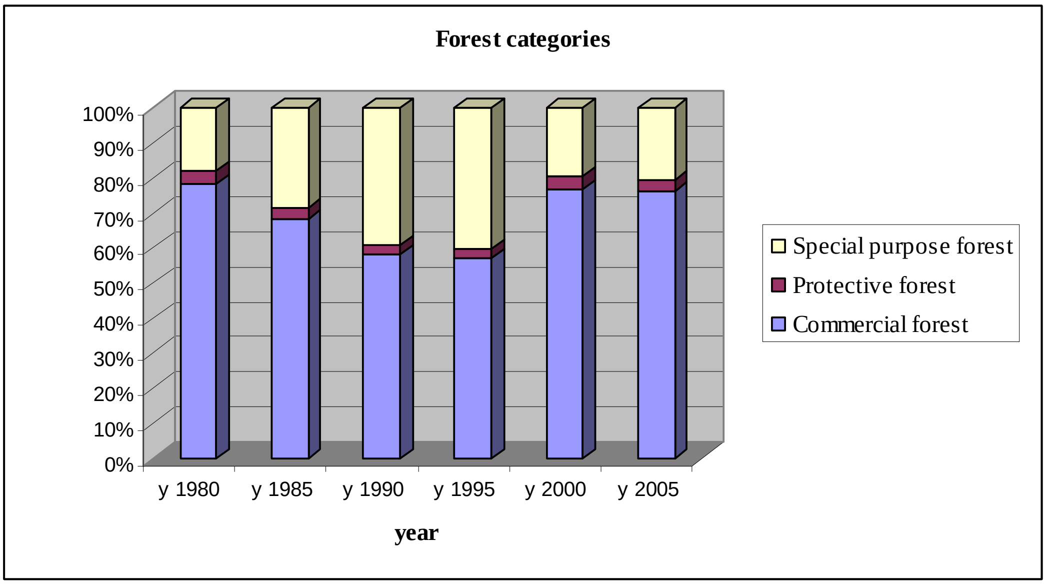
- Forests are divided according to the consideration of forest functions into the 3 forest categories: protection forests, special purpose forests and commercial forests. Protection forests mean forests growing on unfavorable sites, those forests which are protecting lower stands, forests in dwarf-pine vegetation zone.

Special purpose forests are forests not belonging to protection forests and they are at water reservoirs protection zones, in national parks and national reserves. Forests where social or another interest is more important than wood production are included in this group. There can be seen a detriment in the area of special purpose forests in 2000. The reason is that currently the areas affected by inmission are not included.

Commercial forests are the rest.

Table 6. Forest categories an their proportion (%) in Czech Republic. Source: Remeš J. & Podrázský V.

	Commercial forest	Protective forest	Special purpose forest
1980	78.2	4	17.8
1985	68.2	3.1	28.7
1990	58.4	2.5	39.1
1995	57.2	2.7	40.1
2000	76.7	3.5	19.8
2005	76	3.5	20.5



Graph 3. Forest categories in Czech Republic (data from Table 6).

- Forest management plans are instruments of the owner of the forest and are prepared, as a rule, for a period of 10 years. It is obligatory for owners who have more than 50 hectares of forest with a maximum of 20000 hectares, from this size another plan will be needed. Who owns less than 50 hectares has to prepare Forest management guidelines, also valid for ten years. The preparation of guidelines is commissioned by the relevant state forest administration body.

Management plans should be paid by the owner of the forest but expenses of guidelines are born by state.

All individuals and legal entities involved in planned management activities are obliged to meet several binding provisions:

• total cut volume

• minimum portion of soil-improving and reinforcing tree species in forest stand regeneration

• minimum area of tending felling in forest stand below 40 years of age (this appointment is obligatory only in the state and communal forests).

Owners are obliged to keep records of the origin of seeds and plants of tree species in each stand.

- There are four equivalent silvicultural systems in the Czech forest management:

- Clear-cutting system.
- Regeneration by border felling
- Shelterwood system
- Selection system

Some observations about clear cuttings are compiled: Maximum area of clear cut is 1 ha with maximum width up double of mean stand height. Exemption of rule is possible on natural flood plain forests, natural pine forests and on mountain slopes (with length over 250 m) without transportation system. Clear cut is accepted there up to 2 ha.

- About regeneration. The owner is obliged to regenerate the forest stand of each site using suitable forest tree species and to tend them in proper time and in a systematic manner to improve its state, increase their resistance and improve the fulfillment of forest functions.

Start of forest stand regeneration is possible from min. 80 years of the stand age. It is not allowed to drive down stand density under 0,70 before this stand age. During forest regeneration, it is prohibited to add another clear-cutting to young unestablished stands if the total resulting area of unestablished stands exceeds the area and width specified above.

- Collection, transport, cultivation and use of reproductive material of forest tree species are under strict appointments. Collection of forest tree species reproduction material are possible from:

1. Identified sources - forest stands genetic category C (mean quality). Selected sources forests stands genetic category A, B (plus seed stands).
2. Qualified sources - plus trees, seed orchards, intentionally established set of trees specially grown for taking of cuttings, seed stands.
3. Tested sources.

The seedling for planting must to come from the same forest natural region and from the same forest vegetation zone.

In addition, seeds or plants of Norway spruce, Scots pine and European larch must come from plus trees or forest stands approved for seed collection or seed orchard.

- Specific measures for management activities in protection forests and special purpose forests may be determined by the state administration body or proposed in the plan or guideline.

- Each forest must be managed under expert control of professional forest manager. Forest manager has to have license and must be present in all stands.

- All the activities which take place in forest, including developing plans and guidelines as well as any commercial activities with seeds and seedlings are granted by the Ministry of Agriculture.

- To transgress the legal provisions for general use of the forest by citizens, the state forest administration body may impose fines of up to 5000 Czech crowns to even more than15000 crowns. The Act designates specific cases in which the state forest administration body may impose fines on entrepreneurs and forest owners of either 100000 or 1000000 crowns.

- State forest administration. There are three administration levels: cities with administration power, districts offices and Ministry of Agriculture. Ministry of Agriculture is the central body of state forest administration. Ministry of Environmental is the central body for national parks.

3.3.3 The most important common needs to solve in Czech forestry and recommended measures.

There are some serious problems of the Czech forests and forest management.

Long term affecting of forests ecosystems by anthropic (human) activities is bringing some serious negative effects. Forests are continually dying back not only due to human activities, but also as consequence of fungal diseases, windfall and bark beetle attacks. Large areas of the forests in the Czech Republic were destroyed due to air pollution. These damages were caused by extensive industrial development in the central Europe region. Surplur and nitrogen are deposited in forest soils mainly from industrial and transport emissions. Production of nitrogen oxides has even increased in the last few years, in contrast to emissions of sulphur which were damaging the forests the most in the past. Sulphur emissions declined in the 1990s due to the desulphurisation of power plants. Nitrogen is in excess in forest ecosystems and leads to overgrowth and, as a result, spruce is easily splintered and a higher relative amount of nitrogen in woody tissues makes the trees more susceptible to various insect pests and fungi. Although air inmission stress by SO2 was important declined, regeneration processes of forest ecosystems in the air pollution areas are running very slow.

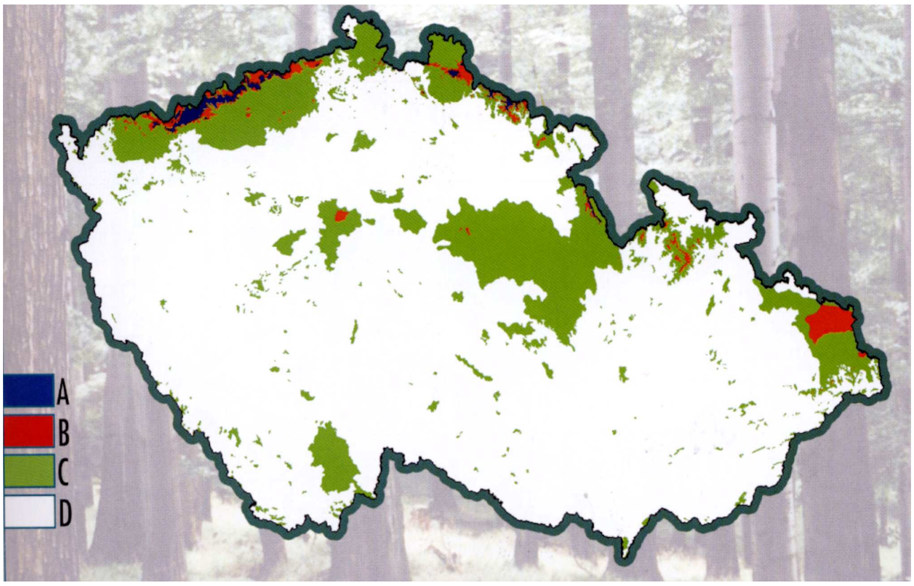


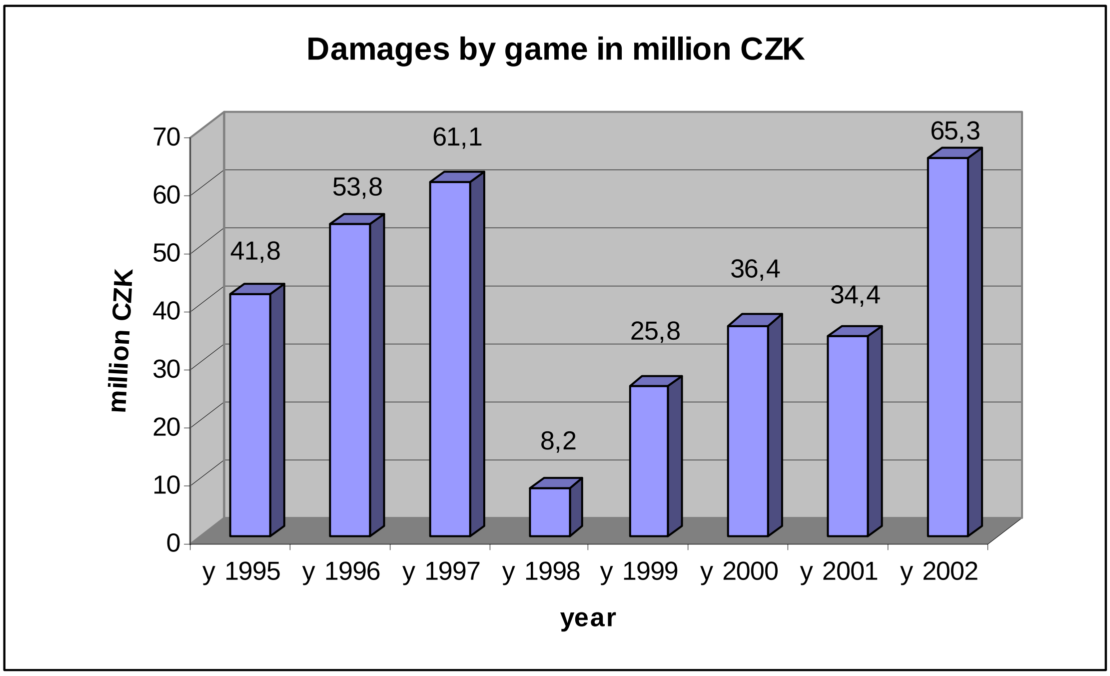
Figure 8. Air pollution damage zones in the Czech Republic. Source ÚHÚL, Forest Management Institute.

In addition the issue of pollution is complicated by other unfavourable factors such as climate variations.

Expected impacts of climate change in forests in the Czech Republic include a significant reduction in the forest area. For those native tree species growing outside their ecologically optimal areas, changing climate conditions will increase their susceptibility to damage and insect infestations. Spruce will be one of the species at highest risk. Further impacts of climate change are predicted to include a higher occurrence of extreme weather conditions (storms, tornadoes, wet snow avalanches, frost) with resulting negative consequences for forests.

The increment of the population of ungulates, specially game, is another very significant negative factor. The aim of keeping these animals in forest is the hunting, in many regions the numbers are several times higher than the natural level would be and which forest would be able to sustain. Damage caused by animal browsing and bark-peeling significantly affects to the tree health. Artificially planted samplings are protected by fences, plastic tubes and other mechanical protections. The pressure makes natural regeneration difficult or even impossible.

Big predators are important to the natural balance of the forests. Lynx (*Lynx lynx*), bear (*Ursus arctos*) and wolf (*Canis lupus*) are part of the native fauna and were present throughout the Czech Republic in the past. Settlements, exploitation of forest, etcetera provoked their extinction in the area. During the last few decades, big predators have been migrating back to the Czech Republic.



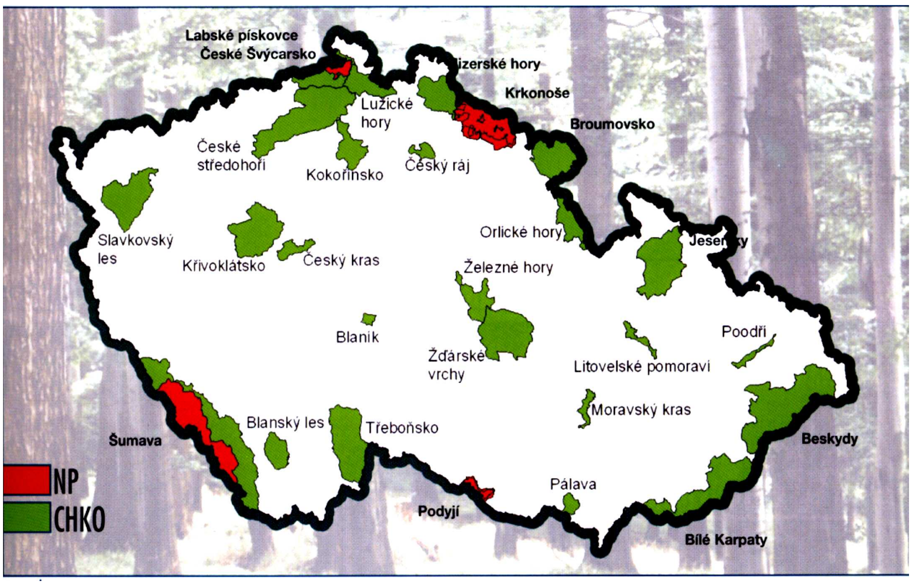
Graph 4. Damage caused by game (in mill. CZK). Source: Remeš J. and Podrázský V.

Insufficient attention paid to soil protection in forest conservation and management is a major problem. Clear-cuttings are especially harmful.

The uncovered layer of humus is quickly mineralized and is washed away by the rain. At the same time particular soil bacteria, fungi and soil fauna (crucial for forest ecosystems and soil functions) die off, indigenous soil fauna facilitate the transport of symbiotic mycorrhizal fungi to the roots of planted trees, the disappearance in effect makes forest regeneration more difficult. The change disrupts important decomposition processes within the soil and leads to a change in soil microstructure. Soil generating ecological processes are interrupted. Soil compaction due to heavy machinery causes soil to lose porosity and thus its capacity to retain water.

Soil is crucial not only for wood production, but also for all life on the earth's surface. Soil life must be protected to the same extent as the above-ground elements of the ecosystem. Soil organisms, some soil animals in particular, will not move to a new suitable area because they lack the ability to migrate. This fact will lead to the complete destabilization of the ecosystem.

Accession to the European Union and the implementation of Natura 2000 into Czech legislation may improve the protection and management of some nature-protected areas. The introduction of compensation for the owners of land under nature protection is needed.



Large protected regions in the Czech Republic
Red colour – National parks
Green colour – Protected landscape areas

Figure 9. Protected regions in Czech Republic.Source ÚHÚL, Forest Management Institute.

The fact that some areas in the Czech Republic are nominally protected nature areas does not guarantee real protection for them. Logging, hunting, alteration of riverbanks and the construction of other technical solutions to flood control have been regularly documented by environmental organisations; even in the nature reserves awarded the highest level of protection. Many nature-protected areas are also endangered by construction of roads, highways and ski lifts.

The government and lawmakers should implement the necessary changes to improve this situation.

Recommended measures

Systematic change of management system is necessary in order to improve the condition of Czech forests. It is essential to abandon the management model of even-aged forests and clear cutting and move towards sustainable, close-to-nature forest management, which ensures a constant wood supply as well as continued function of all elements of the forest ecosystem. Small area shelterwood felling and selective harvesting methods should be preferred. At the same time, regulations should ensure that clear-cut areas which were created in the past will be reforested with pioneer species.

It is crucial to gradually restore the species composition in the forests to one close to the natural corresponding to the given habitat. The change in composition will certainly take hundreds of years, taking into account the duration of rotation periods. Nevertheless it is necessary.

A portion of the trees in managed forests should be ensured to be left to die and decompose, at least several trees per hectare. This will preserve the important habitats of numerous species and maintain a portion of the nutrients in the forest.

Liming and fertilization need to be significantly limited if not abandoned completely. They lead to the creation of artificial ecosystems with the consequence of symptoms of damage, mostly the yellowing of needles.

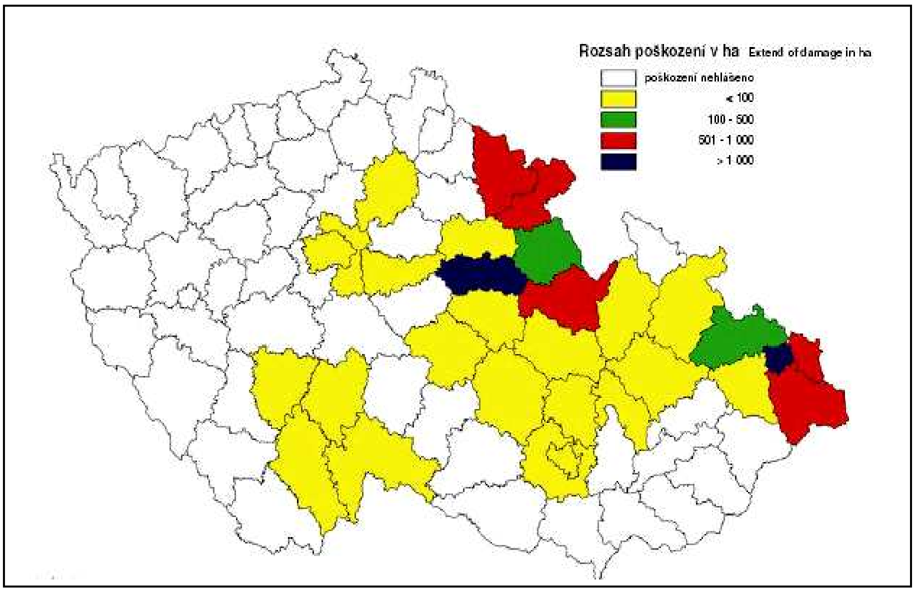


Figure 10. Recorded occurrence of Norway spruce needle yellowing. Source ÚHÚL, Forest Management Institute.

This measure cause lack of biodiversity in soil fauna, followed by destabilization of decomposition processes and changes in the nutrient cycle which run to a disequilibrium in forest ecosystems, especially mountain ecosystems.

About game overpopulation, it is necessary to be adjusted to a level sustainable for the forest. The authorities responsible for game management must not tolerate the overpopulation by hunting associations and legal sanctions should be imposed on hunters both sponsoring overpopulation and hunting above a given limit.

All of the measures mentioned above have to be applied in Czech forests but always regulated by the current forest policy and Forest Act looking for a meeting point between production and protection.

3.3.4 Main forest regeneration systems in Czech Republic

Forest is a dynamic entity. Every time that a disturbance open an area new seedlings appear in the gap. They will take the advantage of the increased light, water and nutrients.

Different tree species have developed big range of regeneration strategies. Each specie has its own climax conditions, if these circumstances are present in the area the target specie will be dominant.

Regeneration of natural (virgin) forests is automatic process, which is taking place in disintegration stage of forests. The trees are mostly old ones. The mortality increase because they are more susceptible of disturbances like wind storms or insect outbreak. The consequence is that gaps are opened and seeds stored in soil start its development.

If there are seedlings of desirable species already established when a forest is cut or otherwise disturbed, a new, high quality forest can develop immediately but the opposite is more often the case. Good quality seed sources weren't available, or if they were, the seeds didn't germinate and grow.

In order to control and optimize regeneration, foresters have developed silvicultural systems to regenerate forests. These systems are designed around the regeneration strategies of the desired species.

Two basic forms of regeneration can be distinguished:

- Natural regeneration. Foresters take the advantage of the growing potential of the stand. The main requirements for a successful regeneration are:
  1. adequate supply of viable seeds
  2. favorable seedbed for germination
  3. suitable microenvironment for subsequent survival and growth of the seedlings.

Successful regeneration takes place when these three factors come together at the same time and in the same place.

- Artificial regeneration includes planting and sowing.

At present, combined regeneration (artificial and natural) is very often used in the Czech Republic.

According to duration of regeneration period:

- Short term regeneration. Below 20-30 years.
- Long term regeneration. Above 30 years.

According to spatial arrangement we can differentiate 3 fundamental regeneration technologies:

- regeneration under shelterwood
- regeneration by clear-cutting and
- regeneration by border felling

It is often necessary to use in the same forest stand several regeneration technologies to achieve the regeneration target.

There are 4 equivalent silvicultural systems in the Czech Republic:

- clear cutting system, generally connected with artificial regeneration. Quite large gaps are opened, no more than 1 hectare is allowed (2 hectares for the exceptions). Light demanding species like Scots pine, European larch and oak are favored, while shade trees like beech and fir are unflavored. Is the responsible of the species composition change in Czech Republic, due to the wide use of this system during the last two centuries.

