

Spruce Monocultures in Central Europe – Problems and Prospects

Emil Klimo, Herbert Hager and Jiří Kulhavý (eds.)

EFI Proceedings No. 33, 2000



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Mendel University of Agriculture and Forestry,
Faculty of Forestry and Wood Technology, Brno



University of Agricultural Sciences, Vienna

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Foreword

In Central Europe, where Norway spruce (*Picea abies* Karst.) was artificially introduced in the 1850s, the widespread cultivation of the species outside its natural range has had both positive and negative effects. The original range of Norway spruce in Europe extends, in addition to the boreal zone, to the mountain massifs of the Alps, the Hercynian, Carpathians, Rhodope and Illyrian regions. Historical information proves that spruce has been found frequently also at the lower altitudes on sites with permanent high soil moisture content and even on sites characterized by a high degree of waterlogging or on peat soils. Relict spruce stands of lower altitudes appear to be an exception. The stands are considered to be the remnants of vegetation from the Atlanticum period of postglacial forest vegetation succession, which has remained on certain sites up to the present time.

On unsuitable sites, site specific pre-stress is loaded upon the tree species, so that they have only little additional resistance against other harmful abiotic and biotic agents. In the past decades, a new harmful factor has occurred – industrial air pollution.

The present conditions of forests in Central Europe, as viewed under the auspices of further negative factors, particularly potential global climatic change, have led towards enhanced efforts to reconstruct forests to more stable and resilient conditions. In many instances such conditions may be achieved by a close-to-nature forest composition, i.e. forests which correspond to the potential natural forest vegetation. In consequence, an all-European discussion on the new orientation of forestry from the viewpoint of its sustainable development and the preservation of a high biodiversity has been accepted as a basic strategic objective.

In order to assess the problem on an European scale, an international workshop titled “Spruce monocultures in Central Europe – Problems and Prospects” was organized by the Institute of Forest Ecology, Mendel University of Agriculture and Forestry, Brno in co-operation with European Forest Institute, the University of Agricultural Sciences, Vienna (BOKU, Vienna) and IUFRO Research Group 8.01 from June 22–25, 1998. Some 60 participants from 12 European countries participated in the workshop, where the main aim was to present the current knowledge and understanding of the functioning of spruce monoculture forest ecosystems, to identify the principal stress factors and the response of these forest ecosystems. Finally, possibilities for and the feasibility of the transformation of spruce monocultures into close-to-nature forest stands should be explored.

The introductory addresses were given by Mr. Oliva, Managing Director of Forests of the Czech Republic Co.; Dr. Vašíček, head manager, Ministry of Agriculture; Dr. Schmutzenhofer, IUFRO secretary; Prof. Hager, Vice-Rector of the University of Agricultural Sciences, Vienna; Prof. Spiecker, EFI; Assoc. Prof. Dr. Židek; Vice-Rector of Mendel University of Agriculture and Forestry, Brno; and Assoc. Prof. Dr. L. Slonek, Dean of the Faculty of Forestry and Wood Technology, Brno.

The aim of the workshop was not to provoke an ‘all-out war’ against spruce dominated forests in Central Europe, but to assess the present conditions and situation of such forests and to discuss the problems, dangers and starting points for the restoration and improvement of these forest ecosystems. Therefore, the problem of growth trends of spruce stands in Europe was evaluated by Prof. Spiecker who together with Dr. Kahle referred to the relationship between the primary production and climatic conditions.

An important point of view on the problem of spruce monocultures in Central Europe was presented by Professor Führer (BOKU Vienna), who could unfortunately not participate in the workshop in person, due to his illness. In his paper, he pointed out the difficult situation of professionals in the field of forest protection, who are asked to comment on possible scenarios concerning the perspectives of spruce monocultures (irrespective of the fact that climate changes may turn over all predictions). Forestry in Central Europe will not be able to abandon or transform all spruce monocultures at present, due to economic reasons. On the other hand, changing approaches and ideas in European forestry and economic aspects result in the conception of more intensive and multifunction-oriented forest management practices, also in spruce. Under certain conditions, which cannot be completely defined at present, spruce management intensification will be impossible due to insect outbreaks. Therefore methods for the assessment of the vulnerability of spruce stands with respect to disorders have to be developed. These should take into account both large-scale and small-scale site criteria as well as parameters which derive from forestry practices. The future forestry practices should be developed upon a knowledge base which gives stronger consideration to the aspects of risk. Sustainable management of spruce could be otherwise problematic.

A certain starting point can be found, according to Führer, in the construction of predisposition models for spruce stands, the main conception of which was presented by U. Nopp. By the means of this expert system, the evaluation of the actual predisposition can be obtained and, in addition, future predisposition conditions can be derived by the change of certain indicators.

A number of participants discussed the problem of spruce monoculture transformation into forest stands of higher biodiversity. The dominant opinion was that it would not be an easy and quick process. Possible global change in climate appears to be one of the main driving factors, which have to be considered (Tesař, MUAF Brno). Problems of forest revitalization in regions affected by air pollution were discussed under the special aspect of utilization of natural regeneration with pioneer species (Emmer, University of Amsterdam). Küssner (Tharandt) recommended completing the process of natural regeneration by active silvicultural practices, as e.g. beech planting.

The problem as a whole was summarized by Prof. Fanta (University of Amsterdam), who concluded: “At the present time, our consideration cannot be narrowed down solely to the conversion of spruce monocultures. New conceptions have to include the transformation of present forests into stable, sustainable forest ecosystems. It means that methods of plantation management have to be changed to methods of ecosystem management. At the same time, educational systems have to be changed on all levels of forestry schools. A new generation of foresters must be educated, which is able to work according to ecosystem principles. This is a new and challenging task for Central European forestry of the 21st century.”

These proceedings do not provide a full set of instructions for forecasting the future of spruce monocultures in Central Europe, but rather try to provoke a discussion on this problem. The discussion should continue and it is gratifying to see that new research projects on this subject appear in Central European several countries.

During the excursion following the workshop, the participants had an opportunity to get acquainted with the results of the Rájec research project (in the Dražanská Upland), which investigates the functioning of this spruce monoculture ecosystem. The research project is

conducted by the Institute of Forest Ecology, Mendel University of Agriculture and Forestry, Brno. The participants of the field trip had also the chance to obtain information on the transformation of spruce monocultures into close-to-nature stands in the Křtiny Training Forest Enterprise 'Masaryk Forest' (TFE).