- Shelterwood system, predominantly based on natural regeneration. The new stand generation grows under canopy of mature stand. Currently this regeneration system is very popular in Czech Republic.
- Border felling system, represents the link between clear cutting and shelterwood system. Specific ecological conditions are created under canopy but just towards the cleared area.
- Selection system. This silvicultural system is not common in the Czech Republic due to historical development, site conditions and stands species composition. There are only some stand conversion forests managed under systems involving coupes to the selection forests in this country (Opočno, Kutná Hora, Křtiny). Some features are: time and spatial arrangement of regeneration is not necessary, basic spatial decision is choice of regeneration cutting method (clear cutting, shelterwood cutting, strip, combined felling) and concurrently choice of starting point of regeneration and progression of fellings with respect to stand state, terrain configuration, climatic conditions. Beginning of forest stand regeneration is possible from min. 80 years of stand age. It is not allowed to drive down stand density under 0,70 before this stand age. Number, size and location of regeneration components are also important parameters of spatial arrangement of regeneration. Selection forest allows us, to remove lumber of all diameters.

Criterions of felling maturity are very important tools of tree selection to cutting in forests regeneration management. Main used criteria of felling maturity are:

1. age of trees and stand
2. diameter of trees
3. tree quality
4. tree increment

Despite of distinct increase of natural regeneration, artificial regeneration is left important regeneration form. Combination of nature and artificial regeneration is considerable especially in connection with necessary change of tree species composition of forests towards to increasing of their biodiversity.

3.4 Uneven-aged management.

Even-aged monoculture forest stands with a dominant position of Norway spruce and Scotch pine constitute the main part of forests in the Czech Republic. The proportion of both species is still distinctly different from the natural state and it amounts to more than 70%. The originally mainly broadleaved and mixed forests were replaced by coniferous plantations since the late 18th century. This change was a response to the results of an uncontrolled system of selective management which was practiced in Europe till the second half of 18th century. This selective system was missing any criteria of sustainability and it frequently led to the devastation of forests (Poleno 2000).

The transformation of even-aged pure spruce or pine forest stands into forest stands with more complex stand structure is a key topic of forest management in many countries, not only in Central Europe but also in North America and the countries in the boreal zone.

The first practical forester, who realized close-to-nature forest management in the territory of Czech Republic was Hugo Konias.

The other protagonists and successors of selection forest management in Czech Republic were Zakopal, Polanský and Kratochvíl. The knowledge of conversion to selection forest could be applied to other management systems, especially to a shelterwood system. Thanks to its variability this management system can be used on a large scale in the forest conditions of the Czech Republic. After 1945, the shelterwood system was applied on a large area of Czech forests (Remeš J., 2006). This system is characterized by elimination of clear cuttings, natural regeneration, relatively long-term regeneration period and sequential conversion of coniferous monocultures into mixed stands.

The clear cutting, seed-tree, and shelterwood methods produce even-aged stands; the selection method (single tree or group selection) creates and maintains uneven-aged stands (Matthews, 1989; Smith et al., 1997)

Stands managed under uneven-aged systems are normally comprised of three or more age classes. An uneven-aged silvicultural system maintains and regenerates a stand with three or more age classes (Helms, 1998).

These cover types are adapted to regenerate under partial canopies following minor disturbances like individual tree mortality, or a moderate disturbance such as a wind storm that would damage up to one third of the stand. Uneven-aged systems are designed to mimic such disturbances. Uneven-aged silviculture can be used to imitate later stages of forest succession, particularly the transition phase (Bormann and Likens, 1979)

As a result, regeneration and most vigorous growth typically occur in small- to medium-sized gaps (small openings). The number and size of gaps created through uneven-aged management are dependent upon species composition, and tree rotation age or size. Normally, these systems are used to manage stands containing mixed trees of all ages, from seedlings to mature trees.

Uneven-aged silviculture maintains a continuous forest cover, thus protecting against soil erosion, offering improved aesthetics, and potentially reducing negative impacts associated with forest fragmentation (Williston, 1978; Chang, 1990; Redmond and Greenhalgh, 1990)

Moreover, Williston (1978) suggest that uneven-aged silviculture is better adapted to steep slopes, fragile soils, very dry sites, and high water tables, and that it maintains genetic variability better than even-aged silviculture.

3.4.1 Uneven-aged Harvest and Regeneration Methods

Stand regeneration is achieved by periodically manipulating the overstory and understory to create conditions favorable for the establishment and survival of desirable tree species. Thinning, regeneration and harvesting usually occurs simultaneously. The harvested trees are essentially replaced by growth on the younger trees left in the stand. These silvicultural systems are designed to maintain an uneven-aged stand condition, while manipulating the multi-age and multi-size structure of the overstory to facilitate continual recruitment and development of quality growing stock.

With the uneven-aged silvicultural system, the tree selection decision (to cut or to leave) considers a number of factors as tree quality, species desirability and desired age and size class distribution.

The following are generally accepted uneven-aged natural regeneration systems:

• **Single-tree Selection:** Individual trees of various size and age classes are periodically removed to provide space for regeneration, and promote the growth of remaining trees. Each regeneration opening (gap) covers an area equivalent to the crown spread of a single large tree that has been removed. Individual trees are selected for removal from all size classes (to achieve desired residual density levels) following recognized order of removal criteria based on tree risk, vigor, quality, and spacing.

The goal is to achieve an optimum distribution of size and age classes so each contains a sufficient number of quality trees to replace those harvested in the next larger size class.

• **Group Selection:** Trees are periodically removed in small groups to create conditions favorable for the regeneration and establishment of new age classes. In general, the openings created may range in size from fairly small 80 m² up to 2000 m². Smaller openings favor regeneration of more-tolerant species, while larger openings favor mid-tolerant species. In general, stands dominated by large crowned tolerant species (such as beech) do not require the creation of large openings to provide sunlight for regeneration, and individual trees are harvested as they mature using the single-tree selection method. However, some of the less-tolerant species benefit from the use of the group selection method to enhance recruitment and growth of new seedlings. One-quarter to one-half acre gaps may also have potential application in the management of uneven-aged stands of mid-tolerant like red oak and white pine on some sites. Potentially, most-tolerant to mid-tolerant species can be managed by applying variations of the selection regeneration method, if appropriate steps are taken to control competition.

In general, stands managed under uneven-aged systems regenerate as a result of manipulation of light levels during the harvest process. In some cases, non-commercial removal of additional cull trees or poorly formed saplings may be needed to further enhance regeneration in specific areas which are not opened up through the normal selection process.

3.4.2 Uneven-Aged Tending Methods

In uneven-aged silvicultural systems, tending operations are not as clearly distinguished from harvest and regeneration operations as in even-aged systems. Harvest and regeneration are perpetual operations, rather than occurring once during a stand's rotation, so tending must also be integrated and not temporally separated. In addition, uneven-aged stands often have a spatially patchy age structure that may require patchy applications or variations of intermediate treatments.

Release treatments are designed to free young trees from undesirable competing vegetation to improve stand composition, growth and quality. These timber stand improvement (TSI) treatments can be applied to regeneration openings created by single-tree or group selection systems, although costs associated with the location and treatment of scattered regeneration patches may be prohibitive. They are probably most needed and feasible where the objective is to facilitate the survival, growth, and development of seedlings and saplings of mid-tolerant species growing in larger openings created through application of the group selection system. In addition, as canopy crowns expand over time, previously created regeneration gaps may need to be re-opened or expanded to maintain the vigorous growth of young trees; this release operation can be conducted concurrently with other periodic cutting operations.

Thinning is an intermediate treatment that entails the removal of trees to temporarily reduce stocking to concentrate growth on the more desirable trees. Thinnings are applied primarily to improve diameter growth, manipulate structure, enhance forest health, recover potential mortality, and increase economic yields. Under the uneven-aged silvicultural system, thinnings are implemented concurrently with periodic harvest and regeneration operations. Stands are normally re-entered on an eight- to 20-year cutting cycle depending on landowner objectives, economic constraints and opportunities, site quality, tree growth rates and stand development. Specific target stand stocking levels (density management) by size and age class are very important to tree growth and quality development. Often, small groups or patches of essentially even-aged trees can be recognized and treated. Tree selection is based on a recognized order of removal that considers tree risk, tree vigor, crop tree release, species composition, and spacing. Additional criteria can also be employed to enhance wildlife habitat, biodiversity, water quality, and aesthetic values.

Temporary improvement cutting may be needed to improve composition or quality in stands that have been previously unmanaged, neglected or poorly managed.

3.4.3 Management rules for transformation

The first rule is to allow enough time without productivity losses. Transformation follows a set sequence of stages which must occur in the correct order. No single stage can be omitted. The following four stages are used to distinguish the different characteristics of regular forest transformation:

- The stage of differentiation, the main aim is to promote each existing valuable element, which ensures structural development.
- The stage of regeneration promotion, the principal focus is on favoring new decentralized regeneration groups.
- The stage of structural development, the focus is to achieve good horizontal and vertical distribution of structural elements.
- The stage of structure achievement, the focus is to achieve vertical individualization of the remaining groups.

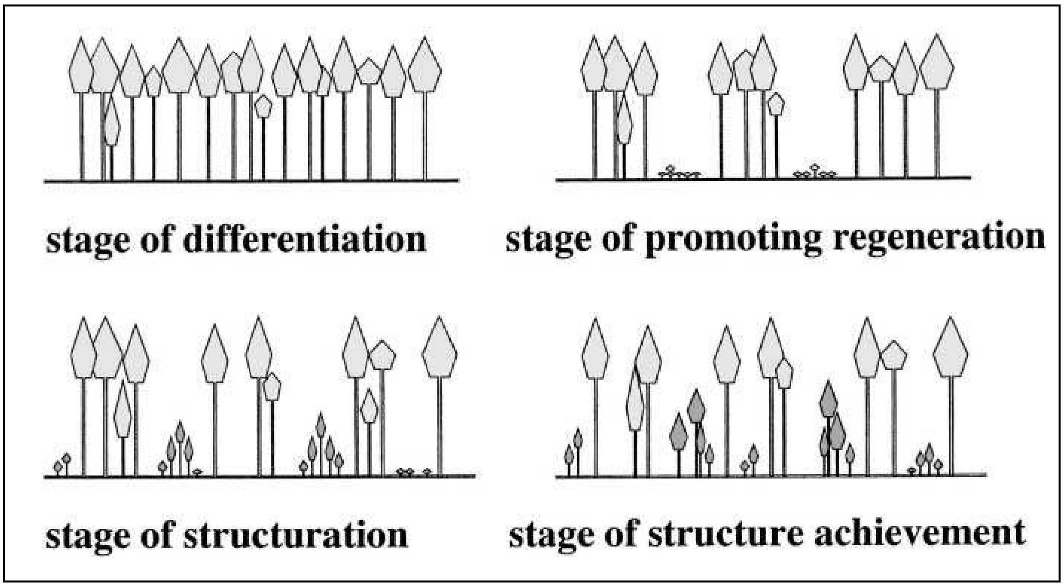


Figure 11. The four stages of transformation of regular forest into irregular ones. Source: Schütz J. 2001: Opportunities and strategies of transforming regular forests to irregular forests.

The second rule is to decide whether to attempt transformation on the present generation of trees or on the subsequent one. There must be enough cover-building trees with potentially long life-spans or this must be achievable using crown thinning; if this is not the case, transformation by differentiating the present stand should not be attempted. It is important to achieve a new, better structured heterogeneous and mixed generation first, as this will support transformation in later stages. Otherwise, there is the risk of opening the cover when mature trees die, before transformation has been achieved, which leads to homogenization of the second growth.

To achieve effective transformation, one must be able to anticipate the successional development and to apply different hierarchical silviculture decisions according to the stage.

3.4.4 Differences between broad-leaved trees and conifers for the selection forest system

The likelihood of creating an irregular structure varies between conifers and broad-leaved species. Conifers maintain a spindle shaped crown, even when there is free space to be occupied. This contrast with broad-leaved tree species whose crowns grow laterally when more space is given. This means that conifers are better suited to a system of individualization within the whole stand of the selection forest. Beech needs three or four times more crown space to produce the same amount of timber increment as fir (Bardoux, 1949). The main reason for this is that the individual growth of broad-leaved trees leads to the development of inadequate stem form. Because broadleaved species grow to fill out stand openings, they close up the cover more effectively than conifers. Therefore, light conditions need to be controlled much more rigorously than when dealing with fir or spruce. Another reason why shade-tolerating conifers are more suited to vertical structure is that they can maintain very slow growth even in limited light conditions, and can stay in quasi-stationary stage over a long period (Schütz, 1969). They manage this without losing their acrotonic stem form. In contrast after being exposed to shade over long period, broad-leaves like beech lose the ability to produce an upright excurrent stem. (Schütz, 2001)

3.4.5 Biodiversity & Ecological stability

The growing recognition of the importance of biological diversity has sparked an interest not only in enhancing structural diversity through uneven-aged management, but also in managing for mixed-species stands (Phillips and Abercrombie, 1987; Lentz et al., 1989).

Maintaining biological diversity, the variations in life forms, genetic makeup, ecological niches and biological processes in a given area (Oliver, 1992), is an increasingly important goal of forest management. This interest reflects a growing understanding among ecologists and the general public of the importance of maintaining diverse assemblages of species. Diverse systems are less susceptible to diseases and pests. IN addition, wild species provide an array of valuable products and genetic material, and they serve as ecological indicators (Burton et al., 1992).

Obviously, no single index can fully capture all the variables that constitute the diversity of a stand of trees. Nevertheless, Shannon's and Simpson's indexes are the most widely used. Shannon's index has the most established history in forestry, having been used to measure tree species, tree size and foliage profile diversity in forest stands (MacArthur and MacArthur, 1961; Ambuel and Temple, 1983; Niese and Strong, 1992; Lu and Buongiorno, 1993; Buongiorno et al., 1994; Buongiorno et al., 1995; Lin et al., 1996).

Shannon's index is not perfect. Perhaps its greatest weakness is that it reflects the proportional distribution of individuals, not their absolute numbers (Schulte J. and Buongiorno J., 1998).

Shannon's index for tree species diversity:

$$\mathbf{H}\ species = \sum_{i=1}^{m} (y_i / y) \ln(y_i / y)$$

Were y_i is the basal area of trees of species group *i*, and *y* the basal area of all trees.

Shannon's index of size diversity:

$\mathbf{H}\ size = \sum_{i=1}^{m} (y_i / y) \ln(y_i / y)$ with *i* standing for the size of trees.

They only measure the diversity of trees being useful indexes of stand level density. They do not recognize other flora or fauna (Schulte J. and Buongiorno J., 1998).

There are often strong correlations between forest structure and community composition (Urban and Smith, 1989). For example, Hansen et al. (1991) report that the total abundance of birds is 50% higher in natural stands than in plantations, while that of amphibians is 130% higher. Similarly MacArthur and MacArthur (1961) found that four-fifths of the within habitat diversity of bird species could be attributed to the variation in vertical distribution and diversity of vegetation. Given the high correlation that exists between tree diameter and height, a stand with a high diversity of tree size can be expected to have a high level of vegetative stratification (Violin and Buongiorno, 1996). High species group diversity would only act to further enhance this stratification, and thereby increase the number of potential niches for species to occupy.

3.4.6 Economical features

Timber production is often the major incentive for landowners. Therefore, in selecting a management regime, it is useful to predict its impact on timber production and revenues.

While many forest landowners and managers will be primarily interested in the economic returns they might expect under a given uneven-aged regime, others will be more concerned with the volume production. For example, national forests are often less concerned with making a profit from timber sales than meeting established "allowable cuts" (Schulte B., 1998).

Several studies (Baker and Murphy, 1982; Baker, 1987; Guldin and Baker, 1988; Baker et al., 1991) have compared the yields from even-aged and uneven-aged loblolly-shortleaf pine stands under various management regimes for 36 to 50 years. The results showed that saw timber volume production was highest for intensively managed even-aged plantations and for uneven-aged selection stands with high stocking levels.

Uneven-aged management can also be financially superior to even-aged management under certain conditions. The infrequent though large revenues from even-aged stands lead to lower net present values at high interest rates than the smaller but more frequent revenues from uneven-aged stands. Chang (1990) further suggested that uneven-aged management can be more profitable when the fixed costs associated with the selection cuts are low. Baker et al. (1991) and Guldin and Gulgin (1990) found that, when the initial growing stock was not considered a cost, the uneven-aged stands gave superior net present values.

Similarly, harvesting uneven-aged stands is more profitable for contractors than harvesting even-aged stands. In a study examining the effects of removal intensity and tree size on harvesting costs and profitability, Kluender et al. (1998) found that single tree selection in uneven-aged stands was more profitable than selection harvests in even-aged stands, clear cutting or shelterwood harvests.

Baker (1989) concludes that uneven-aged stands having as little as 10% stocking but at least 1.1 m^2 ha^{-1} of basal area can be rehabilitated within 15 years by uneven-aged silviculture, and that this will likely cost considerably less than converting the stand to plantation.

Within the past few decades and particularly since the “Brundtland Report” (World Commission on Environment and Development 1987), sustainability has become a key term in emphasizing the relationship between economic progress and nature (Hasenauer H.)

4. MATERIALS. DESCRIPTION OF HETLÍN FOREST

4.1 Location

It is situated in the surroundings of Hetlín, its geographical location is given by coordinates of 49º 50' northern altitude and 15º 11' eastern longitude. The area of the forest is 307 ha and it is composed of 3 parts: the first part (V Kačinách) is the largest one with 149 hectares and it is surrounded by agricultural fields. It lies between Hetlín and Štipoklasy. Second and third part is connected. Both situated on the SE of the Hetlín forest complex. Second part has 83 ha and is composed of two localities: Na Skalce and V Lipinách. Third part has an area of 75 ha and is composed just for one locality, U jezera.

The forest complex is included into a forest region which is called "Českomoravská vrchovina" at the Municipal Forest of Kutná Hora Town.

The Hetlín complex is situated on North border of this forest region.

4.2 Natural conditions

4.2.1 Geological and soil conditions

The forest complex of Hetlín is a wavy plateau on bedrock of gneisses which has been overlapped by Pleistocene sediments. Over them pseudogleys and podzol pseudogleys have developed. Both are characterized by changing water conditions.

Podzol soils occur under spruce and pine monocultures. Physical conditions of the soil are affected by granulity. There is a compact middle layer in the soil profile which constitutes a mechanical border for the tree roots. There are superficial roots developed because they can't cross over this layer, the consequence is that trees are not as stable as that can be under another soil conditions.

Soils are mainly acid with a pH=3,1 - 3,2 (natural conditions for Norway spruce) but according to depth pH increases until 5,1 – 5,3.

4.2.2 Climate conditions

The Elba River goes through Hetlín forest this is the reason why the forest is affected by a warm middle climate. It is located on an undulated plain at an altitude of 445-493 m. The mean annual temperature is about 7 ºC and the average precipitation is 650 mm/year distributed along the year.

There is a special role of underground water. In the cases of small altitudinal differences there is underground water accumulated and this is mainly affecting the growing conditions and soil forming processes.

As it is been said the soil of the majority of the area is pseudogley which characteristics entail a typical water regime: long term over wetting after snow melting and rainfalls and high drying processes during the dry season.

4.2.3 Tree species composition

The main species in the area are, in order to percentage: Norway spruce, Scots pine, European larch, Birch, European beech, Silver fir and Oak.

There have not been high differences in tree species composition during last 60 years. Norway spruce percentage has been without changes but the percentage of other species has changed. The highest losses are in the case of Scots pine because it needs to be cut earlier than other species. The percentage of European larch has increased two times. It has endured in all ages and when the representation increases, it does more than dynamically. The spectrum of broadleaves has enlarged.

4.3 Forest management

4.3.1 The beginning of transformation process

Forest Range Hetlín (Forest District Opatovice) started the transformation process to a mixed uneven-aged forest with the group and single-tree selection silvicultural system on January 1st 1938. Since that day when clear-cutting management system was abandoned (F. Kratochvíl, 1970).

In the beginning of transformation to selection forest František Kratochvíl was the forest manager in Forest District Opatovice. He decided to use the selection system of management on the basis of following facts:

– calamity of *Lymantria monacha* in 1921

– windstorm in 1929

– quite considerable extent of worsening forest soils in almost all localities due to the total changes of original species composition

– big damage of other non-forest landscape by medieval silver mining and agriculture. Due to the effort to extend areas with cereals and sweet beet the ponds were emptied.

– these forests are situated on the edge of a glen under the “draughting effect“ of south-eastern drying winds, which is very dry place.

Because of these reasons it was necessary to repair the natural conditions by establishing such a management system, which would make the best of natural conditions, particularly for the moisture.

In the management plans the following facts were declared as a special target:

– to establish the group single single-tree selection management system

– to extend the forest stands in less favorable climatic positions, connected with recreation and landscape aims

– to extend the area of ponds, especially of forest ponds.

4.3.2 Felling

Emphasis was placed on felling methods. Each tree was evaluated individually and the forest manager marked personally the maturity felling as well as the advanced felling. He considered the method of regeneration, its volume and urgency, intensity of interference, other forest operations, such as forest amelioration and issues related with irrigation, drainage, founding of reservoirs, selection of the best felling method, dragging and transport depending on the condition of forest-road network.

Due to severe fellings were abandoned the distance between skidding lanes were therefore reduced from 80- 100 m to 40- 50 m, with a width of 3 m suitable for both animal carriage and tractor.

4.3.3 Planting

In comparison with spruce or pine monoculture even an admixture of conifers between themselves shows better humification. For that reason even qualitatively worst individuals of pine are saved in homogeneous spruce stands. In particular broadleaves even of the worst quality, which create rare broadleaved admixtures are preserved and areas are opened for them to have some advantage above their competitors with the aim of improving nutritive humus amount and root drainage. At first it was the case of oak and birch, but also rowan, alder and aspen.