We would like to thank Dr. J. Martinek, director of the TFE and Dr. J. Truhlář for organizing the excursion. We also highly appreciate the assistance of Brita Pajari, EFI, in organising the workshop and Minna Korhonen, EFI, in preparing these proceedings.

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Executive summary

In the final discussion of the workshop, it was stated that in comparison with the present distribution of Norway spruce in Central Europe, its original natural range was considerably smaller. The species occurred in mountain massifs of the Alpine, Hercynian and Carpathian regions. Its present distribution originates from the reforestation of extensive clear-cut areas carried out in the second half of the 18th and the beginning of the 19th centuries in the zone of fir/beech and beech plant communities and also in the oak/beech and oak zones.

The history of spruce monoculture distribution is also similar in the other Central European countries where the intensive economic development increased the wood consumption. An effort to achieve maximum financial benefits resulted in the use of species with well-processable and, therefore, marketable wood, i.e. particularly Norway spruce and Scots pine.

Due to the origin of extensive spruce monocultures, new problems and stress conditions occurred: the changes in the root system; distribution within the soil profile; changes in humus forms; increasing nitrogen deficit; soil acidification; decreasing biodiversity; negative effects of snow, wind and ice; effects of insect pests; effects of air pollution; and effects of clear cutting.

In the course of the workshop, many of the problems mentioned above were discussed. It was recommended to continue the analysis of restoration to forests characterized by a higher ecological stability, productivity and biodiversity. It was also recommended to organize further scientific seminars and workshops, as well as experiments in various site conditions, and establish a permanent exchange of information among the scientific institutions in Europe.

Growth of Norway Spruce (*Picea abies* [L.] Karst.) under Changing Environmental Conditions in Europe

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Abstract

Norway spruce is one of the most common and economically most important tree species in Northern and Central Europe. Its area has expanded far beyond the limits of its natural range. Causes and consequences of this expansion are described. Changes in climatic conditions such as changes in the frequency and intensity of extreme warm and dry weather conditions, increased atmospheric depositions and elevated CO₂ are discussed as possible causes for changing growth rates and mortality. Consequences of increased average stand volume and age, as well as stand mixture on forest productivity and stability, are considered.

In order to reduce ecological and economic risks on a European scale, it is of great importance to know on which sites Norway spruce stands are most susceptible to climatic fluctuations and other environmental changes. Knowledge about the economic demands of tree species as well as knowledge about the changing needs of society are important for sustainable forest ecosystem management.

Keywords: Norway spruce, forest growth, European forests, environmental changes, natural range

1. The range of Norway spruce in Europe

1.1 Natural range

The natural range of Norway spruce before major human influences covered a wide area in Europe, from the tree line in the boreal zone to Greece and from France to the eastern edge of Europe to the Urals (Schmidt-Vogt 1977, see Figure 1). Due to this wide distribution and the considerable differentiation in site specific provenances, it is not possible to define very distinct site requirements of this species. Natural spruce forest societies seldom can be

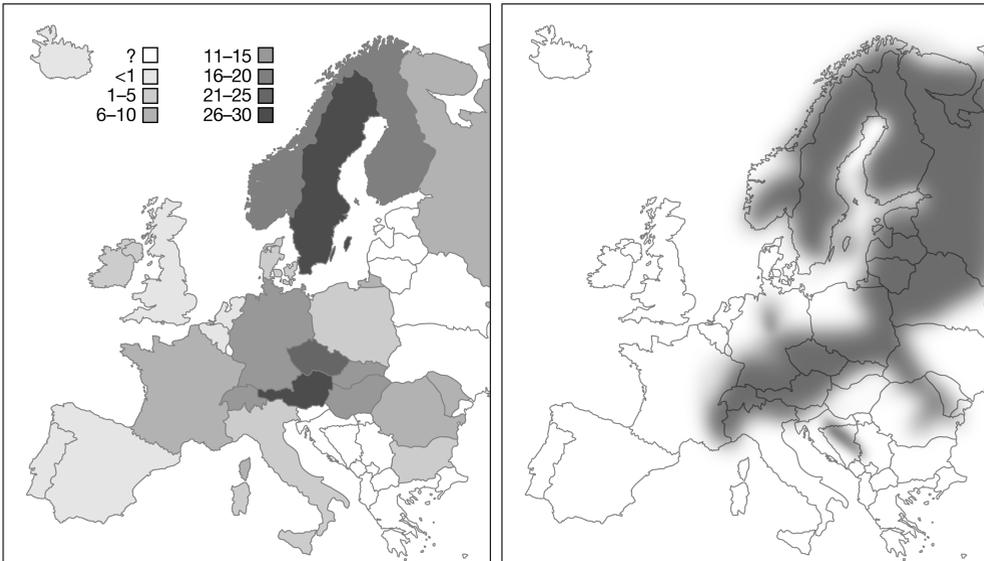


Figure 1. Actual distribution and natural range (shaded area) of Norway spruce in Europe. The actual distribution of Norway spruce is much wider than its natural range.

regarded as mono species forests. Many naturally regenerated stands develop into mixed stands. Natural pure stands can be found only on particular, extreme sites (Mitscherlich 1978; Mielikäinen 1980). Species composition may change during the development of the stand due to growth dynamics and differences in growth response to environmental factors.

Some of the major factors limiting the natural range according to Schmidt-Vogt (1977) are:

- competition with other species like beech and oak,
- history of migration modified by mountain barriers, edaphic factors, and insects, which led to an incomplete migration,
- climatic conditions such as drought periods in summer, frost dryness and late frost, which may also cause germination problems such as in western Norway.

Indications for requirements related to water supply, which is an important limiting factor in the summer, are that at border zones of its natural range Norway spruce is mainly growing on moist northern slopes, when summer precipitation is relatively high. In these zones, the percentage of Norway spruce is increasing with elevation or in river valleys, as well as towards less sun exposed slopes.

1.2 The actual range of Norway spruce in Europe

Norway spruce, today, is one of the most common and economically most important tree species in Europe. Its area has expanded far beyond the limits of its natural range. The highest coverage of Norway spruce, with more than 25% of the total land area, is found in Sweden and Austria where it covers more than 40% of the forest area. Both countries are situated well within the natural range of Norway spruce. A rather high coverage of Norway spruce of 15–25% of the total land area and more than 25% of the forest land, can be found in Finland, Norway, Czech Republic and Slovakia. In Switzerland and Germany Norway

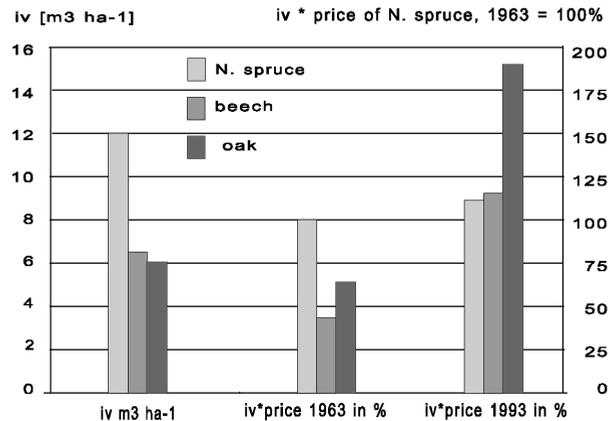


Figure 2. Wood growth relations and value growth relations between Norway spruce, beech and oak. The value relations (based on prices in southwestern Germany) have changed considerably over time.

spruce covers 10–15% of the total land and more than 30% of the forest land. Here spruce has often been planted within its natural range in the mountains, but also outside of it in hilly regions and lowlands.

The western border of the Norway spruce area has moved considerably towards the west. Substantial areas of Norway spruce beyond its natural range can be found in Belgium, Luxembourg, the Netherlands, in Denmark, where Norway spruce covers about half of the 10 % of forest land, in Great Britain, Ireland, most parts of France and the most western parts of Norway.

The highest growth of Norway spruce is often found outside of its natural range (Schmidt-Vogt 1977). Although Norway spruce is said to be a species adapted to continental climates, warm winters do not seem to have a negative impact; long growth seasons may even increase the growth rate.

The reasons for the artificial expansion of Norway spruce are:

- high value production,
- low cost of planting, including low need for repair planting and relatively low damage due to deer browsing and
- high level of knowledge about Norway spruce.

In recent decades, however, some disadvantages have become more evident under certain conditions, including the risk of increased mortality under drought conditions, relatively high susceptibility to snow, ice and storms with rather high salvage cuttings, as well as susceptibility to fungi. In addition, the economic conditions of broadleaved species have improved and society often seems to have a preference for broadleaved trees.

2. Consequences of the artificial expansion of the range of Norway spruce

2.1 Has the growth rate of Norway spruce changed over time?

During the first half of this century the question of whether site productivity will be affected by growing Norway spruce in consecutive generations, was already being asked. According

to former investigations in northeastern Germany, the growth of Norway spruce decreased in the second generation (Wiedemann 1925), the spruce stands described by Wiedemann were growing on dry sites outside the natural range. It was believed that Norway spruce growing in consecutive generations impoverished soil productivity (Wiedemann 1925; Krauss et al. 1939, cit. in Holmsgaard et al. 1961).

In a later German investigation, Moosmayer (1957) could find no decrease in productivity when comparing two consecutive generations of Norway spruce, on a few sites the productivity even increased slightly in the second generation. Genssler (1959) investigated the effects of several consecutive Norway spruce generations from a soil scientist's point of view. The soil parameters and ground vegetation of stands with several consecutive Norway spruce generations were compared with broadleaved trees. In addition, he compared natural Norway spruce stands with planted pure Norway spruce stands. The comparison with broadleaved trees showed that biological soil conditions were affected by growing Norway spruce in consecutive generations, raw humus accumulation was the most visible sign of the resultant biological soil impoverishment. Furthermore, the spruce humus was more acidic and contained less nutrients than that of broadleaved trees, the composition of the spruce raw humus depended on the fertility of the soil. With regard to podzolization, it was found that there was no additional visible podzolization effect by growing Norway spruce for up to 250 years in the same stand as compared with beech. The decreased number of ground species was a visible sign of acidification under spruce stands. The natural spruce stands had their natural species communities which did not exist in secondary spruce stands because of other climatic conditions. After growth comparisons, Genssler concluded that in spite of the soil impoverishment Norway spruce stands were able to produce a sustainable yield.

As the area of Norway spruce stands has enlarged outside of its natural range in Denmark, the interest in associated changes of site productivity has also increased. Holmsgaard et al. (1961) compared the first, second and third generation of Norway spruce, studying not only the growth but also soil parameters and fungal diseases (*Fomes annosus*, *Armillaria mellea*). They found no significant change in the growth rates between stand generations. Furthermore, in the younger stands studied, they found that *Fomes annosus* was more common in the second generation of spruce than in the first, whereas these findings could not be found for older stands. In the case of *Armillaria mellea*, no differences between the generations could be found.

Recent investigations on the effects of consecutive Norway spruce generations consistently showed accelerated growth in the subsequent generation. Yields of Norway spruce in two consecutive generations were investigated in southwestern Sweden by Eriksson and Johansson (1993). The plots were located in a homogenous area of about 100 ha; all first generation stands were established after clearcutting broadleaved stands. In total, 22 observation units in first-generation stands were compared with 17 units in second-generation stands. Comparative analysis showed that in first-generation stands the current annual volume increment often culminated at a stand age of 60–70 years and in second-generation stands at a stand age of 30–35 years. On average, the total volume yield from 0–40 years of age in the second generation stand was 40% higher than that in the first generation stand. Furthermore, dominant tree height at a stand age of 40 years was about 20% higher in the second generation. The authors concluded that the accelerated growth might be due to changes in site productivity probably affected by former land use and an increase in nitrogen deposition.

Long-term plot measurement data of the past, some dating back to the last century, have been processed and compared with present data in Germany by Kenk et al. (1991). The results show that the present growth of the investigated Norway spruce stands was never below that of the previous Norway spruce generations (Figure 3). On poorer sites, growth during the last hundred years increased more than on the more fertile sites.