Decomposition of raw humus and its transformation into the nutritive humus occurred due to thinning from above (opening canopy) connected with sanitation and qualitative selection.

In the beginning some broadleaves (hornbeam, lime, beech) didn't fit well, although they were recommended as the most suitable soil-improving tree species. This phenomenon was the result of soil hyperacidity. Therefore it was necessary to start with broadleaves with are resistant to a lower pH factor (alder, birch, aspen), eventually with soil liming.

5. METHODS

5.1 The experimental plots

The experimental plots are distributed among the surface of Hetlín forest. There are eight plots; six circle plots and two rectangular plots. The size of each rectangular plot is 50 x 100 meters being the area half hectare. The circle plots have a radius of 20 meters, being the area of each circle plot of 0,1256 hectares. The total area sampled is 1,7540 hectares.

The localization of the plots was chosen in preceding work management inventories.

The rectangular plots are both in the stand number 781 and circle plots belong to the stand number 770.

5.2 Measurements: Position, H, DBH, G, Volume

The measurement of diameters was done in the eight plots named Rectangular plot 1, Rectangular plot 2, Circle plot 2, Circle plot 3, Circle plot 4, Circle plot 5, Circle plot 7 and Circle plot 8. In previous measurements also Circle plot 1 and 6 were taken into account but they have been cut recently.

In each plot the DBH (Diameter at the Breast Height) was measured at the height of 1,30 meters of each tree with DBH superior to 10,00 cm. with a Forestry caliper. Precision of dbh measurements is 1mm.

Each tree was localized from the tree reference in the center of the circular plots measuring degrees with Silva Clinometer device and distance with a tape measure.

In the rectangular plots the trees were marked with a number in order to localize them.

The localization of the trees is necessary in order to compare data from preceding and future measurements.

The height was also measured in all the plots but not in all the trees because it’s not necessary. The height was measured with a Vertex device for distances and height measurements. The Vertex calculates the height of the tree knowing the distance from the point of measurement to the tree with a reflector of a signal and taking the measure of the angle from the same point to the top of the crown. Precision of height measurements is 10 cm. The not measured heights were calculated with the regression’s equation obtained for each plot.

The volume was computed with volume equations from Petrás & Rajtík, 1991 according to height and DBH of tree species. It has been calculated for every tree using the specific equation for the corresponding specie.

Basal area (G) was calculated for each plot and for each species of tree. First of all with the DBH of each tree the sectional area of each tree is calculated, with the addition of this data the total section of the trees is found. If we refer this section to one hectare we already have the basal area.

The equivalent mean diameter (dg) is also calculated for each plot and for each species from the data of mean of the sections of the trees. Dg is the diameter of the mean section.

5.3 Evaluation. Statistical processes

The statistical analysis is made for each tree species. It consists in a fundamental description including: Mean, Median, Standard deviation and Variance values for the following parameters: DBH, Height, Basal area and Volume of each tree species in all plots together. The parameters DBH and Height are used in order to fulfill the Correlation analysis. The Correlation analysis is used to choose the best approaching equation (lineal or not lineal) of DBH – Height values, in order to guess the height of the trees not measured. The trees which were not measured belong to Rectangular plot I and Rectangular plot II. The graphics and corresponding regression equation and R^2 coefficient are showed in the Annex 4.

All the calculation process has been fulfilled with the Excel program.

6. RESULT AND DISCUSSION

6.1 Global evaluation (all plots together)

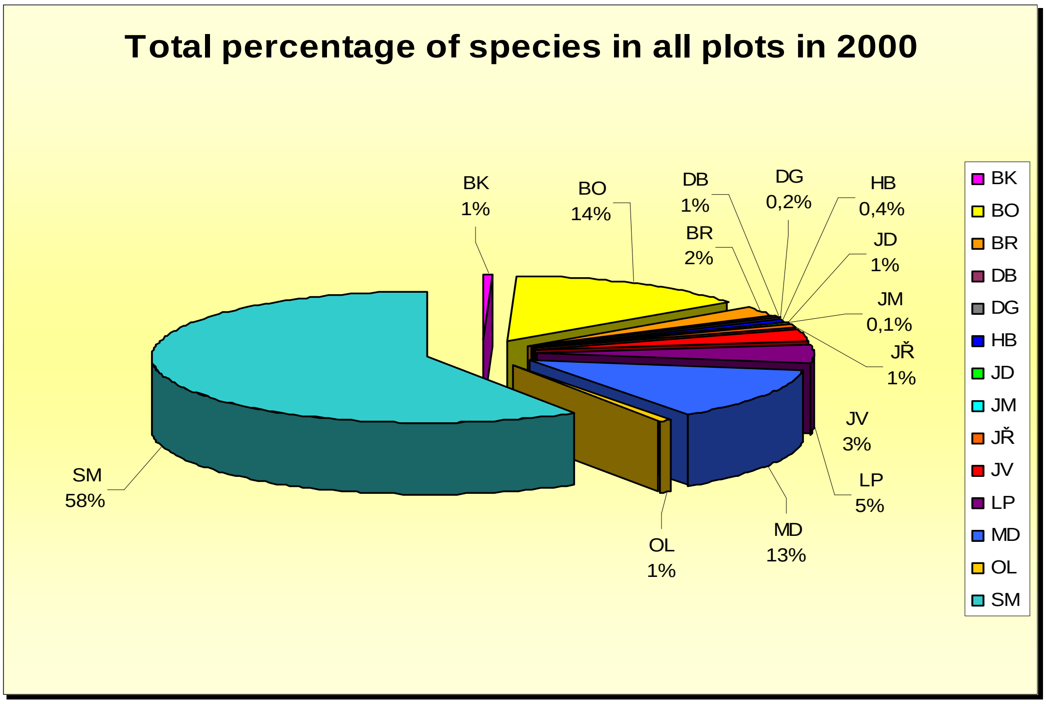
Taking the data from all the plots global evaluation can be carried out.

6.1.1 Species percentage

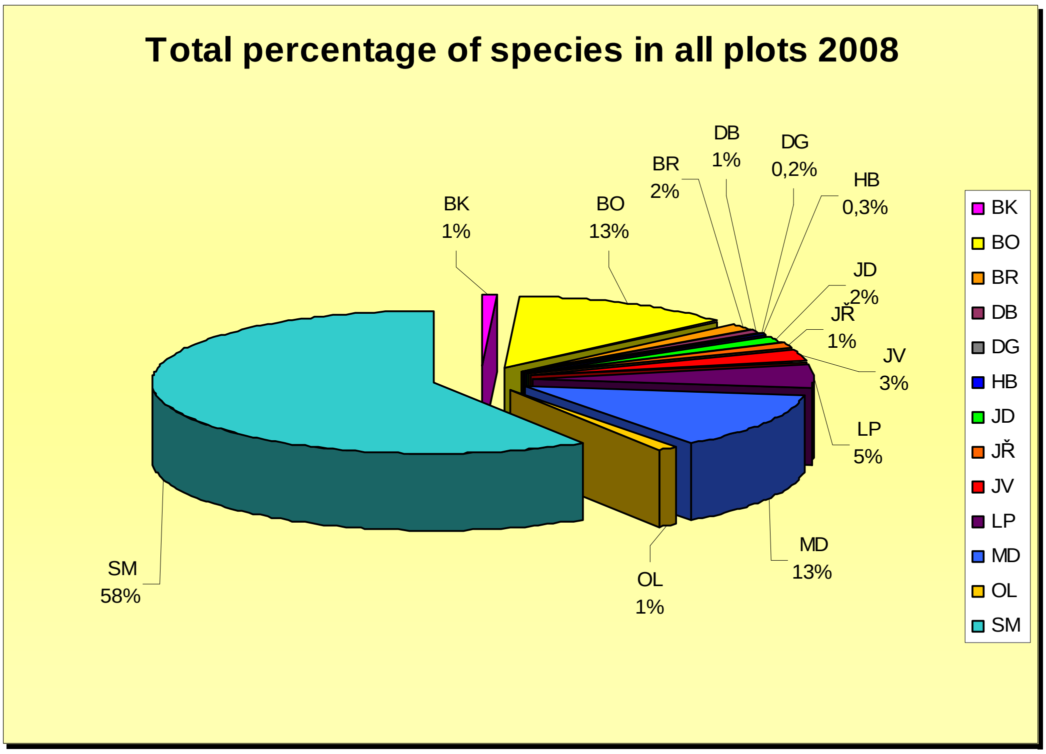
The following table compiles all the species found in the study plots. All of them are named by a code and the Latin name.

	BK	*Fagus sylvatica* L.		JM	*Ulmus glabra* Huds.
	BO	*Pinus sylvestris* L.		JŘ	*Sorbus aucuparia* L.
	BR	*Betula pendula* Roth.		JV	*Acer pseudoplatanus* L.
	DB	*Quercus robur* L.		LP	*Tilia cordata* Mill.
	DG	*Pseudotsuga menziesii* Mirb.		MD	*Larix decidua* Mill.
	HB	*Carpinus betulus* L.		OL	*Alnus glutinosa* L.
	JD	*Abies alba* Mill.		SM	*Picea abies* L.

The next two graphs show the percentage of species in all the study plots together in 2000 and 2008.



Graph 5. Percentage of species in all plots together in 2000



Graph 6. Percentage of species in all plots together in 2008

It is easy to detect from the graphs that there are some dominating species. Norway spruce is the main one in the tree species composition both in 2000 and 2008, its percentage is equal in the measurements, the population is stable. *Pinus sylvestris* and *Larix decidua* have almost the same representation and the proportion is stable too. These three species cover the 85% of the forest area. The 15% left is distributed among the other tree species which are mostly broadleaves. The increment and detriment in the presence of them is not appraisable.

Even if there are not appreciable changes in the presence percentage of species is necessary to point out the high biodiversity of species. The reason is the transformation process. Although Norway spruce, Scots pine and European larch are the main species the other ones have maintained their representation during the last 8 years. It can be deduced that they are enought stable because the more competitive tree species have not occupied their space.

Comparing with the species composition of Czech forests Norway spruce and Scots pine have almost the same representation in the plots than it is in the rest of forests. Something interesting happen with European larch, the present percentage in Czech forest is 3,8% but in the plots it is around 13%. This high presence of *Larix decidua* is probably due to the seed spread of European larch made in Hetlín at the beginning of 19th century. Beech and Oak, quite important species in the forests of this country with a representation of about 6%, have a presence of only 1%. Probably the reason lies on the geologic conditions of the stand which is not appropriate for the development of such species.

In this area and until 18th to 19th centuries Silver fir was one of the main species in the forest complex but currently the percentage is about 2%. The populations have decreased because they are highly vulnerable to the air pollution (more than *Picea abies*). Nevertheless the representation has doubled in last 8 years probably due to the interventions for transformation in the forest of Hetlín.

6.1.2 Statistical analysis and results for the main species.

Basic statistical variables were calculated for each specie in the totality of the plots with the measurements from 2008: mean, median, standard deviation and variance. They were obtained for diameter at breast high, height, basal area and volume. Only the results for the main species (Table 7, 8 and 9) are shown in this chapter, the rest can be found in the Annex 4.

Table 7. Statistical analysis for *Larix decidua*.

Larix decidua	N (nº trees/ha)=	76,4		
	nº trees all plots=	134		
Parameters analyzed	**dbh (cm)**	**Height (m)**	**Basal area (m²)**	**Volume (m³)**
Mean	34,13	27,90	0,1004	1,2922
Median	35,95	29,10	0,1015	1,3202
Standard deviation	10,68	4,44	0,0559	0,7422
Variance	114,11	19,70	0,0031	0,5508
dg	35,72			

Table 8. Statistical analysis for *Picea abies*.

Picea abies	N (nº trees/ha)=	348,3		
	nº trees all plots=	611		
Parameters analyzed	**dbh (cm)**	**Height (m)**	**Basal area (m²)**	**Volume (m³)**
Mean	21,45	20,14	0,0430	0,4849
Median	19,45	20,10	0,0134	0,2790
Standard deviation	9,34	5,94	0,0461	0,6711
Variance	87,27	35,31	0,0021	0,4504
dg	23,44			

Table 9. Statistical analysis for *Pinus sylvestris.*

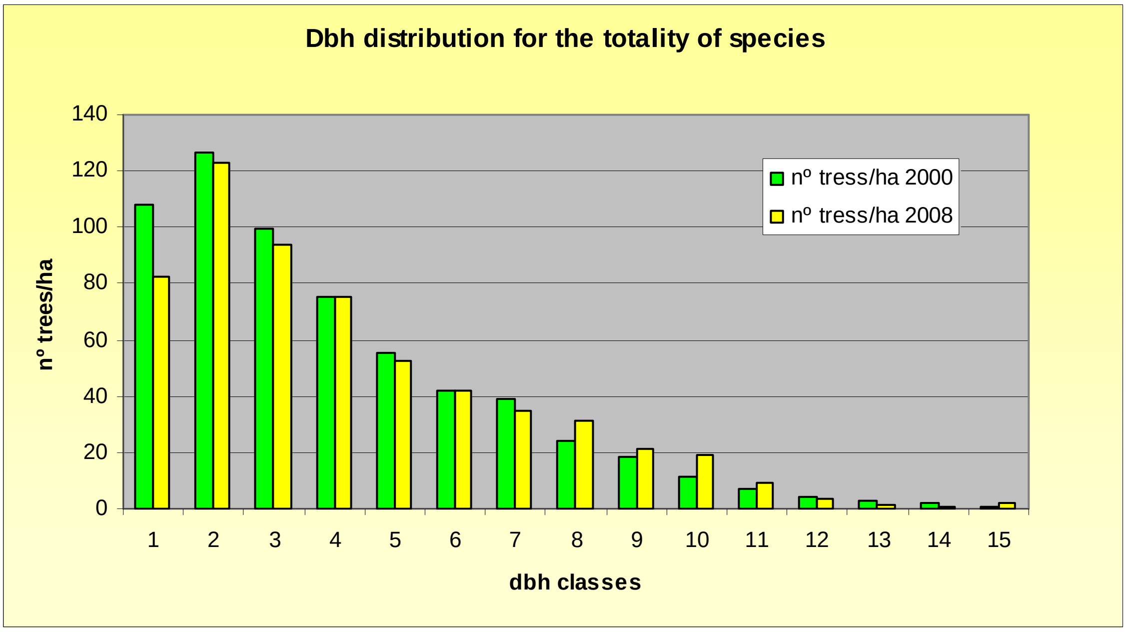
Pinus sylvestris	N (nº trees/ha)=	75,8		
	nº trees all plots=	133		
Parameters analyzed	**dbh (cm)**	**Height (m)**	**Basal area (m²)**	**Volume (m³)**
Mean	37,11	28,93	0,1147	1,5208
Median	36,25	28,65	0,1032	1,3100
Standard deviation	9,13	4,16	0,0562	0,9388
Variance	83,38	17,31	0,0032	0,8642
dg	38,35			

The mean value represents the mean tree type. *Larix decidua* and *Pinus sylvestris* have quite similar results, high values of dbh, height, basal area and volume lead to the outcome that both populations are mature one. The results for *Picea abies* show that this specie is better represented in low dbh classes. As consequence of these conclusions we can deduce that regeneration for Norway spruce is higher than for the other species.

Standard deviation and variance are intimately related. They represent the distance between the values of the serie and the mean. The highest value for the variance of dbh corresponds to *Larix decidua*, the reason is that diameters are well distributed among the different dbh classes. In case of Norway spruce and Scots pine the trees are in bigger percentage in some dbh classes (low classes for Norway spruce and middle classes for Scots pine) because the results for variance and standard deviation are lower.

6.1.3 Dbh distribution for the totality of species

The DBH structure in the years 2000 and 2008 for all the species together is presented in the Graphic number 7. DBH structure is the number of trees of each DBH class per hectare. Dbh classes are numbered from 1 to 15 being the first one dbh class 12 and last one 68, in an interval of 4 units.



Graphic 7. Dbh distribution for the totality of the species.

The graphic 7 shows how the DBH structure is still in transformation process. It also indicates that uneven-aged equilibrium structure can be reached with regard to number of trees of each diameter, because there are a high number of trees in the small DBH classes.

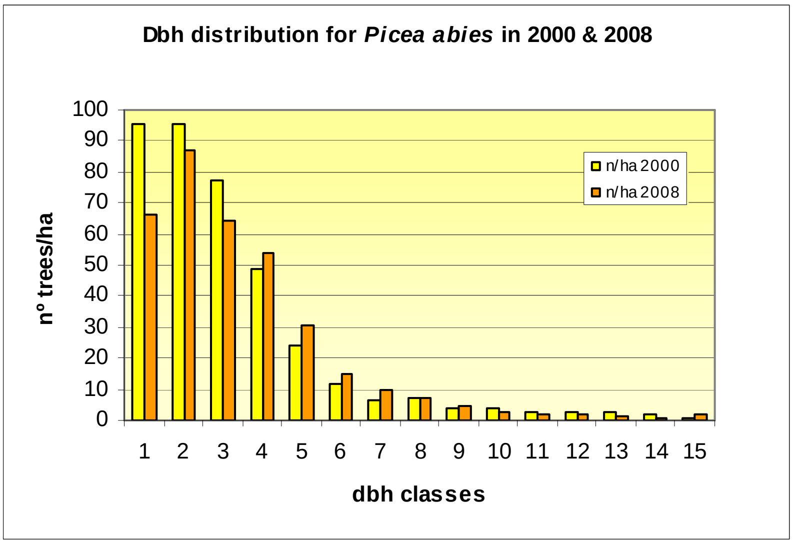
It can be seen that the number of trees per hectare in the low dbh classes is much higher than in the other classes. In order to understand how this structure has been formed, in the Graphics number 8, 9 and 10 the DBH distribution for the main species is showed. The rest of species are showed in the Annex 5.

As it's been said before *Picea abies* is a very important specie in this forest. The representation that it has in dbh classes from 16 to 24 is about 70 %, the remaining percentage (30%) correspond to the broadleaves. Most of them have been introduced recently due to the transformation process.

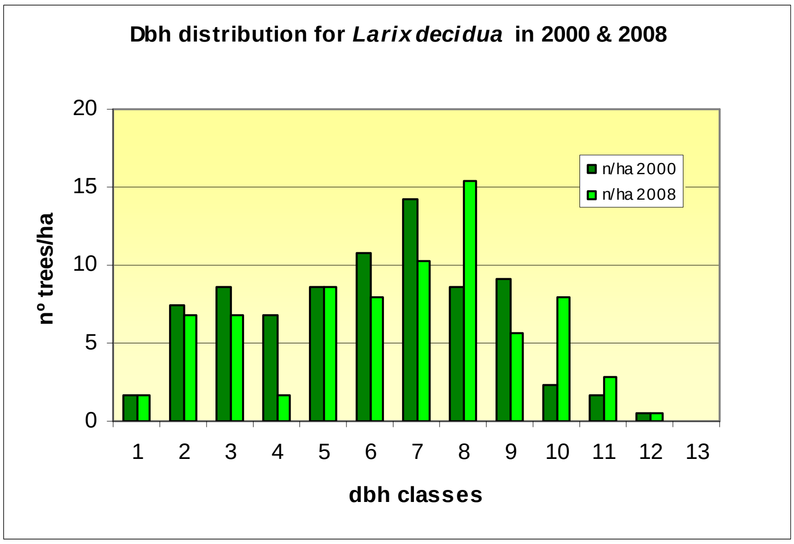
Norway spruce has a big natural regeneration in the area, this is the reason why there are so many young trees. Nevertheless in the dbh class 12 the number of individuals has decreased from 2000, probably some have jumped to the next dbh class but there is not an increment in tree number in dbh class 16 and 20 so in this period there have been some thinnings to favor the better fitted trees and also, and even more important, to favor the development of rare species like *Qurcus robur*, *Fagus sylvatica*, *Carpinus betulus* and so on.

The European larch dbh distribution is sensibly different from Norway spruce one. The trees are not concentrated in the lower classes, actually there are more individuals in middle and big classes. The number of young trees is very low because it is a light demanding specie that needs open areas for a good development. Probably this is the reason why the number of trees per hectare in low and middle classes has decreased.

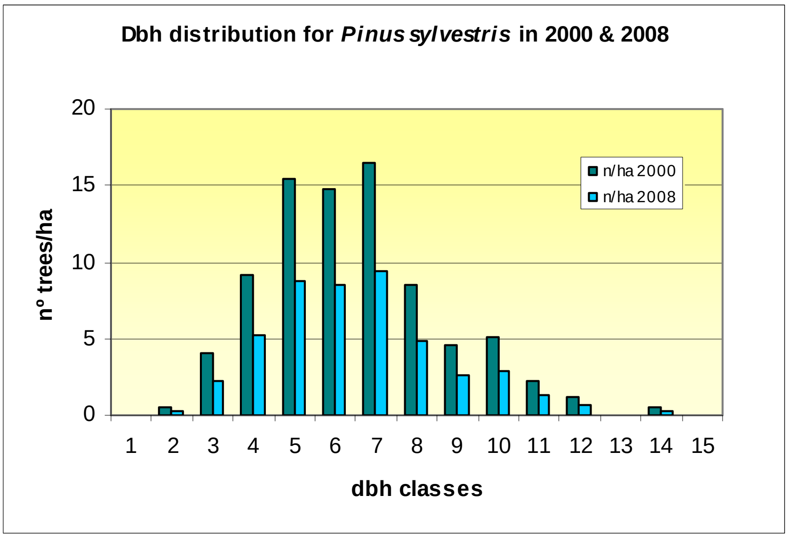
About *Pinus sylvestris* it can be observed that some trees around 20-44 cm have been cut down. Continuing this logging in the future will allow in the succession of species to increase the presence of more shade-tolerant species, such as Norway spruce and Silver fir. The problem of Silver fir is that, although being good shade-tolerant specie, the number of trees is too low and regeneration is being grazed by game.