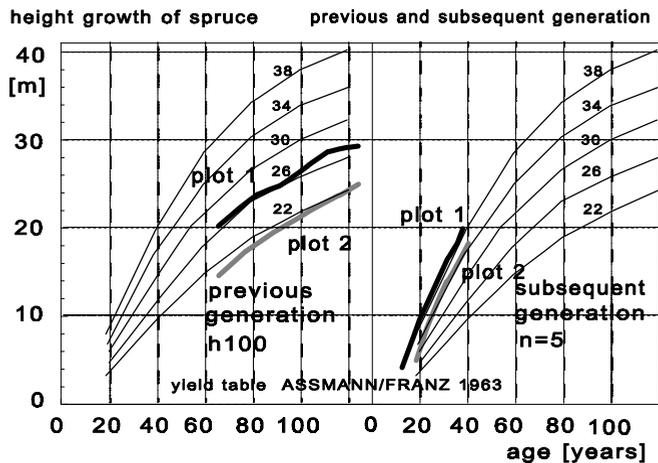


Figure 3. Height growth of two consecutive Norway spruce generations on the same plot. Growth was accelerated in the second generation.

Finally, in a recent investigation, Unthelm (1996) compared the growth of Norway spruce cohortes with different germination times on the same site in Germany. He found a considerable accelerating height growth during the last 50 years indicating a volume growth increase of 50 %. In the publication Spiecker et al. (1996), on growth trends in European forests, Norway spruce growth and its changes are described by 13 papers. No trend was found in Finnish Lapland, Russian Karelia, Southern and Central Finland, and Norway. However, some of the studied stands in the southernmost part of the area, close to the city of Helsinki showed signs of accelerated height growth during the last 40 years. An increasing growth trend was found in the neighborhood of St. Petersburg, Russia, and in several studies in Southern and Central Sweden (Elfving et al. 1996; Mielikäinen and Sennov 1996; Eriksson and Karlsson 1996). Previously, an increasing trend in the height and volume development of two successive Norway spruce generations had been reported by Eriksson and Johansson (1993). As many as ten studies on Norway spruce in Central and Western Europe conclude that Norway spruce growth, in general, has been accelerating in recent decades. A few exceptions, with significant reduction in volume growth, have been reported by Pretzsch (1996) from some forests located at high elevations of the German Middle Mountains, and the Alps. Other investigations in the Middle Mountains of Germany and France have shown an increase in forest growth (Kenk et al. 1991; Badeau et al. 1996). Although growth trends vary with species, location and site, there is clear evidence that in general, height growth, as well as volume growth, have increased in recent decades. The results derived from long-term observations on permanent plots on tree analysis are supported by inventory results (Köhl 1996; Pretzsch 1996; Schadauer 1996; Wenk and Vogel 1996), which are representative of large areas, but cover only shorter observation periods. In recent decades, similar time specific growth fluctuations were observed in Switzerland, France and southwestern Germany; showing a decrease in growth at the end of the 1940s and in the 1970s and an increase in the 1980s. There are indications that these growth variations were caused, at least to some extent, by climatic factors (Kahle 1994; Bräker 1996; Schneider and Hartmann 1996).

Although the methods applied varied according to the data available, most studies showed the same general trend, that the growth of Norway spruce is accelerating on many sites.

Possible causes for these changes could be any growth influencing factors that have changed with time. However, there is still a distinct lack of knowledge about the causes of this accelerating growth (Spiecker et al. 1996). Five possible causes can be identified:

1) Land use history

In many regions of Europe, the former use of forests, not only for wood production, but for litter raking, pasturing and tree harvesting, have a long-term effect on soil conditions because of large-scale nutrient losses. Furthermore, former agricultural land was often abandoned because of poor site productivity and marginal return rates, which, in some cases have been caused by excessive utilization. Successive recovery of the soil may have increased site productivity in recent decades. In addition, soil preparation is used especially in Northern Europe, in order to create better conditions for forest regeneration. Intensive harvesting, including removal of forest biomass, may potentially affect productivity. It is generally believed that traditional stemwood harvesting does not lead to the impoverishment of soil because the nutrient content of wood is rather low (Mälkönen 1976). In field experiments with slash removal, Staaf and Olsson (1991) found that soil acidity had increased in plots where slash had been removed and that removal of all slash caused higher acidity than the removal of slash except needles. According to Kreuzer (1979), the nutrient losses by intensive whole-tree utilization are similar to that of litter utilization and may affect production conditions on poor sites.

2) Forest management

Forest management practices such as regeneration methods, tending, thinning and harvesting regimes have an effect on site productivity. The growth of young stands may be strongly influenced by soil preparation, selection of species and provenances, quality of plant material or weed control. Intensified thinning may have some effect on site productivity by altering nutrient cycling and reducing competition for light, nutrients and water. Species composition affect root systems, litter quality and nutrient storage.

Fertilizers and lime have been applied to parts of European forests for many decades in order to increase site productivity and to overcome some effects of site degradation caused by former land use. Drainage plays an important role in the peatland forestry of Northern Europe.

3) Natural disturbances and climate

Natural disturbances play an important role in forest growth. Fire, drought, storms, snow, avalanches or pests cause interventions in the natural succession and change the driving factors of forest growth, such as competition for light, nutrients, water and tree species composition. Furthermore, they may change tree competition and may have an impact on selection processes. Damage caused by game, for instance through grazing, mainly affects the growth and survival of young trees and may result in a shift of species and age distribution, thus delaying stand establishment and tree growth.

Growth response to climatic influences varies with species, provenance, competition status and site conditions. Changes in average climatic conditions such as air temperature affect the length of the growing season and influence site productivity. A positive correlation between air temperature increase and plant growth seems possible. Extreme events, such as late spring frosts, summer droughts, unusual cold and wet or hot and dry summers, as well as extreme and abrupt temperature changes, may reduce growth. Extreme climatic events not only have a direct effect on trees, but also on insects or microbial pathogens, on disturbances such as fire or windthrow, and on biological as well as chemical and physical processes in the soil. Correlations of these factors with growth have been reported in many parts of Europe. Droughts generally cause growth decrease. For example, in Central Europe such a recession

in growth due to drought occurred in the late 1940s. The drought that attracted the most attention occurred in the mid 1970s at the time of the initial discussion on defoliation and forest dieback. The long-lasting after-effects of such extreme events further complicate the detection of possible causes of changes in site productivity.