Graph 8. Dbh distribution for Norway spruce in 2000 & 2008.



Graph 9. Dbh distribution for European larch in 2000 & 2008



Graph 10. Dbh distribution for Scots pine in 2000 & 2008

6.1.4 Volume, basal area, mean dbh (dg), number of trees per hectare values and increment values.

Number of trees/ha, Volume, G (basal area) and Dg values found in 2000 and 2008 for each tree species and for the totality of trees are presented in Table 10. With these data the increment of these values is also calculated. This allows us to guess the Total Current Increment for Volume, number of trees per hectare and G.

Table 10. Volume, G, dg and Total Current increment in 2000 and 2008.

2000	**nº tree/ha**	**Volume (m3/ha)**	**G (m2/ha)**	**dg**
Fagus sylvatica	3,0	2,81	0,176	28,75
Pinus sylvestris	82,7	103,60	8,763	35,14
Betula pendula	14,3	7,15	0,736	26.01
Quercus robur	3,0	0,41	0,059	16,17
Pseudotsuga menziesii	1,0	2,03	0,150	40,20
Carpinus betulus	2,0	0,36	0,051	16,25
Abies alba	3,0	1,50	0,141	22,86
Ulmus glabra	0,6	0,08	0,010	16,00
Sorbus aucuparia	6,0	0,52	0,096	15,63
Acer pseudoplatanus	17,0	4,77	0,506	19,69
Tilia cordata	10,0	4,16	0,575	15,32
Larix decidua	80,0	84,93	6,863	33,23
Alnus glutinosa	7,0	1,47	0,158	19,18
Picea abies	384,0	251,05	14,200	22,80
Total	613,5	464,83	32,482	
Mean				23,17
2008				
Fagus sylvatica	5,0	3,07	0,288	27,68
Pinus sylvestris	47,0	166,82	12,958	38,35
Betula pendula	11,0	12,15	1,154	26,63
Quercus robur	1,0	1,20	0,160	17,74
Pseudotsuga menziesii	1,0	3,16	0,196	48,17
Carpinus betulus	1,1	0,61	0,060	20,26
Abies alba	10,0	2,82	0,297	18,18
Ulmus glabra	0,0	0,00	0,000	0,00
Sorbus aucuparia	6,3	0,93	0,154	17,56
Acer pseudoplatanus	15,0	0,53	0,056	22,05
Tilia cordata	30,0	6,76	0,735	18,00
Larix decidua	76,0	98,71	15,216	35,72
Alnus glutinosa	5,7	2,03	0,194	21,24
Picea abies	348,0	268,47	24,361	23,44
Total	557,1	567,26	55,829	
Mean				23,64
Ingrowth	**45,6**	**8,95**	**23,347**	**0,47**
Cut+missing	**77,7**	**41,85**	**2,505**	
Total current increment	**-24,3**	**135,33**	**2,505**	
Total annual current increment	**-3**	**16,92**	**0,313**	
% annual current increment	**-0,5**	**3,64**	**0,964**	

The total number of trees/ha has decreased in 0,5%. This happens because there were more trees in 2000 than in 2008. There have been more trees harvested than those which had reached the minimum diameter. *Pinus sylvestris* and *Picea abies* have been the species more affected by this logging. On the other hand the number of trees recruited per year is 6, most of the Norway spruce trees.

Comparing the volume stock in 2000 and 2008. There can be observed and increment, every year around 17 m^3/ha (which means 4%), which is a very high value. The reason of this phenomenon is that some trees were considered in the measurements on 2008 like new recruitments with diameters from 30 to almost 60 centimeters. For sure these trees were already there in 2000 but they were not measured then. The mentioned event occured in circular plots. Trees from rectangular plots are numbered but not in the circular plots, maybe these big trees are in the border and it was confusing their inclusion in the plot in previous measurements. The result is a great increment in volume stock. These trees represent a volume stock of 60,8 m^3/ha. If we don't cosider named trees for measurements the volume stock for 2008 is 506,5 m^3/ha and the current volume increment per year 9,32 m^3/ha (2%) which is a normal value.

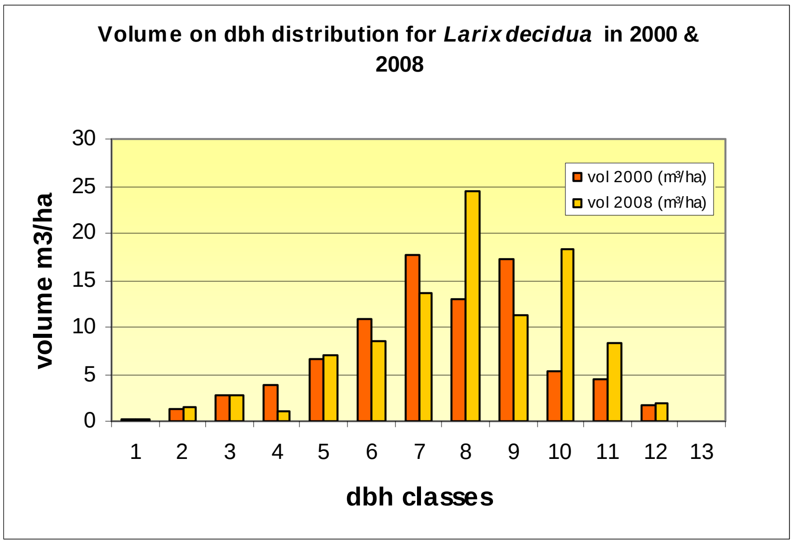
All the species have experienced this phenomenon but *Ulmus glabra* that has already disappeared from the plots.

The volume harvested and felled during the last 8 years is 51 m^3/ha, which represents 82% of the grown volume for the same time.

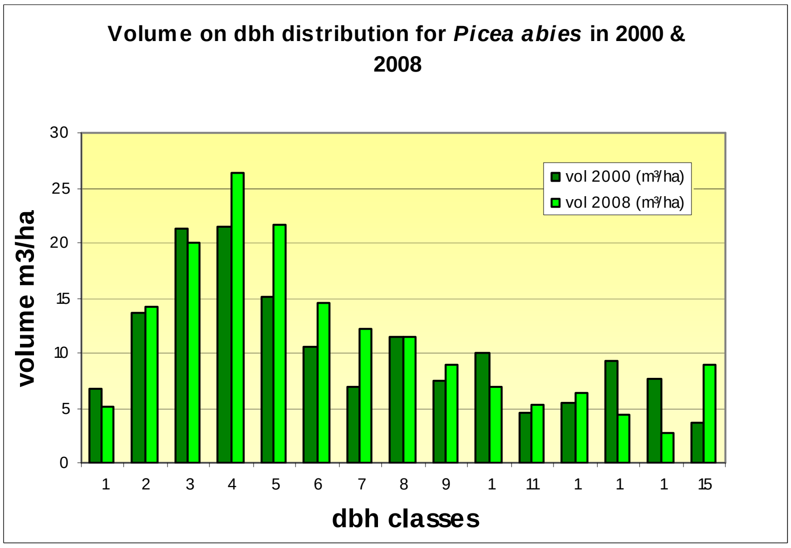
Picea abies takes in the 44% of the totality of the basal area in 2008, *Larix decidua* the 27% and *Pinus sylvestris* the 23%. The three species together represent the 94% of the basal area for this year, it means that these are dominant species. Actually the tallest trees are pines, larches and spruces so these species regulate the light conditions of the stand.

While Scots pine has 300 trees/ha less than Norway spruce, the volume is only 100 m^3/ha lower, which represents quite more than half of the volume(62%). The meaning is that Scots pine trees have wider diameters and bigger height.

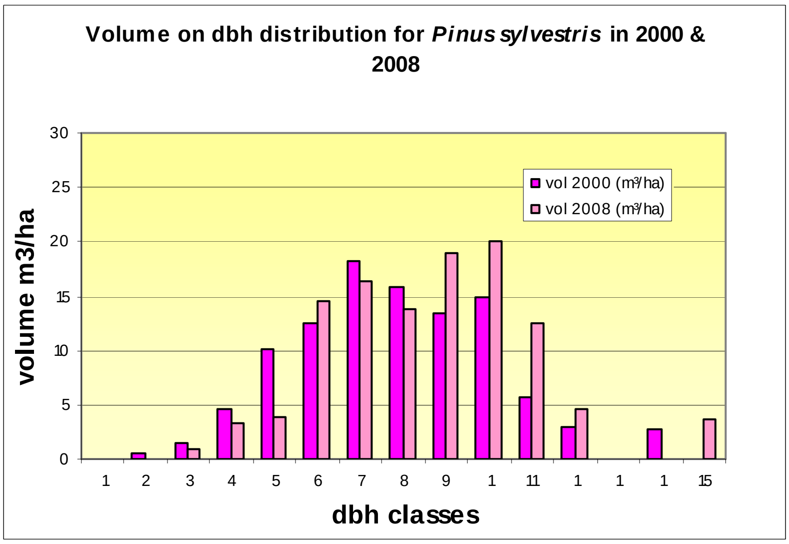
In the Annex 6 the graphics showing the Volume in the DBH distribution for all the trees and for each species can be consulted. Only the graphics for the main tree species are showed here. Graphics 11, 12 and 13.



Graph 11. Volume on dbh distribution for European larch in 2000 & 2008



Graph 12. Volume on dbh distribution for Norway spruce in 2000 & 2008



Graph 13. Volume on dbh distribution for Scots pine in 2000 & 2008

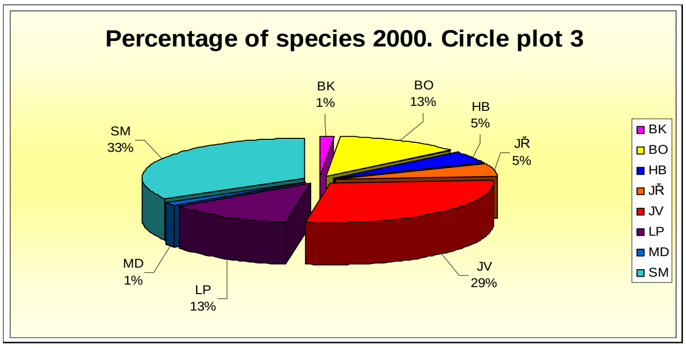
6.2 Evaluation according to each plot

Separate plot analysis is carried out by sing independently the data from each plot.

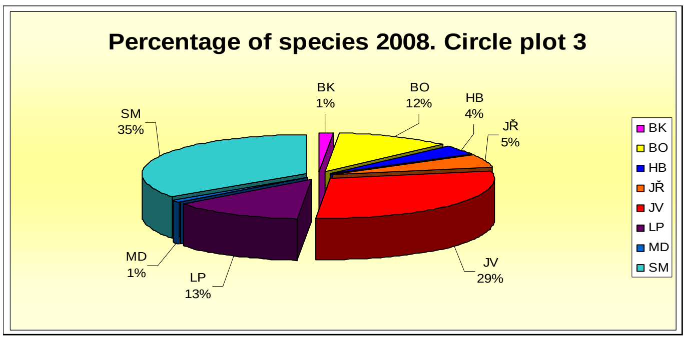
6.2.1 Percentage of species for each plot

The percentage is calculated according to the number of trees from each specie in the different plots. Only the graphs from Circle plot 3 percentage of species evolution is shown in this chapter like an example. The graphs from other plots can be seen in Annex 7.

BK	*Fagus sylvatica* L.	JM	*Ulmus glabra* Huds.
BO	*Pinus sylvestris* L.	JŘ	*Sorbus aucuparia* L.
BR	*Betula pendula* Roth.	JV	*Acer pseudoplatanus* L.
DB	*Quercus robur* L.	LP	*Tilia cordata* Mill.
DG	*Pseudotsuga menziessi* Mirb.	MD	*Larix decidua* Mill.
HB	*Carpinus betulus* L.	OL	*Alnus glutinosa* L.
JD	*Abies alba* Mill.	SM	*Picea abies* L.



Graph 14. Percentage of species in 2000 for Circle plot 3.



Graph 15. Percentage of species in 2008 for Circle plot 3.

6.2.2 Volume, basal area, mean dbh (dg), number of trees per hectare values and increment values

In the Table 11, we can find the results of Stock Volume in each experimental plot in the years 2000 and 2008. The table also contains some basic statistical analysis and the difference between maximum and minimum volume values of all the plots (in percentage).

The values Stock Volume in both years are also presented in the Graphic 16.

Table 11. Stock Volume ad statistical results for each plot in 2000 & 2008

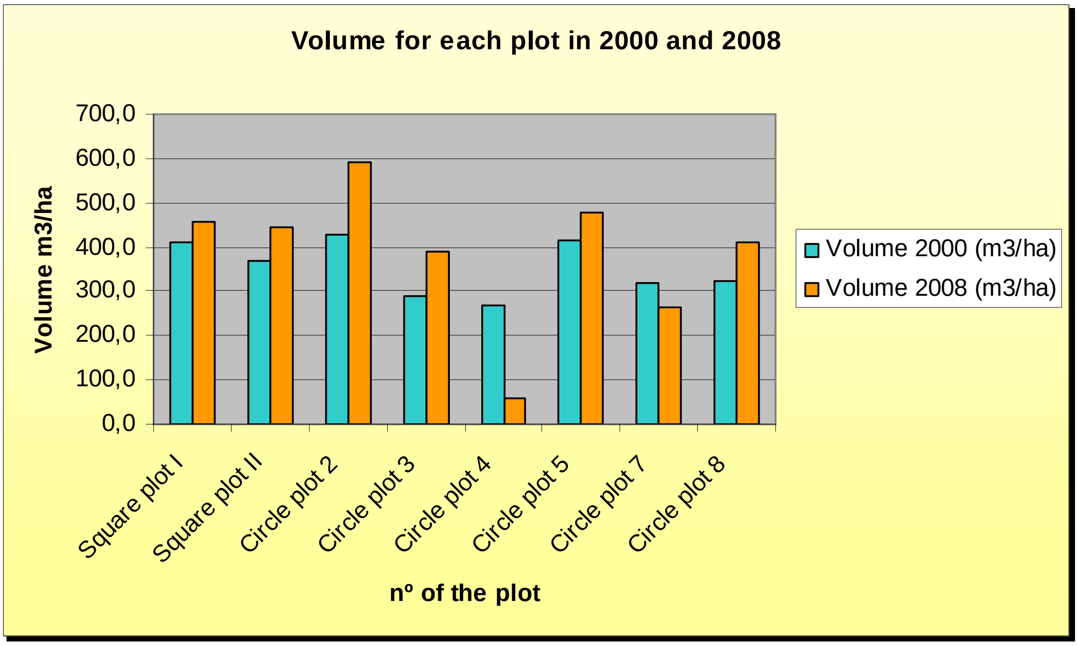
Plot	Volume 2000 (m3/ha)	Volume 2008 (m3/ha)
Rectangular plot I	411,4	456,0
Rectangular plot II	368,2	446,1
Circle plot 2	428,0	591,7
Circle plot 3	289,7	388,4
Circle plot 4	266,4	58,7
Circle plot 5	414,1	477,5
Circle plot 7	320,3	265,7
Circle plot 8	324,7	411,9
Mean	352,8	387,0
Standard deviation	61,4	161,0
Maximum	428,0	591,7
Minimum	266,4	58,7
Difference	161,7	533,0
Percentage of difference	37,8	90,1

The variability of Stock Volume between plots was higher in the year 2008. This means that the distribution of Stock Volume in Hetlín forest was more equal in 2000. The cause of this fact is the change of volume in Circle plot 4: in 2000 the percentage of Norway spruce in this plot was 58%, in 2008 the percentage is only 21%. More than half of Norway spruce has been cut and new gaps resulted from this cutting. At the same time there have been registered some new Silver fir trees with small diameters. This is the result from a plantation of *Abies alba* in the gaps which were opened. Final result from cutting big trees and the ingrowth of new ones is an appraisable detriment of volume stock.

Stock Volume also decreased in Circle plot 7. There some *Pinus sylvestris* were cut leading to the regeneration of Norway spruce.

The rest of the plots have suffered an increment of volume stock. High increment has taken place in Circle plot 2. Some trees have been recruited but they are such big trees, diameters from 30 to 57 cm and heights from 27 to 38 m, everything point to that they weren't taken into account on previous measurements. Their volume means almost 10% of Circle plot 2 volume stock.

The percentage of difference between maximum and minimum values of Stock Volume in all the plots has increased.

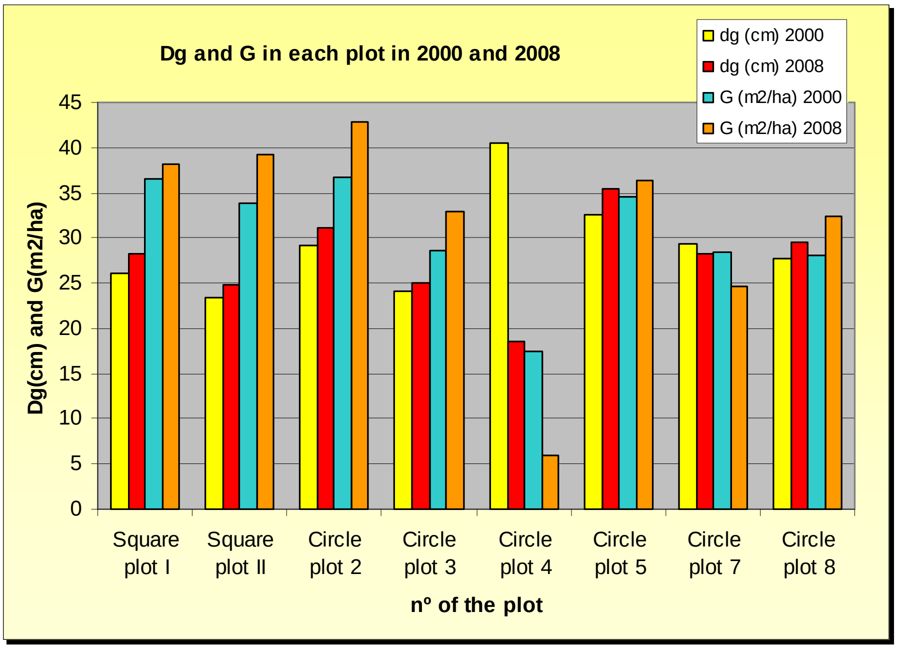


Graphic 16. Volume Stock in each experimental plot in 2000 and 2008. Data from Table 11

Values of Basal area (G) and Mean diameter (Dg) in 2000 and 2008 are presented in the Table 12. Some basic statistical analysis has been done (mean, standard deviation). The difference of maximum and minimum values between plots has also been calculated. These values are presented in the Graphic 17. The variability of mean diameter between plots has decreased lightly but the variability of basal area has increased, almost double, again due to the loggings in Circle plot 4.

Table 12. Dg & G increment for the period 2000-2008 in each plot

Plot	dg (cm) 2000	dg (cm) 2008	G (m2/ha) 2000	G (m2/ha) 2008
Rectangular plot I	26,19	28,19	36,5	38,1
Rectangular plot II	23,44	24,85	33,8	39,3
Circle plot 2	29,25	31,1	36,7	42,8
Circle plot 3	24,1	25,07	28,6	32,9
Circle plot 4	40,55	18,49	17,5	5,9
Circle plot 5	32,6	35,42	34,6	36,3
Circle plot 7	29,34	28,24	28,5	24,6
Circle plot 8	27,68	29,49	28,1	32,5
Mean	29,14	27,61	30,5	31,5
Standard deviation	5,5	5,0	6,4	11,7
Maximum	40,6	35,4	36,7	42,8
Minimum	23,4	18,5	17,5	5,9
Difference	17,1	16,9	19,1	36,9
Percentage of difference	42,2	47,8	52,2	86,2



Graphic 17. Dg increment and G increment for each plot in 2000 and 2008

7. RECOMMENDATIONS

How it is showed in Table 13 current increment of Scots pine is 5.1 m^3/ha·year (approx. 29% of Total Current Increment) and Norway spruce has Current Increment of 9,35 m^3/ha·year (approx 54% of Total Current Increment). Proportionally Current Increment of Norway spruce is two times the Scots pine one. Again this so high volume increment for Norway spruce is the consequence of taking new trees with big diameters.

Table 13. Current Volume Increment & Percentage of C.V.I.

Main species	Ingrowth Vol. (m^3/ha)	Cut & missed Vol. (m^3/ha)	Current annual volume increment (m^3/ha*year)	Percentage of CVI/year
Picea abies	10,93	68,33	9,35	2,01
Larix decidua	0	5,8	2,90	0,62
Pinus sylvestris	2,17	25,69	5,11	1,10

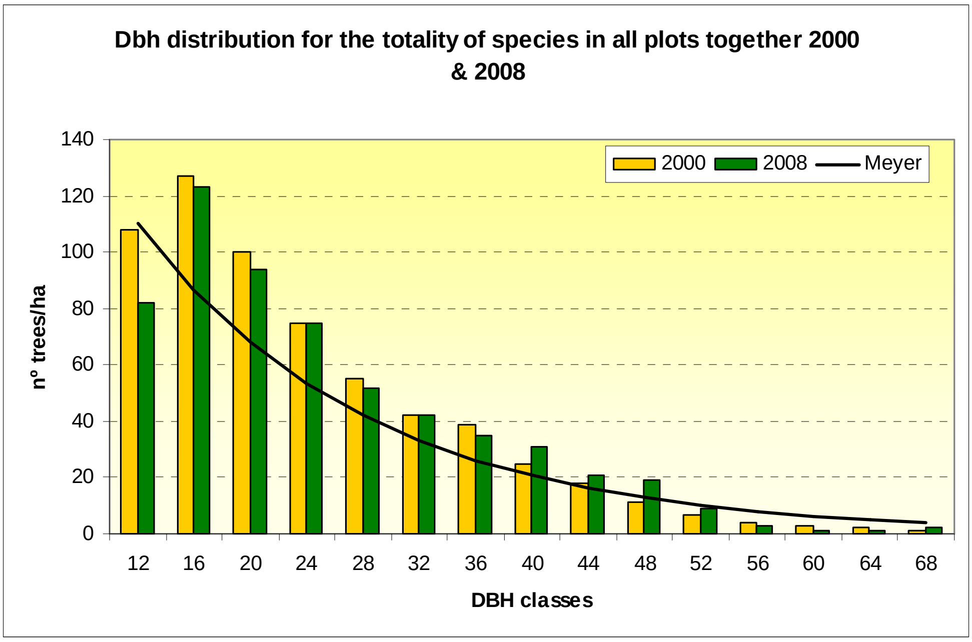
In order to reach an irregular stand distribution along the time it's recommendable to continue cutting down Scots pine trees mainly from 44, 48, 52 DBH classes. Also an increment of the harvested volume of Norway spruce is recommended because, even cutted volume is very high there is an elevate number of trees recruited. Other tree species will result favored from this action, they will have more space available for their development.

Inclusively for well represented species like Norway spruce, Scots pine and European larch this intervention will be positive for the diameter growing and natural regeneration.

The dbh distribution of the number of trees in dbh classes is compared with the model curve of selection forest according to Meyer. It's a fundamental tool for the uneven-aged management.

$$y = k\, e^{-\alpha x}$$

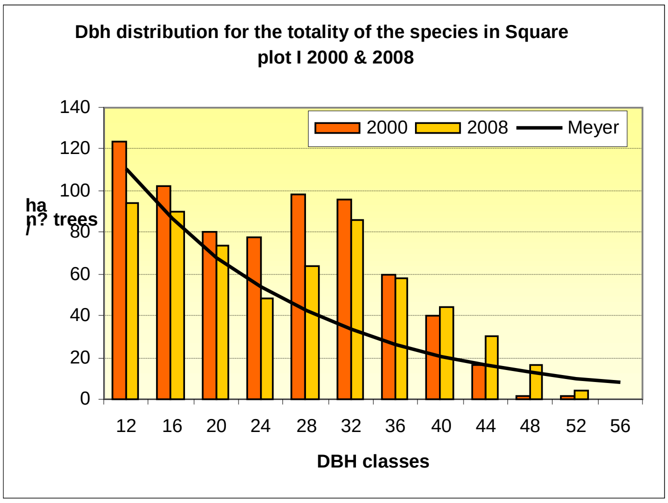
y – tree frequency; x – DBH; α (0,06), k (56,5) – constants which are characteristic for selection forests (B) according to Meyer (Korf 1955).



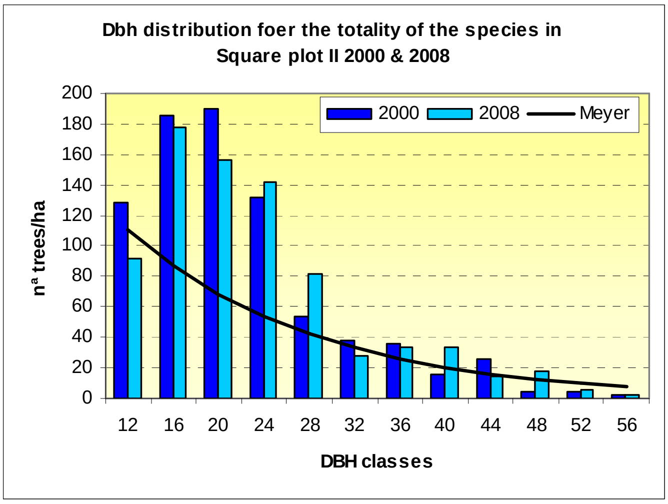
Graph 17. Dbh distribution for the totality of the species in all plots together in 2000 & 2008 and Meyer's curve.

Basing the recommendations on the comparison of the forest situation with the expected one gave by Meyer's curve some general suggestions can be done. The amount of trees in diameter class 12 has decreased, so thinnings should be incremented. The trees that should be selected for cutting must belong to diameter classes from 16 to 48 and in short from 16, 20 and 24. But natural selection has to be taken into account, because probably due to the competence some of these trees will be eliminated naturally.

The majority of the trees are included in Rectangular plot I and Rectangular plot II (30% in Rectangular plot I, 39% in Rectangular plot II). A more specific proposal for these two plots could be useful. The dbh distribution of the number of trees in dbh classes for these two plots is compared with the model curve of selection forest according to Meyer.



Graph 18, Dbh distribution for the totality of the species in Rectangular plot I in 2000 & 2008 and Meyer's curve



Graph 19, Dbh distribution for the totality of the species in Rectangular plot II in 2000 & 2008 and Meyer's curve

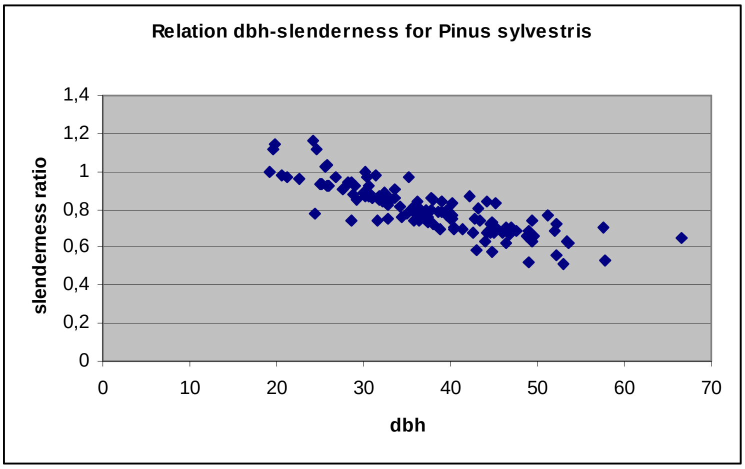
From the graphics for percentage of species in each plot (Annex 7) it can be noticed that in Rectangular plot I Norway spruce, Scots pine and European larch are the most important species with a very similar percentage but in Rectangular plot II Norway spruce represents the 86% and European larch 13%. Dbh distribution for these three species in both rectangular plots can be consulted in Annex 8.

In both plots the number of trees in dbh class 12 has decreased so new thinnings are recommended. In Square plot I the cuttings should be done in dbh classes from 28 to 44. The trees to be cut should be European larch and Scots pine because most of the trees in this plot for mentioned dbh classes belong to these species. For the Rectangular plot II the further values from suggested ones by Meyer's curve come from dbh classes from 16 to 28. As it is been said the percentage of Norway spruce in this plot is very high and especially for classes 16 to 24 (70% of total number of Norway spruce trees in Rectangular plot II). To cut down trees from named dbh classes will favor the increment on dbh enlargement for all species, phenomenon that will lead to new recruitments. Also the opened gaps can be occupied for new trees of less represented species. Especially in Rectangular plot II where *Picea abies* is clearly dominant the introduction of new species should be afforded.

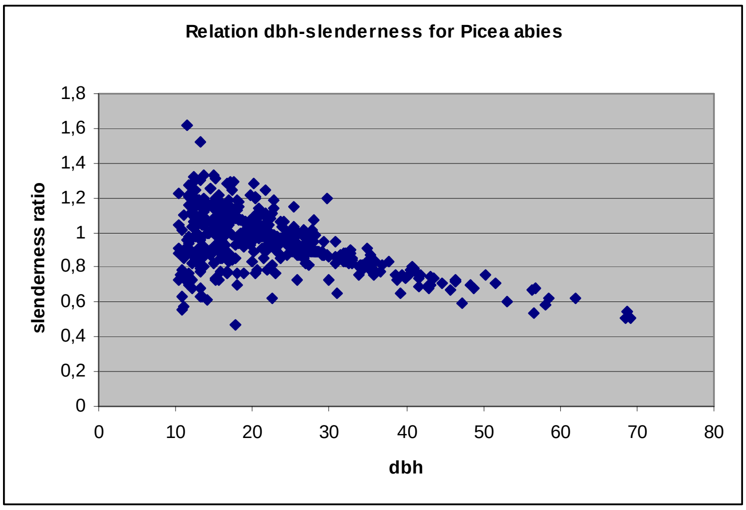
From the point of view of stability, Slenderness ratio indicates for not good stability for values bigger than 1-1,20 for coniferous and around 1,80 for broadleaves. The relation dbh-slenderness has been calculated for all the species with an enough amount of trees to get useful information.

The specie with better stability is Scots pine with only few trees over 1 (see Graphic 20), corresponding to some trees with dbh around 20 to 30 cm.

Effects of high competition for Norway spruce and European larch trees are reflected in Graphic 21 and 22. It indicates that trees with diameter lower than 25-30 are too slim and probably it's already required thinnings where the trees are too close.

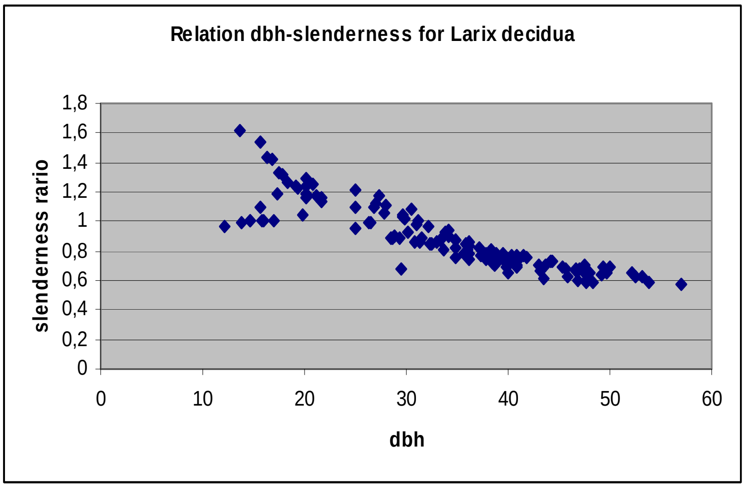


Graphic 20. Relation between dbh and slenderness ratio for Scots pine.

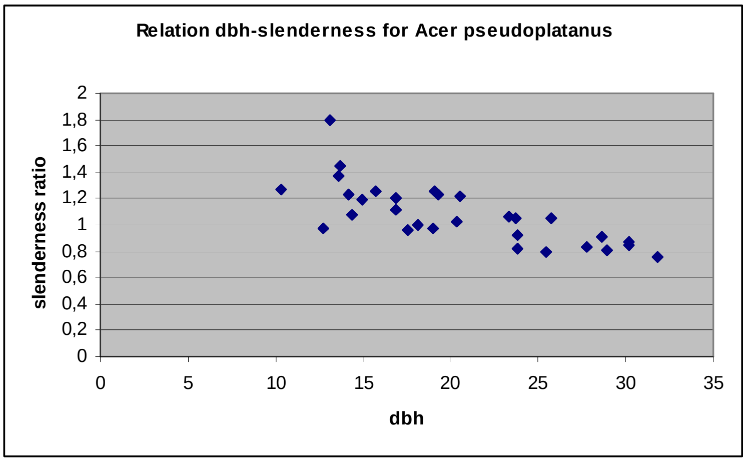


Graphic 21. Relation between dbh and slenderness ratio for Norway spruce.

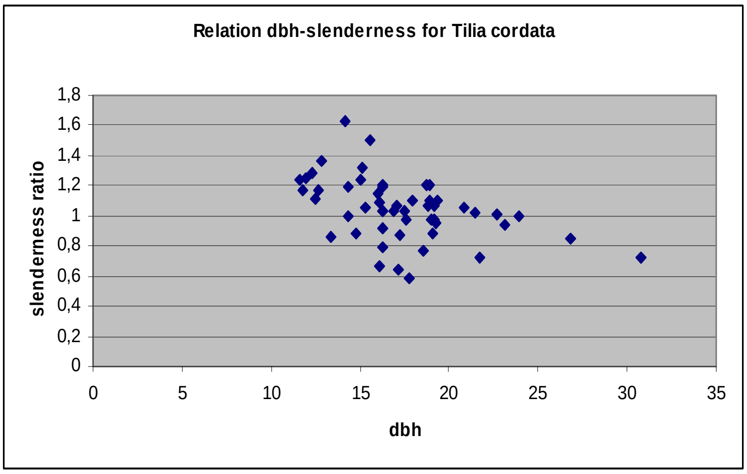
For Norway spruce there are some trees with a very low value for slenderness ratio. The reason of this fact is that this specie is the most sensitive to snow breaks so some trees with big diameter have short height due to the crown is broken.



Graphic 22. Relation between dbh and slenderness ratio for European larch.



Graphic 23. Relation between dbh and slenderness ratio for *Acer pseudoplatanus*.



Graphic 24. Relation between dbh and slenderness ratio for *Tilia cordata*.

Non depending on the specie the trees which are so close, with high slenderness ratio or which present breaks or infections should be cut down along the transformation process.

8. CONCLUSIONS

Uneven-aged forest management is becoming more important between researchers and forest managers. This trend is highly supported by many logical reasons that are reflected in this report. Unfavorable changes of the environment are our legacy from the past and actually the fragile ecosystems are loosing their resilience. The conversion of the clear cutting management system to the selection system is the most important objective of forest management in Hetlín forest complex.

From the economical point of view while many forest landowners and managers will be primarily interested in the economic returns they might expect under a given uneven-aged regime, others will be more concerned with the volume production. There have been an enlargement in the volume stock in the measured plots. The Current Increment Volume in selection forests is higher because effects of competition for light and nutrients are lower because of the different age of the trees.

Much more effort is needed but on the other hand it is a flexible system allowing to drive the evolution of the forest in order to approach it to the economical and social needs along the time. It is necessary to consider that prevention from damages by windstorms and snow is one of the goals of the uneven-aged management. To avoid this kind of damages also means an economical reward. The broadleaves which were introduced have a higher resistance to snow breaks and windstorms. The success in their establishment will mean and increment in the stability of the stands. It is been also found out that trees belonging to plots with better dbh structure suffer less from crown breaks.

To mix different tree species combined with periodical human intervention have been demonstrated to lead to a better development of the stands. Some species have a very important role in soil amelioration or in creating new growing conditions which will favor another species.

The forest complex of Hetlín is on the beginning of the transformation process as it can be seen by number of trees and dbh distribution for the different species. Although the interventions that have taken place till the moment have modified the situation more are needed to reach the target distribution. Specially in those stands where one specie is clearly dominant severer thinnings should be done and adequate species have to be planted in the gaps.

The introduction of new species , mainly broadleaves, in the stands is not working as well as it was expected. There is a high competition and the natural characteristics are not optimal for the development of these species, especially soil and light conditions. Pseudogley soil and its typical water regime mean a problem for the achievement of mixed stands. *Fagus sylvatica* is a shade tolerant specie which is suitable for the vegetation zone were Hetlín forest is situated but the soil conditions curb its development. Another example is *Abies alba.* It was a very important specie in the study area in the past but the population of Silver fir was very damaged in 60's and almost disappear due to the high concentration of sulphur dioxide in air, currently and since 1990 its concentration has decreased until non toxic levels. Nowadays recuperation of *Abies alba* is taking place by plantings but the achievement is very difficult because of the grazing by game. Measures for prevention are being used but probably only few of the planted trees will survive.

Nevertheless we don't have still as much information about this "new" silvicultural system as we had about even-aged management system. But some goals are being reached and time by time the techniques will be improved. Hopefully this system will be wider use in next decades and the knowledgement about uneven-aged forests will increase.

9. REFERENCES

Ambuel, B. and Temple, S.A. (1983): Area-dependent changes in the bird communities and vegetation of S. Wisconsin forests. Ecology 64, pp. 1057–1068

Badoux E. (1949): L'allure de l'accroissement das la forêt jardinée. Mitt. Schweiz. Ans. Forstl. Versuchswes. 26, pp. 9-58.

Baker, J.B. (1987): Production and financial comparisons of uneven-aged and even-aged management of loblolly pine. In: Phillips, D.R. (Ed.), Proc. of the Fourth Biennial Southern Silvicultural Research Conf., November 4–6, 1986, Atlanta, GA. GTR SE-42. USDA For. Serv., Southeastern For. Exp. Stn., Asheville, NC, pp. 267–273

Baker, J.B. (1989): Recovery and development of understocked loblolly-shortleaf pine stands. South. J. Appl. For. 13 3, pp. 132–139

Baker, J.B., Guldin, J.M. and Guldin, R.W. (1991): Natural regeneration methods for loblolly and shortleaf pines. For. Farmer 50 3, pp. 59–63

Baker, J.B. and Murphy, P.A. (1982): Growth and yield following four reproduction cutting methods in loblolly-shortleaf pine stands. South. J. Appl. For. 6 2, pp. 66–74

Baker et al (1996): Uneven-Aged Silviculture for the Loblolly and Shortleaf Pine Forest Cover Types. USDA Forest Service Southern Research Station General Technical Report SO-118. (Chapter I)

Bormann, F.H., Likens, G.E. (1979): Pattern and Process in a Forested Ecosystem. Springer-Verlag, New York, NY. pp. 253

Buongiorno, J., Dahir, S., Lu, H.-C. and Lin, C.-R. (1994): Tree size diversity and economic returns in uneven-aged forest stands. For. Sci. 40 1, pp. 83–103

Buongiorno, J., Peyron, L., Houllier, F. and Bruciamacchie, M. (1995): Growth and management of mixed-species, uneven-aged forest in the French Jura: Implications for economic returns and tree diversity. For. Sci. 41 3, pp. 397–429

Bürgi M. and Schuler A. (in press): Driving forces of changes in forest management- an analysis of regeneration practice in the forest of the Swiss lowlands during the 19th and 20th century. Forest Ecology and Management.

Burton, P.J., Balisky, A.C., Coward, L.P., Cumming, S.G. and Kneeshaw, D.D. (1992): The value of managing for biodiversity. For. Chron. 68 2, pp. 225–237

Chang, S.J. (1990): An economic comparison of even-aged and uneven-aged management of southern pines in the mid-South. In: Hickman, C.A. (Ed.), Proc. of the Southern Forest Economics Workshop on Evaluating Even- and All-Aged Timber Management Options for Southern Forest Lands, March 29–30, 1990, Monroe, LA. GTR SO-79. USDA For. Serv., Southern Exp. Stn., New Orleans, LA, pp. 45–52

Führer E. (1994): Forschungsinitiative gegen das Waldsterben FIW II. Von der Waldschadensforschung zur Waldökosystem- Sanierungsforschung. Österr. Ges. Für Waldökosystemforschung und experimentelle Baumforschung. Univ. für Bodenkultur Wien. 7, pp. 1-10.

Gaillard M.J. (1984): Etude palynologique de l'evolution tardi- et postglaciaire de la vegetation du Moyen-Pays Romand (Suisse). Dissertationes Botanicae 77, pp. 1–322.

Gaillard M.J. (1985): Late.glacial and Holocene environments of some antient lakes in western Swiss Plateau. Dissertationes Botanicae 87, pp. 236–273.

Gayer K. (1886): Der gemischte Wald, seine Begründung und Pflege, insbesondere durch Horst- und Grup- penwirstschaft. Parey, Berlin, 168 pp.

Güde J. (1960): Der historische Fichtenvorstoß in das oberösterreichische Alpenvorland im Raume von Lambach. Centralbl. f. d. ges. Forstwesen 77, pp. 1-18.