4) *CO₂ increase*

The effect of predicted global warming on tree growth has not yet been entirely investigated. Badeau et al. (1996) found in their investigations at high elevations that trees growing outside the range of forest management and that are exposed to low nitrogen deposition showed a clear positive growth trend. This may have been caused by the increased content of CO₂ in the atmosphere but also by other changes in environmental conditions. An increase in CO₂ concentration may stimulate photosynthesis, reduce respiration and relieve water and low-light stress. However, because the growth response is modified by species and site, it is difficult to draw general conclusions regarding its effects on forest growth.

5) *Nitrogen deposition*

The increased nitrogen deposition is regarded as a further probable growth promoting factor that has arisen during the last decades. The positive growth trends observed in many parts of Europe may be at least partially caused by increased nitrogen depositions. The fact that no trend was detected in some parts of Northern Europe may be explained by low nitrogen deposition.

Growth response to the five causes described above is modified by species and site. It is difficult to draw general conclusions regarding the causes and their effects on forest growth. It is possible that one cause has changed growth, however, it is more likely that several different causes have influenced forest growth simultaneously and that their combined effects may even have changed individual effects. These factor combinations may differ at various locations but they may also have similar effects on growth.

2.2 Do climate fluctuations have an effect on Norway spruce growth and mortality?

Climate changes as a result of the “greenhouse effect” are believed to be a global environmental threat. The exploitation of forests and other natural resources, the accumulation of anthropogenic emissions and the increasing amount of carbon dioxide and other greenhouse gases in the atmosphere might damage the functions of ecosystems and decrease biodiversity. Climate changes affect the competition of individual tree species. This may cause major disturbances in natural as well as in managed ecosystems, also affecting nutrient cycling. Trends in forest productivity and mortality are generally associated with climatic variation, particularly with variation in precipitation. High air temperature and low precipitation during growth seasons reduced growth rates and increased tree mortality even at higher altitudes in the Black Forest where the average precipitation is high and the average temperature is relatively low (Spiecker 1995b).

There are indications that in some regions in Central Europe Norway spruce is showing an increased sensitivity to climate variation (Kahle 1994). Changes in the frequency and intensity of extremely warm and dry climatic conditions during the last decades and effects of increased atmospheric depositions have been discussed as possible causes for this observation. Since there is a general tendency to increase the average stand volume and average age of trees in Europe, it is of great interest to know the effects of density and age on growth, sensitivity of growth, and mortality.

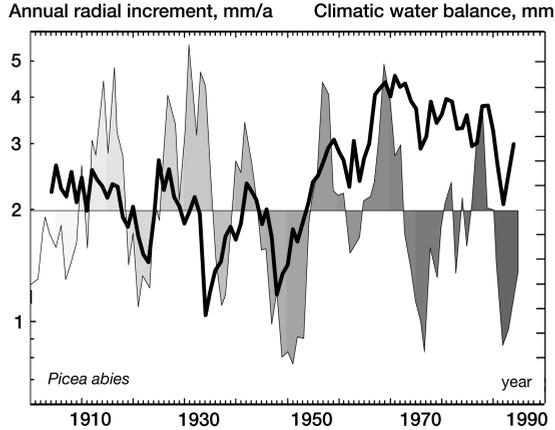


Figure 4. Annual radial increment and climatic water balance. The climatic water balance is calculated based on the method of Thornthwaite and Mather (1955). Here the deviation of the water balance during May to September of the five preceding years from the long-term average (1900–1990) is plotted over time. A correlation with radial increment of Norway spruce in the Black Forest is evident.

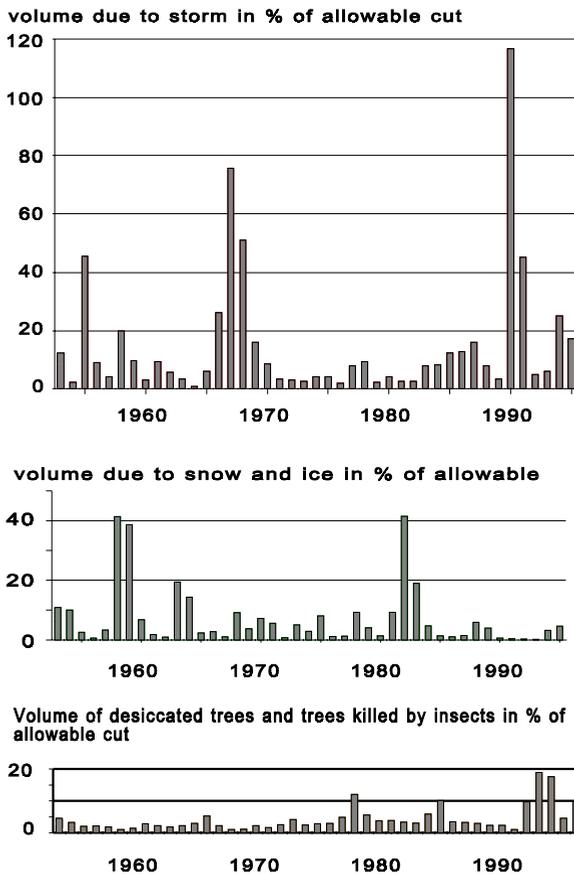


Figure 5. Salvage cuttings due to storm, snow and ice as well as desiccation and insects. The cutting volume is expressed in percent of the allowable cut. The annual variation is high.

Norway spruce stands and their development are not only affected by site conditions, but also by effects of fire, storm, snow, insects, desiccation, avalanches, pests and pollutants. The occurrences of which are changing with time and are unable to be predicted with any certainty. They do, however, have a major impact on stand development and cause considerable economic risks.

In central Europe, the two most important influences are storm and snow. Figure 5 shows the mortality due to storm, snow and ice as well as insects, as a percentage of the allowable cut during the last 40 years in the public forests of the Black Forest. Norway spruce covers about 50% and silver fir about 20% of this forest, which has a total size of 240,000 ha (Ministerium Ländlicher Raum). Most of these fellings include Norway spruce. The annual variation of the salvage cuttings is rather high.

The volume of desiccated trees and trees killed by insects is of special interest in relation to the 'forest decline' discussion. As compared to fellings due to storm and snow the volume of desiccated trees and trees killed by insects is generally rather low. Growth variation and mortality due to desiccation and insect damage are closely related to climatic fluctuations and especially to drought conditions (Figure 6).

Impacts of climatic fluctuations on forest have often been underestimated in the past. It has been shown that growth rates and mortality are closely related to climatic stresses, especially drought.

2.3 The effect of stand mixture on Norway spruce growth

Mixed stands have been found to be more resistant to various forms of damage, as they are more diverse in their fauna and flora composition, and more attractive aesthetically than pure, single-species stands. Broadleaved trees are supposed to improve the conditions for growth by making the soil less acidic through their litter. Stand composition affects litter and humus quality and abiotic site factors like soil physics and chemistry. The pH of the soil is generally lower in conifer than in broadleaved stands and conifer litter is in general less hospitable for decomposers (Mitchell and Kirby 1989). However, the changes resulting from forest management, for example site preparation, fertilization, thinning and felling, probably are larger than those caused by tree species. Liljelund et al. (1986) showed in a literature review that a replacement of deciduous forests by conifers induces soil acidification and that new conifer plantations on formerly open land have similar effects. Remarkable losses of nitrogen

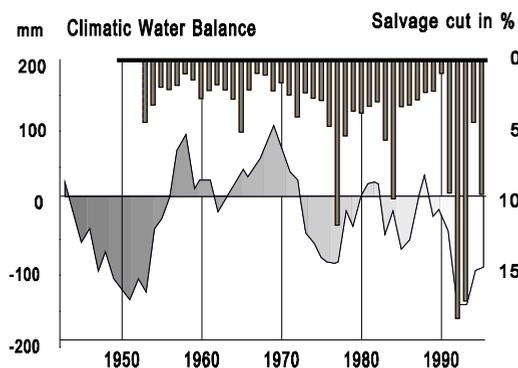


Figure 6. Salvage cuttings of desiccated trees and trees killed by fungi and insects in % of allowable cut. The annual variation correlates with the climatic water balance (see Figure 4).

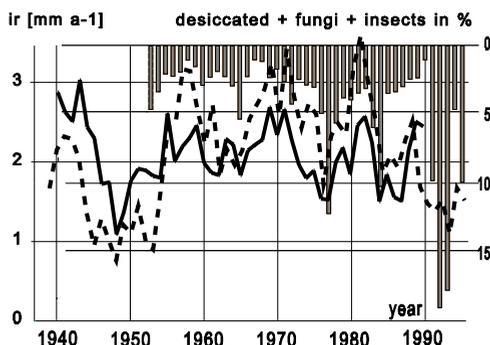


Figure 7. Salvage cuttings of desiccated trees and trees killed by fungi and insects as a % of the allowable cut and annual variation of radial growth (ir). Growth and mortality are correlated.

from the ecosystem have been noticed as a result of the change from deciduous tree species to Norway spruce in Germany (Kreutzer 1981; Feger 1993).

In Sweden, Jonsson (1961) found that the growth of Norway spruce was positively influenced by the species mixture when compared with pure stands. The diameter increment of Norway spruce increased with higher proportions of birch in their immediate neighborhood. In addition, in later Swedish growth and yield studies Norway spruce stands, which were developed under birch shelter, showed a higher production compared with pure Norway spruce stands (Tham 1988; Burkhart and Tham 1992). Furthermore, it was found in Finnish investigations, that mixed stands of pine and spruce on sites of medium fertility grew better (Pukkala et al. 1994) and were more profitable (Vettenranta 1996) than pure stands of pine or spruce. Vettenranta (1996) simulated around 100 different treatment schedules during the rotation in a naturally regenerated even-aged stand of Norway spruce and Scots pine. In the optimum treatment program, the proportion of pines was decreased by half of the basal area in the first thinning and by the end of the rotation to about one third. When thinning from above, the proportion of pines should be maintained at a slightly higher level.

Mielikäinen (1985) investigated the effect of different treatments on the total growth and saw timber production of naturally regenerated spruce-birch mixed stands. The growth of *Betula pendula* in spruce-birch mixed stands was faster, the smaller its proportion to the stand volume. The competing effect of a high proportion of *B. pendula* reduced the volume growth of Norway spruce whereas the proportion of *B. pubescens* had no effect on the growth of spruce. A low proportion (25%) of *B. pendula* in a spruce stand with a rotation of 80–90 years was calculated to result in an increase of 3–5% in volume growth compared to the alternative, where all birches were removed in the first thinning. The saw timber production and the stumpage revenue were 6–11% higher in mixed stands than in pure Norway spruce stands, provided no reduction of saw timber production due to technical quality is assumed.

3. Management implications

3.1 Regeneration and conversion strategies

European wood resources have increased constantly since the 1950s and are greater now than at any time during the last 200–300 years (Kuusela 1994). The average age of trees is also

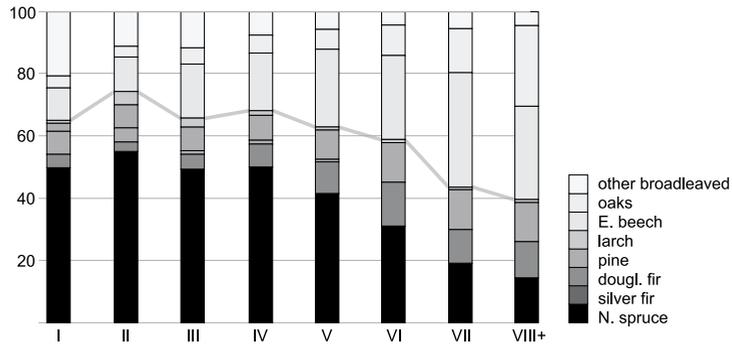


Figure 8. Age class distribution of Norway spruce in Baden-Württemberg (Southwest Germany). The younger stands show the highest percentage of Norway spruce.

continuously increasing; which signifies reduced vitality of the forests and increased storm risks (Spiecker 1995a). This development is, according to Kuusela (1994), a result of the management regimes used in the 19th and 20th centuries. It has also been affected by the decreasing importance of commodity functions of forests, rapid changes in energy sources, changes in production and traffic technologies, as well as changes in the use of wood for construction work. In addition, as a result of rising living standards, protective, environmental, social and cultural functions became more important. These changes, in turn, have an effect on the objectives of forest management.