Guldin, J.M. and Baker, J.B. (1988): Yield comparisons from even-aged and uneven-aged loblolly-shortleaf pine stands. South. J. Appl. For. 12 5, pp. 107–114
Hansen, A.J., Spies, T.A., Swanson, F.J. and Ohmann, J.L. (1991): Conserving biodiversity in managed forests: Lessons from natural forests. Biosci. 41 6, pp. 382–392
Hasenauer H.: Glossary of Terms and Deffinitions Relevant for Conversion. 269 pp. 5-23. In: Spiecker H., Hansen J., Klimo E., Skovsgaard J., Sterba H., Teuffel K., (2004): Norway Spruce Conversion- Options and Consequences. European Forest Institute. Netherlands.
Helms J.A. (1998) The Dictionary of forestry. Society of American Foresters, Bethesda, MD, USA.
Hönlinger H. (1909): Weitere Beweise für die Unrichtigkeit der Reinertragslehre. Wien und Leipzig: K. u. k. Hof-Buchdruckerei und Hof- Verlags- Buchhandlung Carl Fromme. 48 pp.
Johann E. et all.: Hystory of Secundary Norway Spruce Forests in Europe. 269 pp. 25- 62. In: Spiecker H., Hansen J., Klimo E., Skovsgaard J., Sterba H., Teuffel K., (2004): Norway Spruce Conversion- Options and Consequences. European Forest Institute. Netherlands.
Korf, V.:Hospodářská úprava lesů 1955. Taxace lesů II. část. Praha, SZN 1955, 363 s.
Kluender, R.A., Lortz, D., McCoy, W., Stokes, B. and Klepac, J. (1998). Removal intensity and tree size effects on harvesting cost and profitability. Forest Prod. J. 48 1, pp. 54–59
MacArthur, R.H. and MacArthur, J.W. (1961): On bird species diversity. Ecology 42, pp. 594–600
Matthews, J.D. (1989): Silvicultural Systems. Oxford University Press, pp. 284
Lentz, R.J., Sims, D.H., Ince, P.J. (1989). Are our traditional attitudes restricting forestry management options? In: Waldrop, T.A. (Ed.), Proc. of Pine-Hardwood Mixtures: A Symposium on Management and Ecology of the Type, April 18–19, 1989, Atlanta, GA. GTR SE-58. USDA For. Serv., Southeastern For. Exp. Stn., Asheville, NC. pp. 20–24
Lin, C.-R., Buongiorno, J. and Vasievich, M. (1996): A multi-species, density-dependent matrix growth model to predict tree diversity and income in northern hardwood stands. Ecol. Model. 91, pp. 193–211
Lu, H.-C. and Buongiorno, J. (1993). Long- and short-term effects of alternative cutting regimes on economic returns and ecological diversity in mixed-species forests. For. Ecol. Manage. 58, pp. 173–192
Němeček J. & Kozák J. (2001): The Czech taxonomic soil classification system and the harmonization of soil maps. Czech Agricultural University, Department of Soil Science and Geology, Kamýcká 129, 165 21 Praha 6 – Suchdol, Czech Republic.
Neuhäuslová Z. et al (1998): Map of Potencial Natural Vegetation of the Czech Republic. Academia Praha, 341pp.
Niese, J.N. and Strong, T.F. (1992): Economic and tree diversity trade-offs in managed northern hardwoods. Can. J. For. Res. 22, pp. 1807–1813
O'Hara K. (2002): The historical development of uneven-aged silviculture in North America. Division of Forest Science, ESPM, 145 Mulford Hall, University of California, Berkeley, CA94720-3114, USA. Forestry, volume 75, nº 4
O'Hara K. & Gersonde R. (2004): Stocking control concepts in uneven-aged silviculture. Environmental Science, Policy and Management, 151 Hilgad Hall, University of California. Berkeley, Berkeley, CA 94720-3110, USA. Forestry, volume 77, nº 2
Oliver, C.D. (1992): A landscape approach: Achieving and maintaining biodiversity and economic productivity. J. For. 90 9, pp. 20–25

Phillips, D.R. and Abercrombie Jr., J.A. (1987): Pine-hardwood mixtures: A new concept in regeneration. South. J. Appl. For. 11 4, pp. 192–197
Petráš R. & Rajtík J. (1991): Sústava česko-slovenských objemových tabuliek drevín. Lesnícky časopis, year 37, volume 1, pp 49-56.
Poleno Z. (2000): Criteria of felling maturity of individual trees in forest manager under systems involving coupes. Journal of Forest Science 46, pp. 53-60.
Pressler M. R. (1880): Die neuere Opposition gege Einführung eines natioökonomisch und forsttechnisch correcten Reinertragswaldbau. In: Der rationelle Walwirth und sein Nachhaltswaldbau höchsten Reinertrags. Heft 8: Zweite revidierte und ergänzte Auflage. Tharand und Leipzig. Verlag der Pressler'schen Werke. 176 pp.
Quitt E. (1971): Klimatické oblasti Československa [Climatic regions of Czechoslovakia], Stud. Geogr. 16 (1971), pp. 1–74
Redmond, C.H., Greenhalgh, R. (1990): An economic analysis of even-aged versus uneven-aged management on nonindustrial private land in southern Arkansas. In: Hickman, C.A. (Ed.), Proc. of the Southern Forest Economics Workshop on Evaluating Even- and All-Aged Timber Management Options for Southern Forest Lands, March 29–30 1990, Monroe, LA. GTR SO-79. USDA For. Serv., Southern Exp. Stn., New Orleans, LA. pp. 69–79
Remeš J. (2006): Transformation of even-aged spruce stands at the School Forest Enterprise Kostelec nad Černými lesy: Structure and final cutting of mature stand. Faculty of Forest and Environment, Czech University of Agriculture in Prague, Prague, Czech Republic. Journal of Forest Science, 52, 2006 (4), pp. 158-171.
Remeš J. & Kozel J. (2006): Structure, growth and increment of the stands in the course of stand transformation in the Klokočná Forest Range. Faculty of Forest and Environment, Czech University of Agriculture in Prague, Prague, Czech Republic. Journal of Forest Science, 52, 2006 (12), pp. 537-546.
Reynolds R.R., Baker J.B. and Ku T.T. (1984): Four Decades of Selection Management on the Crossett Far Forestry Forties. University of Arkansas, Agriculture Experiment Station, Bulletin 872, 43 pp.
Schulte B. & Buongiorno J. (1998): Effects of uneven-aged silviculture on the stand structure, species composition, and economic returns of loblolly pine stands. Department of Forest Ecology and Management, University of Wisconsin-Madison, 1630 Linden Drive Madison, WI 53706 USA.
Schütz J. (1969): Etude des phénomènes de lcroissance en hauteur et en diamètre du sapin (*Abies alba* Mill.) et de l'épicéa (*Picea abies* Karst.) dans deux peuplements jardines et une forêt vierge Beihefte Z. Schweiz. Forstver (44) Bühler Zürich.
Schütz J. (1999): Close-to-nature silviculture. Is this concept compatible with species diversity? Department of Forest Science, Swiss Federal Institute of Technology, ETH-Zentrum (ETH-Z), CH-8092 Zürich, Switzerland. Forestry, volume 72, nº 4.
Schütz J. (1999): Uneven-aged silviculture: tradition and practices. Department of Forest Science, Swiss Federal Institute of Technology, ETH-Zentrum (ETH-Z), CH-8092 Zürich, Switzerland. Forestry, volume 75, nº 4.
Schütz J. (2001): Opportunities and strategies of transforming regular forests to irregular forests. Department of Forest Science, Swiss Federal Institute of Technology, ETH-Zentrum (ETH-Z), CH-8092 Zürich, Switzerland. Forest Ecology and Management 151, pp. 87-94
Schwartz J., Nagel L. & Webster C. (2005): Effects of uneven-aged management on diameter distribution and species composition of northern hardwoods in Upper Michigan. School of Forest Resources and Environmental Science, 1400 Townsend Drive, Michigan Technological University, Houghton, MI 49931-1295 USA.

Seeling U. (2001): Transformation of plantation forest—expected wood properties of Norway spruce (Picea abies (L.) Karst.) within the period of stand stabilisation. Forest Products Laboratory, Albert- Ludwigs-University of Freiburg, Werderring 6, D-79085 freiburg, Germany. Forest Ecology and Management 151, pp. 195-210.

Smith, D.M., Larson, B.G., Kelty, M.J., Ashton, P.M.S. (1997). The Practice of Silviculture: Applied Forest Ecology (Ninth edn.). John Wiley and Sons, New York. pp. 537

Urban, D.L. and Smith, T.M. (1989). Microhabitat pattern and the structure of forest bird communities. Am. Nat. 133, pp. 811–829

Viewegh J. (2005): Czech Forest Ecosystem (Site) Classification. Electronical device. Faculty of Forestry and Environmental. Department of Dendrology and Tree Breeding. Czech University of Agriculture in Prague, Prague, Czech Republic.

Volin, V.C. and Buongiorno, J. (1996): Effects of alternative management regimes on forest stand structure, species composition, and income: A model for the Italian Dolomites. For. Ecol. Manage. 87, pp. 107–125

Walker M.J.C. (1995): Climatic changes in Europe during the last glacial/interglacial transition. Quaternary International 28, 63–76.

Williston, H.L. (1978). Uneven-aged management in the loblolly-shortleaf pine type. South. J. Appl. For. 2, pp. 107–114

10. ANNEXES

ANNEX 1 Maps and Pictures of Hetlín complex

In Figures from 12 to 15 maps of Hetlín and surroundings can be found:

- Figure 12. Situation of Hetlín in relation with Kutná Hora.
- Figure 13. Historical map of Hetlín complex 1838-1852.
- Figure 14. Aereal picture of Hetlín complex 2003.
- Figure 15. Map of Hetlín complex.

Figure 12. Situation of Hetlín in relation with Kutná Hora

Figure 13. Historical map of Hetlín complex 1838-1852.

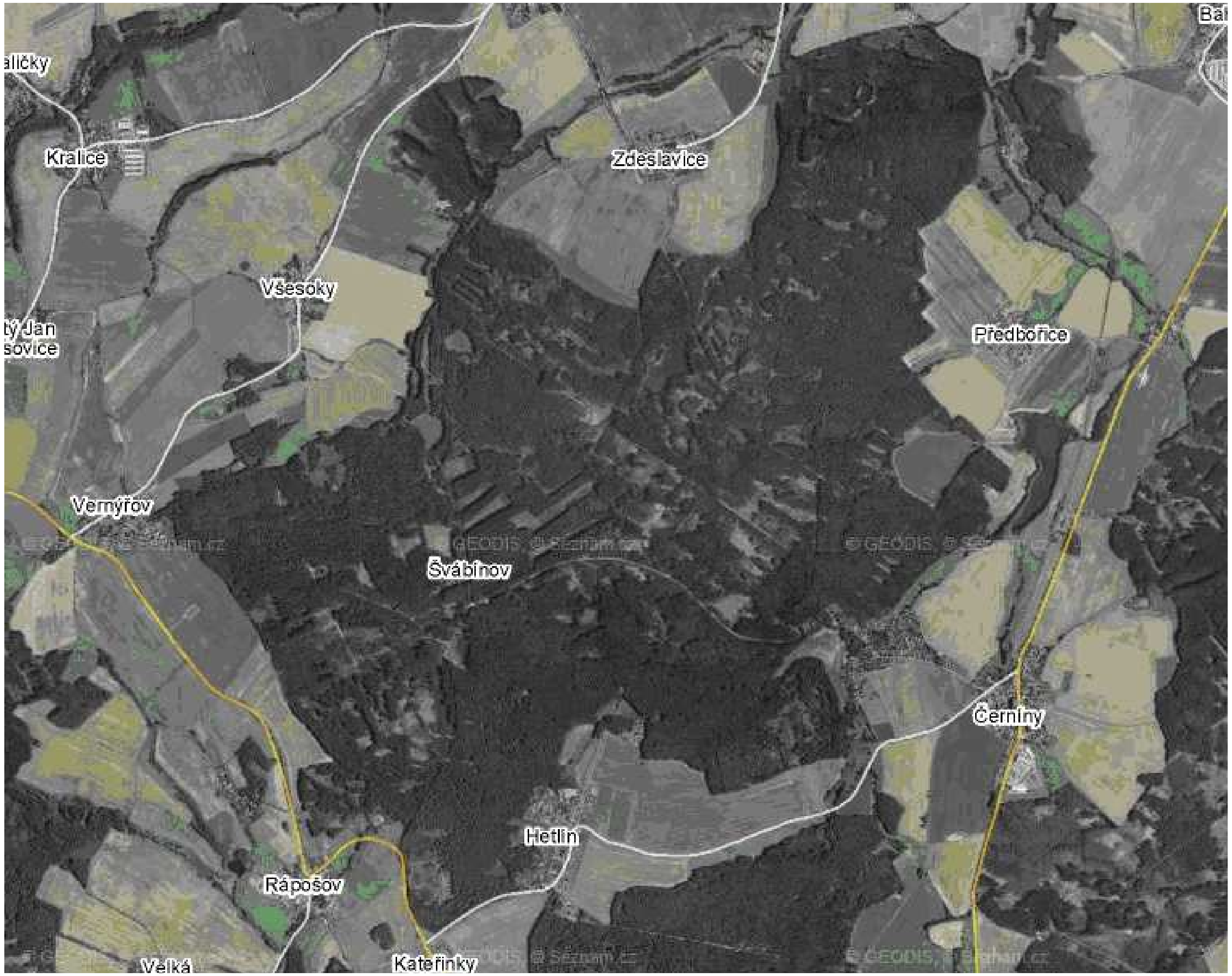


Figure 14. Aereal picture of Hetlín complex 2003.

Figure 15. Map of Hetlín complex

ANNEX 2 Location maps for the plots

Figure 16. Stand Map of the area of Hetlín forest where plots are contained

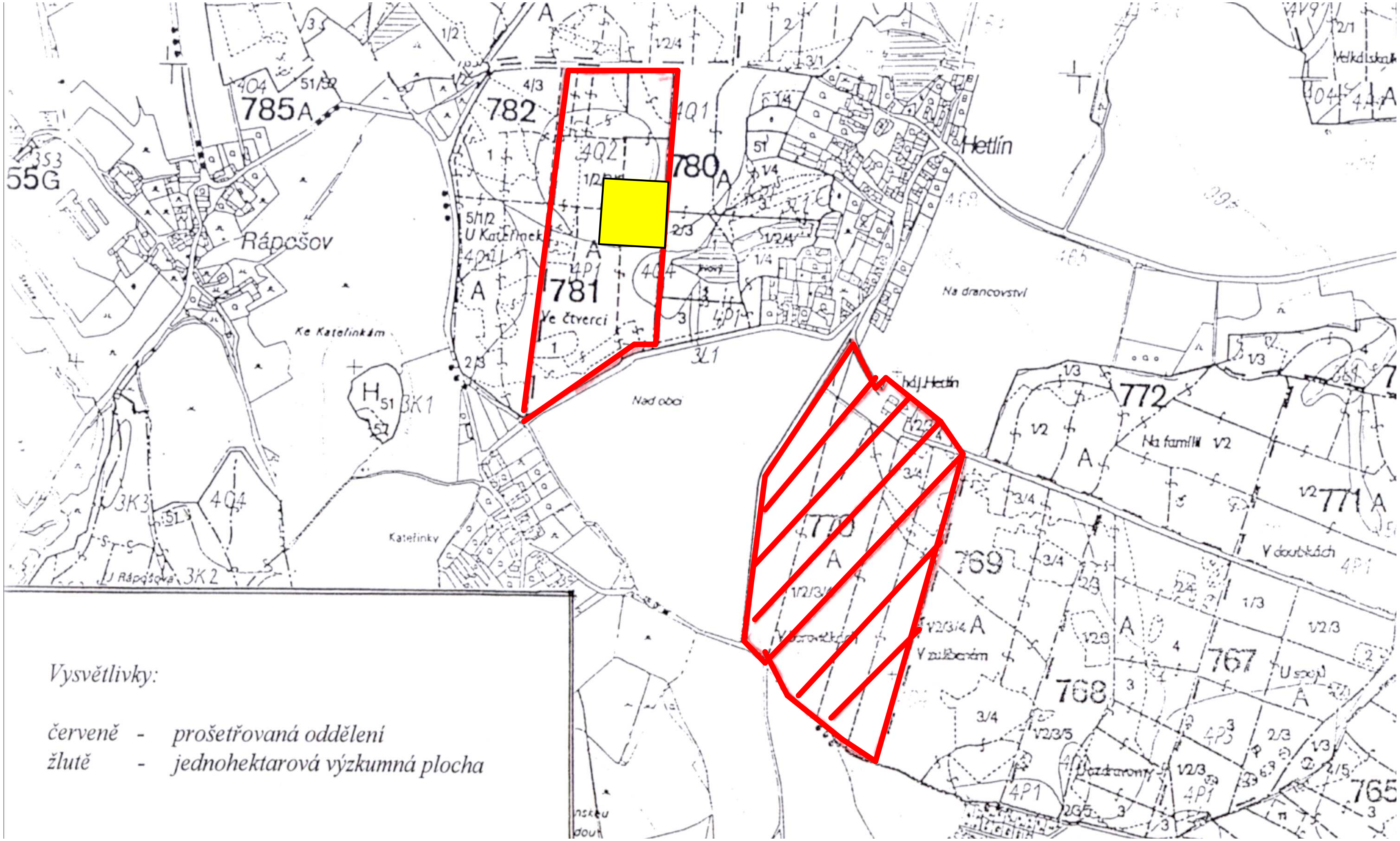


Figure 17. Location map of rectangular plots.

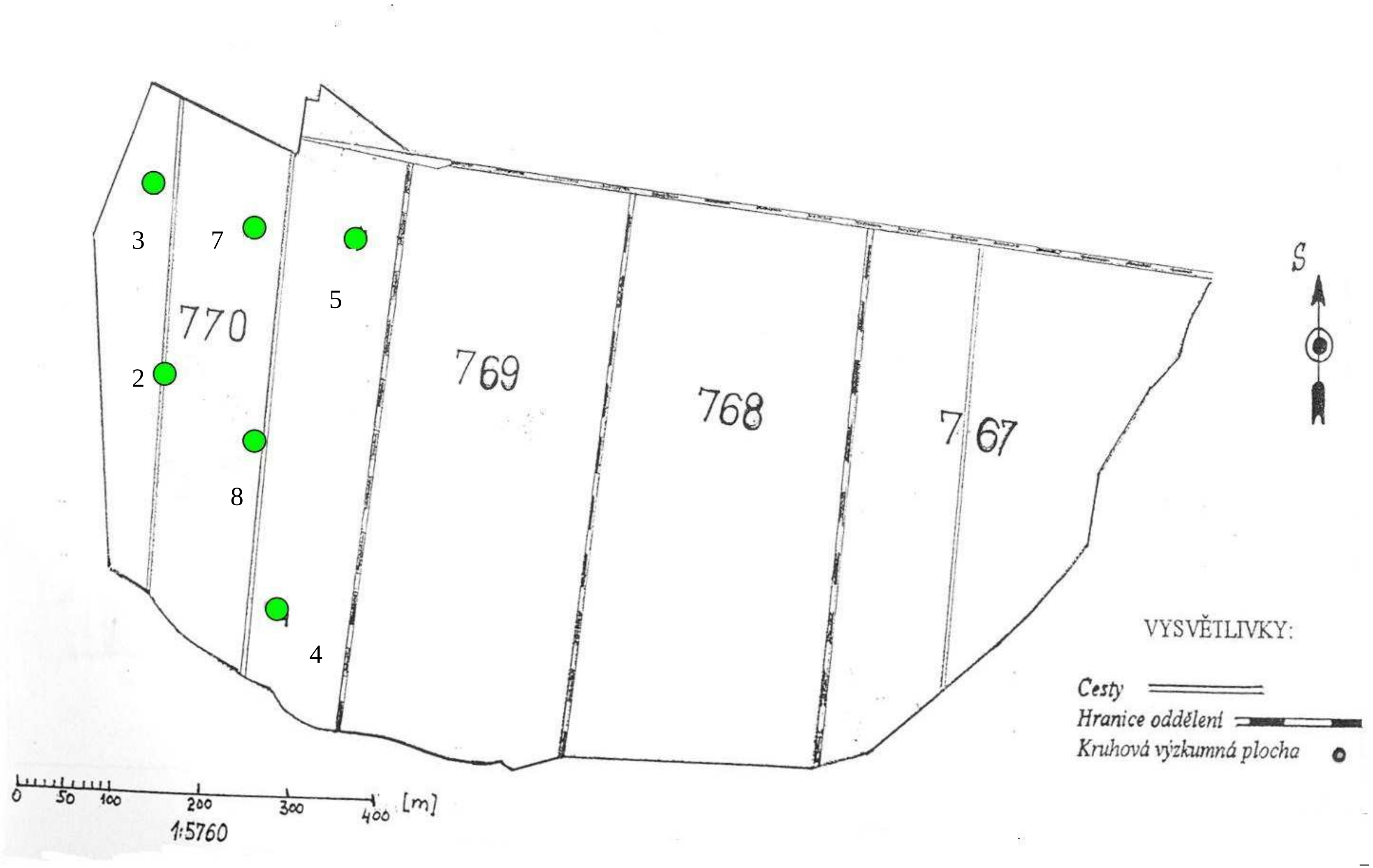


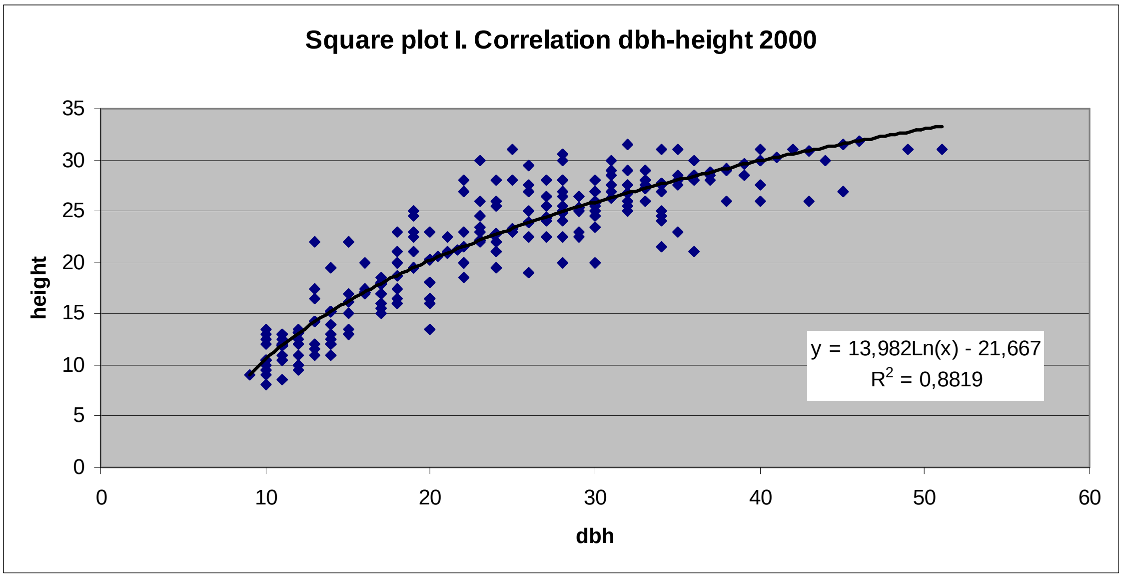
Figure 18. Location map for circle plots.

ANNEX 3 Tables for Total Percentage of species

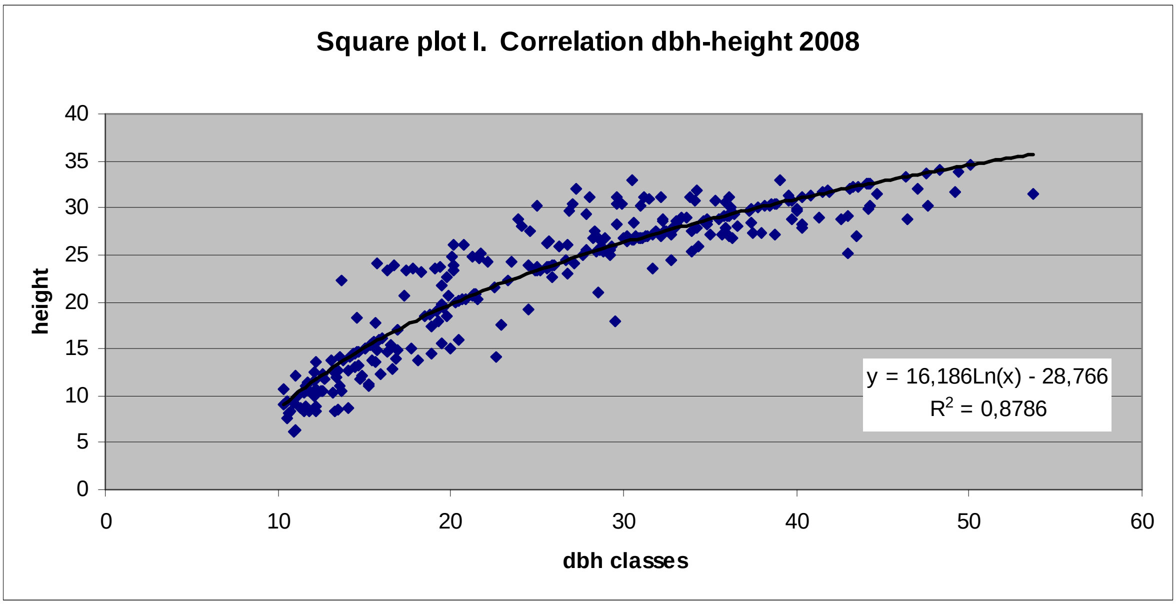
	Total plots			nº trees/plot							
Tree species composition	nº trees/all plots	nº trees/ha	Percentage %	Rectang. plot I	Rectang plot II	Circle plot 2	Circle plot 3	Circle plot 4	Circle plot 5	Circle plot 7	Circle plot 8
2000											
BK (*Fagus sylvatica*)	6	3	0,5	0	0	0	1	1	0	2	2
BO (*Pinus sylvestris*)	156	89	14,3	100	4	19	10	0	0	8	15
BR (*Betula pendula*)	25	14	2,3	20	1	1	0	0	3	0	0
DB (*Quercus robur*)	6	3	0,5	6	0	0	0	0	0	0	0
DG (*Pseudotsuga sp.*)	2	1	0,2	0	0	0	0	0	2	0	0
HB (*Carpinus betulus*)	4	2	0,4	0	0	0	4	0	0	0	0
JD (*Abies alba*)	6	3	0,5	2	0	1	0	0	3	0	0
JM (*Ulmus sp.*)	1	1	0,1	0	0	0	0	0	0	1	0
JŘ (*Sorbus aucuparia*)	12	7	1,1	2	0	0	4	2	1	1	2
JV (*Acer pseudoplatanus*)	30	17	2,7	0	0	4	23	0	0	1	2
LP (*Tilia cordata*)	50	29	4,6	0	0	4	10	4	0	0	32
MD (*Larix decidua*)	142	81	13,0	90	51	0	1	0	0	0	0
OL (*Alnus sp.*)	10	6	0,9	0	0	0	0	0	7	3	0
SM (*Picea abies*)	641	365	58,8	130	352	43	27	10	36	37	6
Total	1091	622	100	350	408	72	80	17	52	53	59
2008											
BK (*Fagus sylvatica*)	8	5	0,8	0	0	0	1	3	0	2	2
BO (*Pinus sylvestris*)	132	75	12,7	84	4	16	9	0	0	4	15
BR (*Betula pendula*)	19	11	1,8	15	1	1	0	0	2	0	0
DB (*Quercus robur*)	6	3	0,6	5	1	0	0	0	0	0	0
DG (*Pseudotsuga sp.*)	2	1	0,2	0	0	0	0	0	2	0	0
HB (*Carpinus betulus*)	3	2	0,3	0	0	0	3	0	0	0	0
JD (*Abies alba*)	18	10	1,7	4	0	1	0	10	3	0	0
JŘ (*Sorbus a ucuparia*)	10	6	1,0	1	0	0	4	3	1	1	0
JV (*Acer pseudoplatanus*)	30	17	2,9	0	0	4	23	0	0	0	3
LP (*Tilia cordata*)	52	30	5,0	0	0	4	10	5	0	0	33
MD (*Larix decidua*)	135	77	13,0	83	51	0	1	0	0	0	0
OL (*Alnus sp.*)	10	6	1,0	0	0	0	0	0	7	3	0
SM (*Picea abies*)	611	348	59,0	114	344	43	27	6	31	39	7
Total	1036	591	100	306	401	69	78	27	46	49	60

ANNEX 4

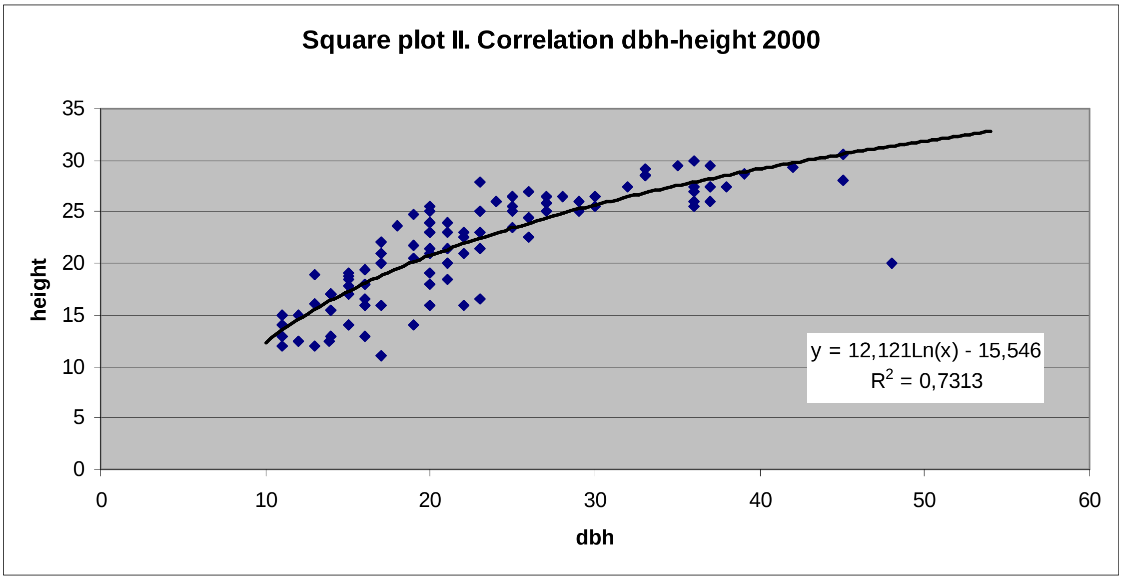
Graphics of Correlation analysis & Tables for statistical analysis for the totality of the species in all plots together



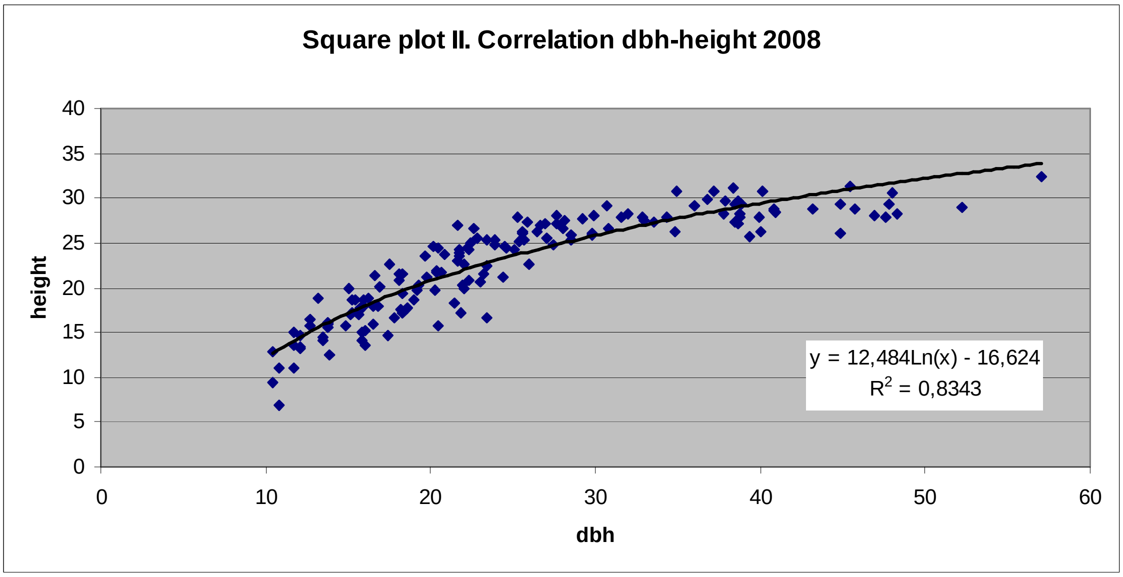
Graphic 25. Correlation DBH – H, R sq. Value & Equation regression for Rectangular plot I in 2000



Graphic 26. Correlation DBH – H, R sq. Value & Equation regression for Rectangular plot I in 2008



Graphic 27. Correlation DBH – H, R sq. Value & Equation regression for Rectangular plot II in 2000



Graphic 28. Correlation DBH – H, R sq. Value & Equation regression for Rectangular plot II in 2008

Fagus sylvatica	N (nº trees/ha)=	4,6		
	nº trees all plots=	8		
Parameters analized	**dbh (cm)**	**Height (m)**	**Basal area (m^2)**	**Volume (m^3)**
Mean	27,11	19,89	0,0632	0,6728
Median	29,58	20,15	0,0687	0,7593
Standard deviation	8,89	5,69	0,0364	0,4452
Variance	78,99	32,36	0,0013	0,1982
dg	27,68			

Table 15. Statistical analysis for *Fagus sylvatica*.

Betula pendula	N (nº trees/ha)=	10,8		
	nº trees all plots=	19		
Parameters analized	**dbh (cm)**	**Height (m)**	**Basal area (m^2)**	**Volume (m^3)**
Mean	26,42	25,19	0,0571	0,6045
Median	25,60	25,40	0,0515	0,5485
Standard deviation	5,58	3,17	0,0241	0,2916
Variance	30,67	10,06	0,0006	0,0851
dg	26,63			

Table 16. Statistical analysis for *Betula pendula*.

Quercus robur	N (nº trees/ha)=	3,4		
	nº trees all plots=	6		
Parameters analized	**dbh (cm)**	**Height (m)**	**Basal area (m^2)**	**Volume (m^3)**
Mean	16,91	14,38	0,0234	0,1753
Median	15,65	14,15	0,0192	0,1317
Standard deviation	3,83	2,53	0,0110	0,1136
Variance	14,68	6,42	0,0001	0,0129
dg	17,74			

Table 17. Statistical analysis for *Quecus robur*.

Pseudotsuga menziesii	N (nº trees/ha)=	1,1		
	nº trees all plots=	2		
Parameters analized	**dbh (cm)**	**Height (m)**	**Basal area (m^2)**	**Volume (m^3)**
Mean	46,53	34,35	0,1716	2,7751
Median	46,53	34,35	0,1716	2,7751
Standard deviation	6,33	2,47	0,0463	0,8889
Variance	40,05	6,13	0,0021	0,7902
dg	48,17			

Table 18. Statistical analysis for *Pseudotsuga menziesii*.

Carpinus betulus	N (nº trees/ha)=	1,7		
	nº trees all plots=	3		
Parameters analized	**dbh (cm)**	**Height (m)**	**Basal area (m^2)**	**Volume (m^3)**
Mean	20,78	20,57	0,0350	0,3595
Median	20,15	20,10	0,0319	0,3077
Standard deviation	4,43	1,94	0,0148	0,1987
Variance	19,66	3,77	0,0002	0,0395
dg	20,26			

Table 19. Statistical analysis for *Carpinus betulus*.

Abies alba	N (nº trees/ha)=	9,7		
	nº trees all plots=	17		
Parameters analized	**dbh (cm)**	**Height (m)**	**Basal area (m^2)**	**Volume (m^3)**
Mean	17,04	14,92	0,0269	0,2666
Median	15,40	14,00	0,0186	0,1363
Standard deviation	7,40	5,29	0,0290	0,4359
Variance	54,82	27,98	0,0008	0,1900
dg	18,18			

Table 20. Statistical analysis for *Abies alba*.

Sorbus aucuparia	N (nº trees/ha)=	6,3		
	nº trees all plots=	11		
Parameters analized	**dbh (cm)**	**Height (m)**	**Basal area (m^2)**	**Volume (m^3)**
Mean	16,00	14,92	0,0208	0,1251
Median	15,60	16,50	0,0191	0,1156
Standard deviation	3,01	3,75	0,0077	0,0668
Variance	9,38	15,24	too low value	0,0048
dg	17,56			

Table 21. Statistical analysis for *Sorbus aucuparia*.

Acer pseudoplatanus	N (nº trees/ha)=	15,4		
	nº trees all plots=	27		
Parameters analized	**dbh (cm)**	**Height (m)**	**Basal area (m^2)**	**Volume (m^3)**
Mean	17,05	17,85	0,0244	0,2314
Median	15,83	18,40	0,0201	0,1810
Standard deviation	5,08	3,97	0,0146	0,1803
Variance	25,80	15,79	0,0002	0,0325
dg	22,05			

Table 22. Statistical analysis for *Acer pseudoplatanus*.

Tilia cordata	N (nº trees/ha)=	29,6		
	nº trees all plots=	52		
Parameters analized	**dbh (cm)**	**Height (m)**	**Basal area (m^2)**	**Volume (m^3)**
Mean	17,37	17,77	0,0248	0,2282
Median	16,98	17,80	0,0226	0,1916
Standard deviation	3,75	3,62	0,0116	0,1456
Variance	14,09	13,11	0,0001	0,0212
dg	18			

Table 23. Statistical analysis for *Tilia cordata*.

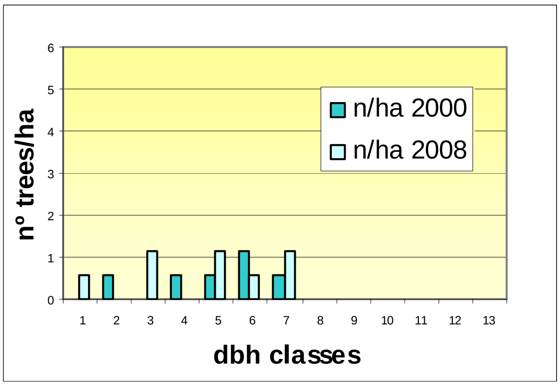
Alnus glutinosa	N (nº trees/ha)=	5,7		
	nº trees all plots=	10		
Parameters analized	**dbh (cm)**	**Height (m)**	**Basal area (m^2)**	**Volume (m^3)**
Mean	20,40	22,42	0,0341	0,3564
Median	20,48	24,50	0,0333	0,3131
Standard deviation	4,49	5,10	0,0144	0,1941
Variance	20,18	25,97	0,0002	0,0377
dg	21,24			

Table 24. Statistical analysis for *Alnus glutinosa*.

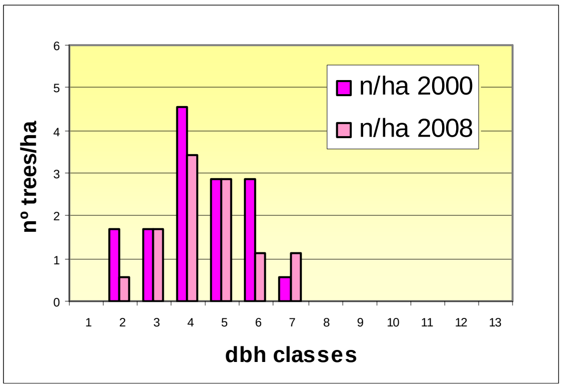
ANNEX 5.

Graphics for dbh distribution of the totality of species in all plots together

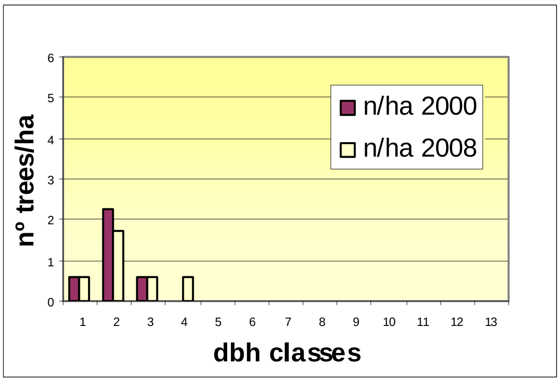
Graph 29-34. Dbh distribution for each specie in all plots together.



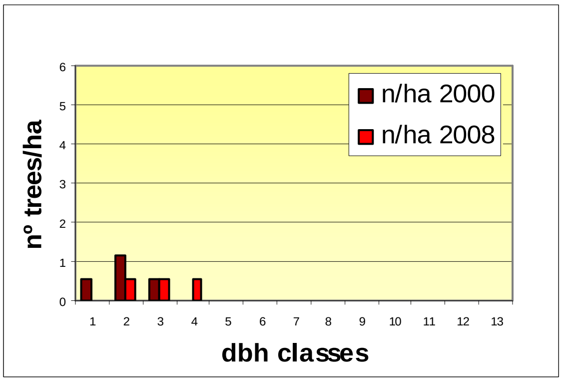
Dbh distribution *Fagus sylvatica* 2000 & 2008



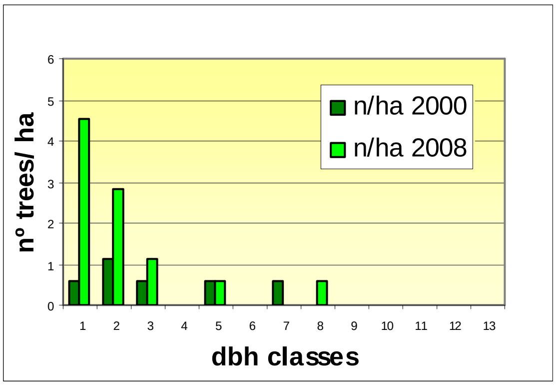
Dbh distribution *Betula pendula* 2000 & 2008



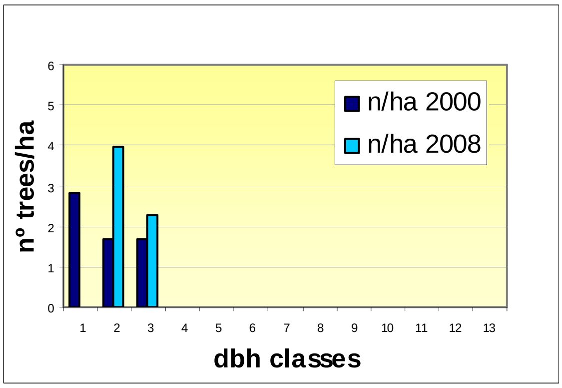
Dbh distribution *Quercus robur* 2000 & 2008



Dbh distribution *Carpinus betulus* 2000 & 2008

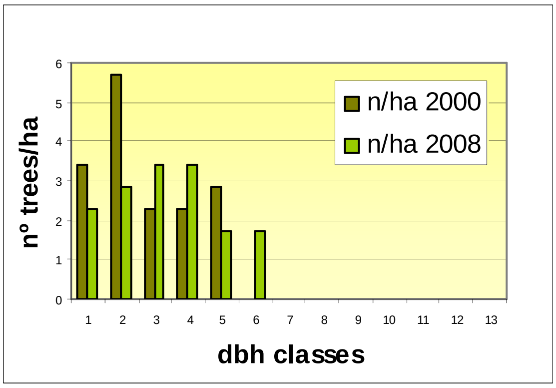


Dbh distribution *Abies alba* 2000 & 2008

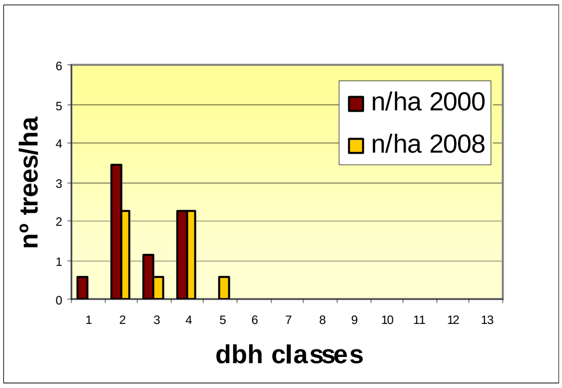


Dbh distribution *Sorbus aucuparia* 2000 & 2008

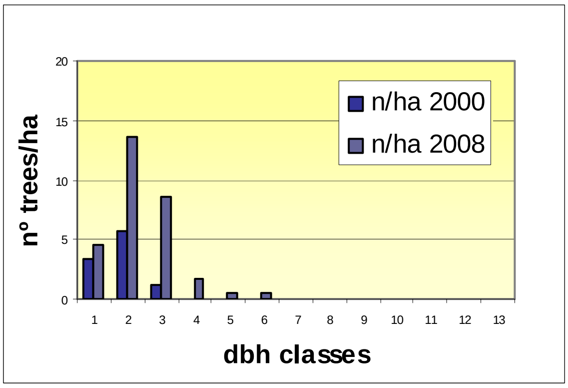
Graph 35-37. Dbh distribution for each specie in all plots together.