The discussion about the future of the forest sector has never been more intensive and politically-orientated than it is today. Principles of sustainable forest management, forest laws, directives and regulations are constantly being reviewed. Within this, healthy ecosystems with rich biodiversity are recognized as being essential goals. At the Ministerial Conference held in Helsinki, Finland, in 1995, resolutions concerning the protection of European forests were passed, providing a sound basis for sustainable forest management. Many countries are currently revising their forestry policy in order to accommodate principles of sustainable forest management. Ecological concerns are demanding higher biodiversity, including genetic diversity and more 'close to nature forestry'. There is an emotional aversion to monocultures, especially conifer monocultures. In addition, changes in economic conditions favor broadleaved species in some parts of Europe.

Most forests in Europe are man-made; larger areas of untouched natural forests exist mainly in the boreal coniferous zone and some in high mountain areas. It is recommended that parts of the forests should be reserved for different conservation purposes. In addition to this special conservation area where any forestry activity is prohibited, there may exist some small valuable areas in managed forests worthy of conservation. Rules of sustainable forest management in Europe have been described by Stokland and Framstad 1991; Hoen and Winther 1993; Kangas and Kuusipalo 1993; Hannelius 1994; Parviainen and Seppänen 1994; Larsen 1995; Makkonen-Spiecker 1996; v. Teuffel 1996. From this, it can be concluded that the most preferable method of regeneration is natural regeneration, the use of herbicides and pesticides should generally not be permitted. The proportion of broadleaved trees should be increased together with other indigenous tree species in consideration of the site's biological properties. This will result in an increase in the rate of mixed forest stands.

A conversion of Norway spruce forests on sites where this species is not adapted to stable more natural forests in the foreseeable future is only possible through active forest management. The age composition illustrated in Figure 8, shows that the percentage of

Norway spruce in younger age classes in the state of Baden-Württemberg is especially high (Forstliche Versuchs- und Forschungsanstalt Ba.-Wü. 1993).

A similar situation can be found in many other European countries. This implies that the percentage of Norway spruce will continue to increase in the near future if species distribution is not actively changed by regeneration, tending and thinning. In Germany, for example, large forested areas were clearcut for reparation payments soon after World War II and were often afforested with highly productive even-aged forests. In recent decades, the negative impact of these activities on the biodiversity of stands encouraged the conversion of stands to so-called close to nature forest types. To convert some of the Norway spruce forests without cutting premature trees will take considerably longer than one century.

Regeneration methods have an effect on both the composition and the structure of the subsequent stand. The outcome of natural regeneration is largely influenced by factors such as tree species, seed crop, weather conditions and deer population. The effect of the regeneration method on the stand structure was examined by Uuttera and Maltamo (1995) on different sites in the southeastern part of North Karelia, Finland and in the southwestern part of the Republic of Karelia, Russian Federation. It was shown that the stand structure of artificially regenerated forests resulted in less variation when compared with the naturally regenerated stands. Differences between the regeneration methods became clearer as the forest site fertility increased. The authors regarded the variation of the stand structure as being an essential factor for the potential biodiversity of the stand, also at its young vegetation succession stage. For the transition from forests not suited to the site, where appropriate species do not occur naturally into more stable close to nature forests artificial regeneration is needed. The establishment of new tree crops, by natural or artificial means, must follow regeneration fellings, using site adapted tree species. The management strategies, in general, must conform with the prevailing environmental conditions. The forests have to be viewed as ecosystems and the forest management as ecosystem management, focused on creating and preserving a high biodiversity. Forests are major sinks in carbon cycling and their sustained management is of immediate economic and ecologic importance. Therefore, weakening the stability of the forest ecosystem will also reduce the economic and social benefits of forests.

3.2 Tending and thinning

If the growth of the forests is higher than the cuttings, as is the case in Europe today, the forests will become dense and over-aged and their resistance to diseases and natural risks will be weakened. Dense conifer stands also offer less space for light-demanding tree species and ground vegetation, challenging their existence and, therefore, reducing biodiversity (Mitchell and Kirby 1989). In this situation, a conversion to stable, more natural forests is only possible through active forest management, which includes the necessity to cut timber. Without intervention, forest health will decline (Spiecker 1995a). The tending of young stands aims at creating a mixed stand structure.

Long-term site productivity can be maintained or even increased under intensive forest management by means of efficient, sustained-yield forestry practices, but not by exploitative practices. The efficient, sustained-yield forestry practices of today use methods which operate along the lines of the natural development of the forest ecosystems. Thinning operations are necessary in order to avoid increment losses resulting from overstocking and mortality and to preserve the vitality and diversity of the forests. These new demands on forest management require early intensive thinnings, preference for mixed forests and no substantial increase in the mean age of the trees.

Competition control requires site adjusted tending and thinning methods because diverse species may react differently to site conditions. Furthermore, changes in site productivity may alter competition between trees. Mixed stand structures can be maintained and improved by thinning. An adjusted thinning regime is also required to counterbalance accelerating growth rates, otherwise an increase in growing stock will continue and the stability of forests will be reduced. Thinning practices result in an increased total harvest and early thinnings, in particular, increases the proportion of large-sized timber in the total harvest volume.

3.3 The age of regeneration fellings

According to national forest statistics in several European countries (e.g. Kuusela 1994), the annual drain – thinnings and final cuttings – has remained at the same level during the last decades, the wood production being 40–50% higher than the harvest cuttings. Only in exceptional cases has removal reached the level of wood volume increment. This indicates that stand density is increasing; the mean age of forests is rising. A high standing volume of mature trees provides not only an increased potential for wood supply but it also causes a risk for the health of these trees. The resistance of dense and over-aged forests against diseases and against natural risks like storm and snow breakage is reduced. Consequently, according to German forest assessments, the percentage of strongly declining trees in the age class of trees over 60 years, is nearly three times higher than in the age class of trees under 60 years.