Dbh distribution *Acer pseudoplatanus* 2000 & 2008



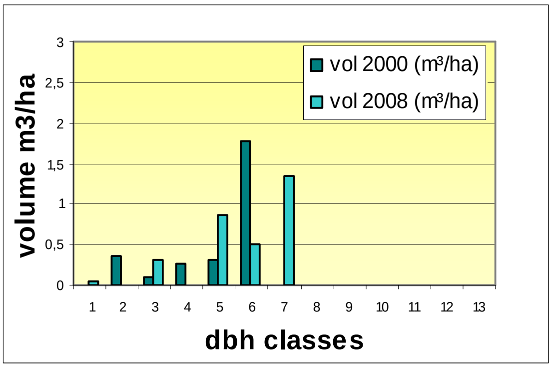
Dbh distribution *Alnus glutinosa* 2000 & 2008

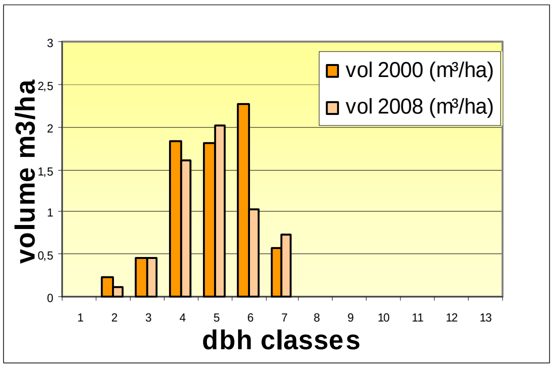


Dbh distribution *Tilia cordata* 2000 & 2008

ANNEX 6.

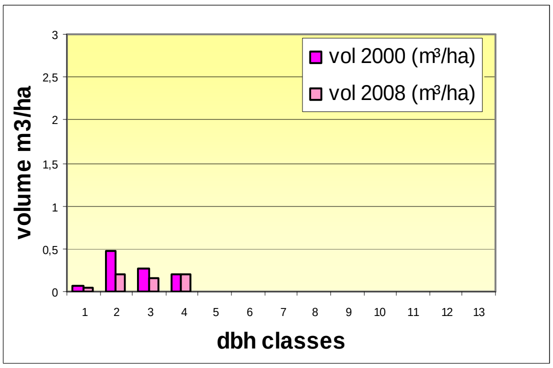
Graphics of volume on Dbh distribution for the totality of the species in all plots together

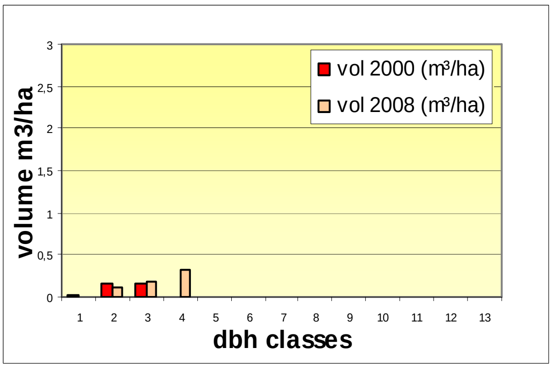




G.38. Vol on Dbh distribution for *Fagus sylvatica.*

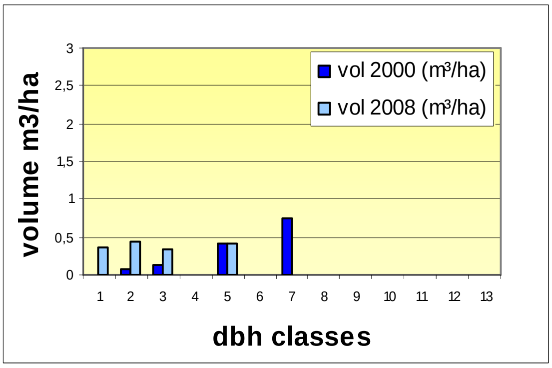
G.39.Vol on Dbh distribution for *Betula pendula*

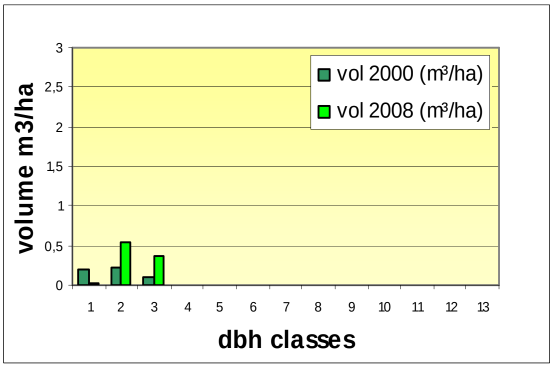




G.40.Vol on Dbh distribution for *Quercus robur*

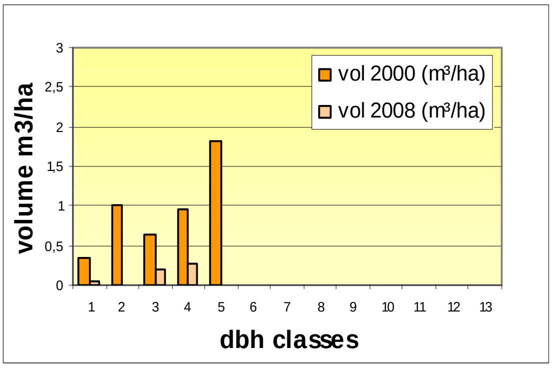
G.41 Vol on Dbh distribution for *Carpinus betulus.*

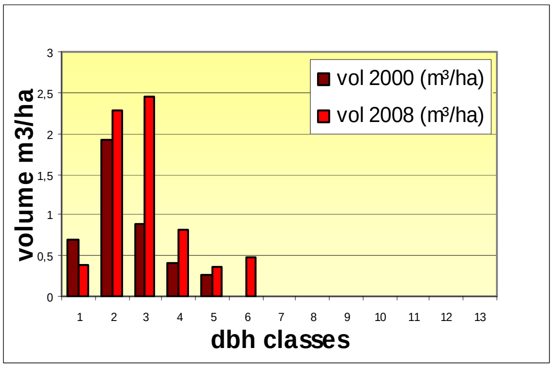




G.42.Vol on Dbh distribution for *Abies alba.*

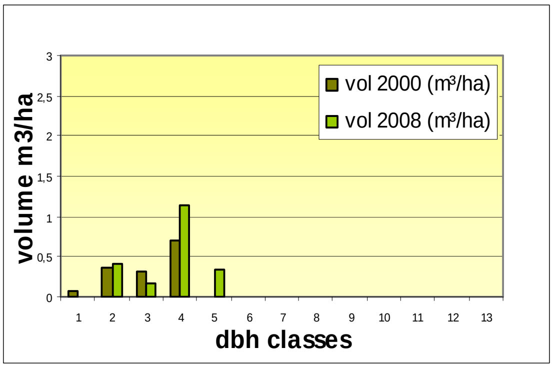
G.43 Vol on Dbh distribution for *Sorbus aucuparia*





G.44Vol on Dbh distribution for *Acer pseudoplatanus*

G.45Vol on Dbh distribution for *Tilia cordata*

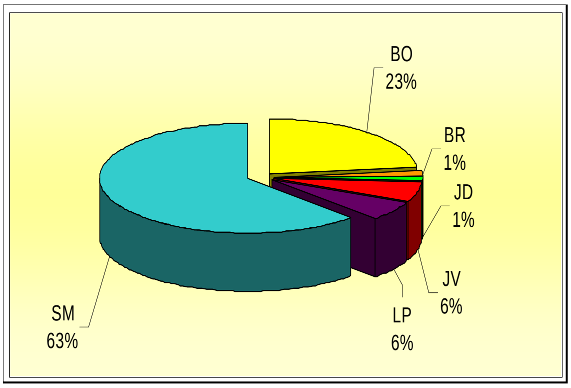


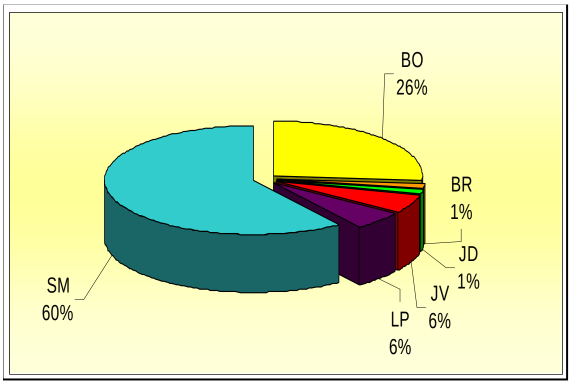
G.46Vol on Dbh distribution for *Alnus glutinosa.*

ANNEX 7.

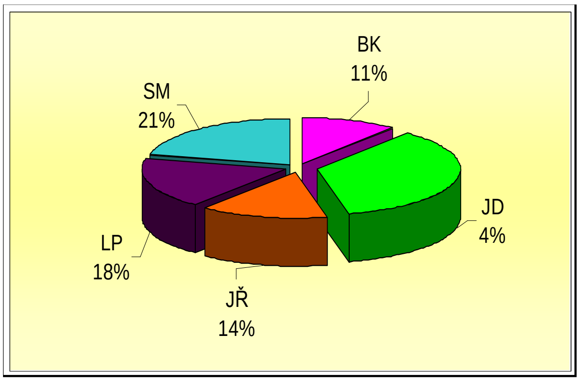
Graphics of Percentage of Species in each plot

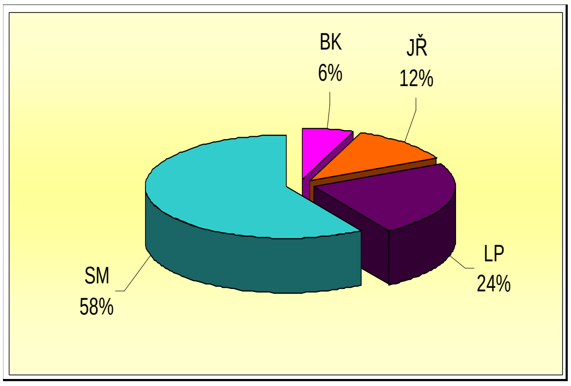
Graphs 47-60. Graphics of percentage of species in each plot



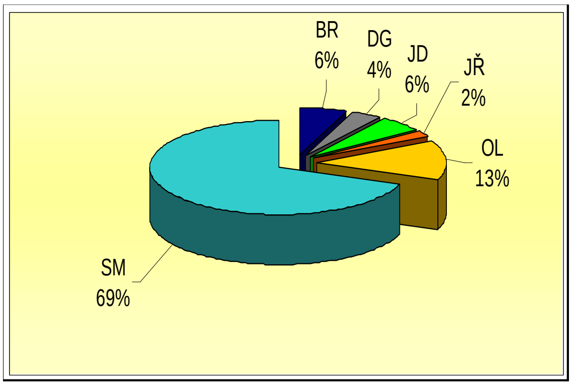


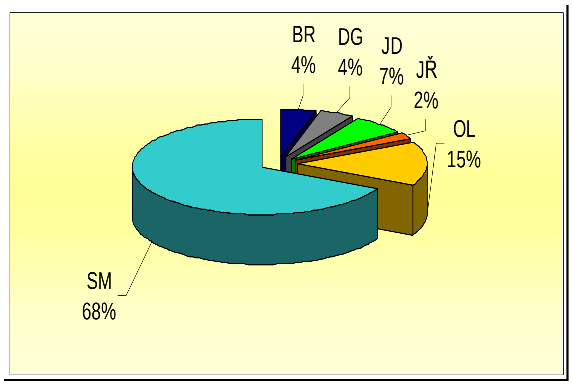
Circular plot 2, 2008 & 2000



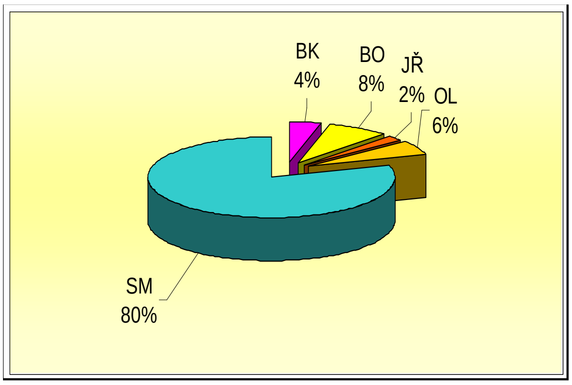


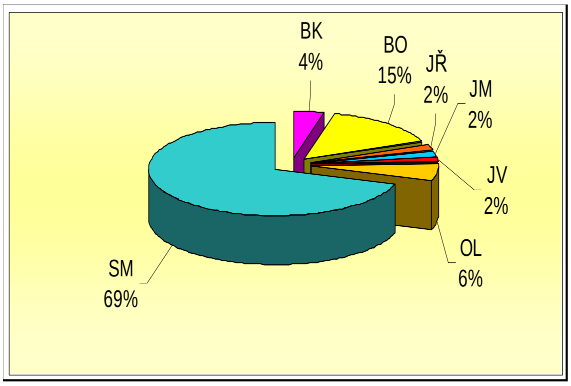
Circular plot 4, 2008 & 2000



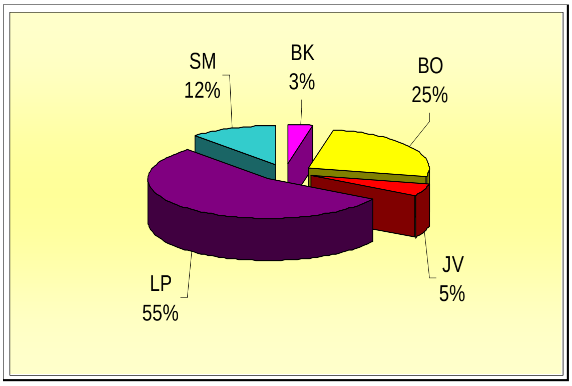


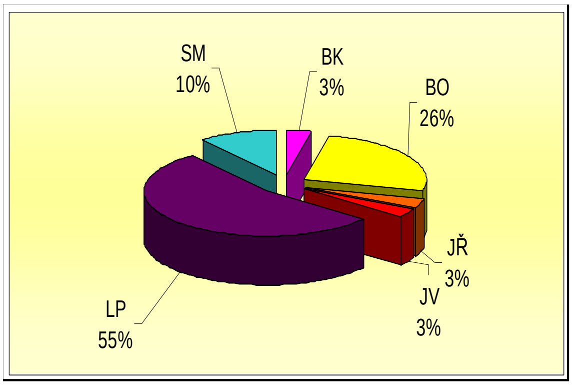
Circular plot 5, 2000 & 2008



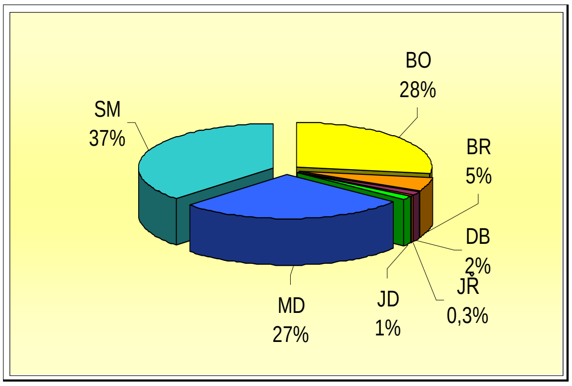


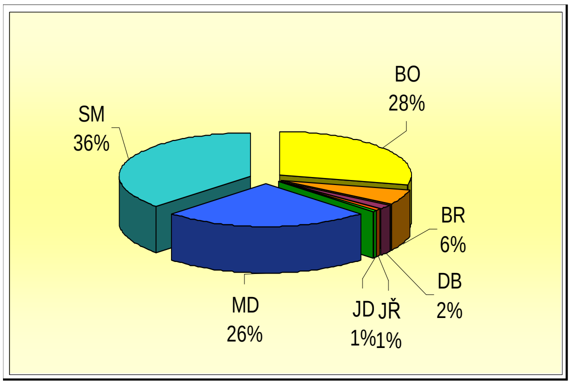
Circular plot 7, 2008 & 2000



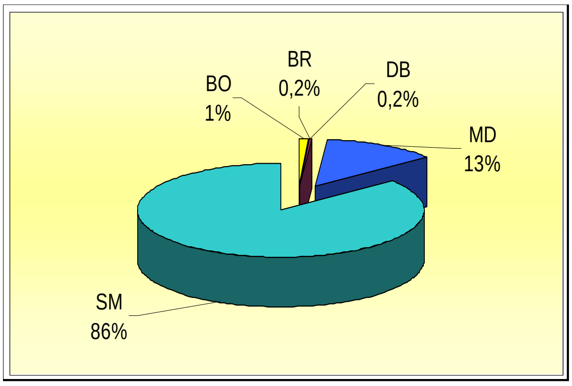


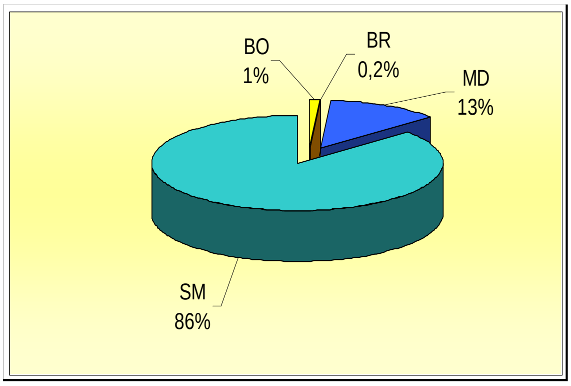
Circular plot 8, 2008 & 2000





Rectangular plot I, 2008 & 2000.

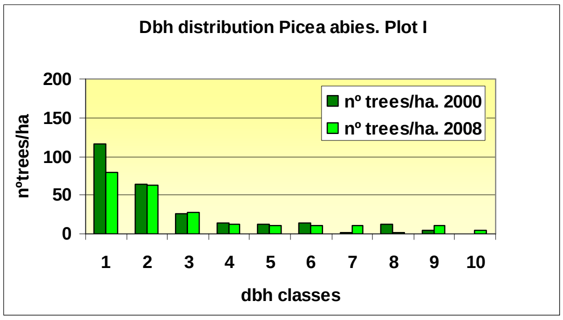


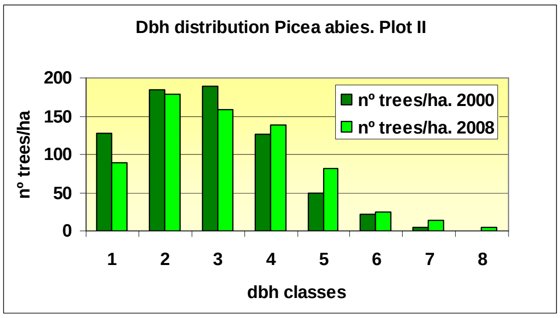


Rectangular plot II, 2008 & 2000.

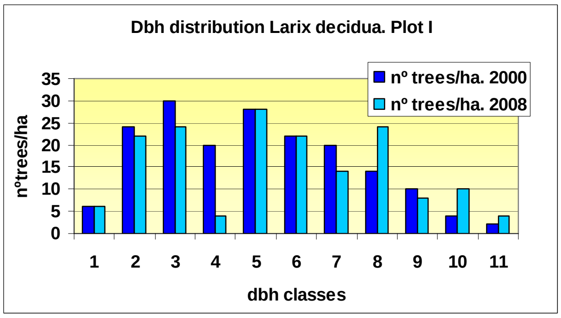
ANNEX 8

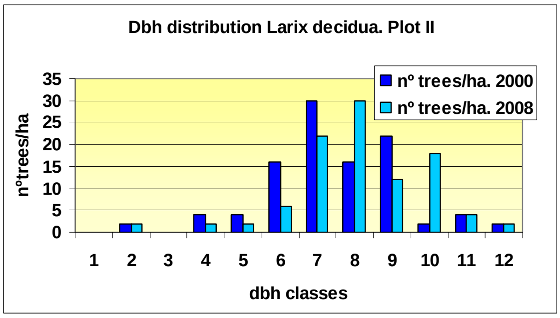
Dbh distribution for Norway spruce, European larch and Scots pine in Rectangular plot I and II



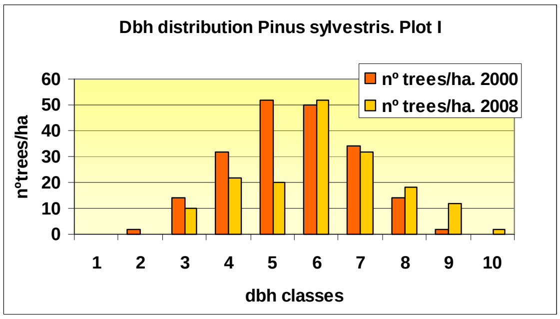


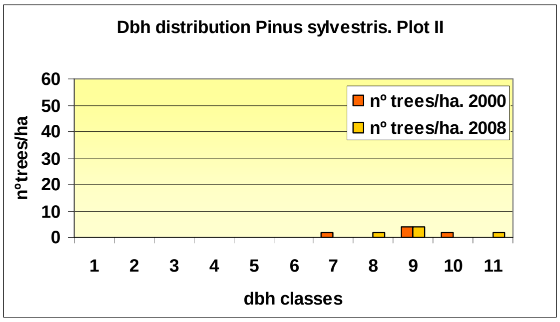
Graph 61 and 62 Dbh distribution *Picea abies* in Rectangular plot I & II.





Graph 63 and 64 Dbh distribution *Larix decidua* in Rectangular plot I & II.





Graph 65 and 66 Dbh distribution *Pinus sylvestris* in rectangular plot I & II.