An increasing growth trend may influence the rotation age. Fast growing trees reach the desired dimensions earlier than before; the economically optimal rotation age may be lowered. According to Eriksson and Johansson (1993), an increasing growth trend may also influence the growth rhythm of trees. Trees may grow faster when they are young, but may reach the culmination of current annual increment earlier than in former generations. This effect may not be visible in today's forests because increased site productivity also accelerates the growth of old trees (Spiecker et al. 1996). Increased biological growth improves the economics of forestry, which might make European wood more competitive (Prins 1996). If increased site productivity would make it possible to reduce wood costs, European removals would take a larger market share, reducing the rise in imports from other regions.

There will be a need to carefully revise the tools of forest management, notably yield tables and long-term management plans. Clearcuttings as a regular regeneration method should be offset with other methods where appropriate. Nest trees for birds and dying trees should be left standing or lying on the ground as substrate for organisms which favor decaying wood material.

4. Conclusions

Norway spruce is one of the most common and economically most important tree species in Europe. Its growth has accelerated in recent decades on many European sites. Climatic fluctuations, especially extreme events like storm, snow and ice, as well as drought periods, have an impact on the growth rates and mortality of Norway spruce. Changes in the frequency and intensity of extremely warm and dry climatic conditions and increased atmospheric depositions have an impact on the susceptibility to drought and other stressors. Pure Norway spruce stands outside their natural range are especially susceptible to these influences.

On various sites, a change from monocultures to mixed stands is advisable from an ecological and an economic point of view. As there is a tendency towards increases in

average standing volume and average age of trees in Europe, it is of great interest to know the effects of density and age on growth, diversity, and mortality. In order to reduce risks on a European scale, it is of great economic and ecological importance to know on which sites Norway spruce stands are most susceptible to climatic fluctuations and other stressors. In those areas, a change in species composition is most urgent.

Sustainable forest management in a changing environment is the key question in present European forestry. Knowledge about forest growth reactions and growth trends is just one important aspect of sustainable forest ecosystem management. It also helps forest production to provide income to the forest sector, to provide renewable raw material for the wood industry and to provide goods and services for people. Scientifically sound information on forest management has increased. Stressors and their effects on ecosystems have been identified and appropriate forest management systems have been developed. This information needs to be compiled and disseminated in a proper way.

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The Impact of Air Pollution and Strategies for Spruce Monoculture Conversion in Central Europe

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Abstract

Spruce monocultures must also be coped with by future generations of foresters. The methods of transformation will be neither ambiguous nor direct as it is impossible to define them clearly. The level of acid air pollution has been decreasing recently in Central Europe. However, it would be inexcusable to underestimate this factor for various reasons. The remedy of forest damage lags behind the trend of decreasing air pollution level. Consequently, disturbed forest stands may respond to any future air pollution episode by new losses.

Keywords: Norway spruce, monocultures, stands conversion, air pollution, climate changes

Introduction

Stand conversion is the essential change of stand species composition through premature or accelerated regeneration into stands with a different tree species composition.

As a special silvicultural system of forest management they are substantiated at places where the existing spruce monocultures fail at, being unproductive, are not capable of fulfilling protective and social functions and their very existence is against the principles of sustainable forestry, since they endanger the forest ecosystem foundations, particularly by affecting the soil. The ideas about the conversions, their necessity, degree and extent have been developing in dependence on the degree of knowledge and on goals of forest policy. Silviculturists faced this problem and tried to do their best with the help of scientists for almost one hundred years, however results obtained until now were insufficient (Schmidt-Vogt 1991). The conversions of spruce monocultures widely applied after the expansion of forest typology in the 1950s and 1960s were conducted by efforts aimed at increasing forest

productivity and stability and hence ensuring economic safety. The issue of spruce monoculture conversions entered a considerably new level with the ever more pressing problem of air pollution.

This paper aims to summarize possible approaches to the management of the affected forest according to the hitherto forestry empiricism. Should the affected ecosystems be managed effectively, the management must take environmental principles into account, i.e. the principles of ecologically-based silviculture or forest management – ecotechniques. By setting up this definition, we find ourselves somewhere at a crossroads of all aspects of the issue, i.e. in the theory of silviculture. In this position, silviculture provides backgrounds for the general decision-making in forest policy, is responsible for the practical solution of the issue and on the other hand, also stimulates forest science to reveal the so-far unclarified phenomena.

Air pollution as an additional site factor

Air pollution affects the biosphere at all levels of live matter organization, from the level of cells through to the level of terrestrial and water ecosystems, up to landscape ecosystems. We have to speak of this global level of impact because Norway spruce, a prevailing species in Central Europe, is an especially sensitive tree species to acid type air pollution. This means that the consequences of air pollution affecting the forest are becoming a general environmental problem. They are, therefore, an object of concern for world governmental and non-governmental organizations, which was recently expressed in a resolution from Rio de Janeiro in 1992 and has also been included in the Helsinki Resolution.

The acid type air pollution occurs on a global scale on our continent. Yet, there are still considerable regional differences in terms of its intensity, in terms of the concentration and doses of pollutants in dependence on a short-, medium- and long-distance air pollution transfer. Orographic effects have a strong influence. Air pollution not only hampers the growth and development of tree synusia but also impacts other compartments of forest ecosystems. Chemical stress induces results in the formation of newly structured ecosystems with new functions.

System harmful agents, such as insects, fungi or unfavorable meteorological factors may cause tree injury in spruce plantations, presumably at a certain age and it is possible to protect the species against them to a certain extent. In contrast, air pollution affects physiology almost equally in all trees irrespectively of their age and can even cause extinction of species, when its impact is too strong.

The global air pollution danger has become an absolute factor for determining a new site at some places, which called for work on the silvicultural consolidation management of the forest (Otto 1991) at the turn of the 1960s and 1970s. Its conception focused mainly on production within several future decades. The management scope was rather empirical and it had to be scientifically justified post factum and corrected on exact groundworks. There is an essential difference in the fate of the spruce monocultures. Formerly, they suffered from a certain harmful agent, characteristic symptoms accompanying a particular stage of stand development. In contrast, air pollution shows a multi-factorial effect – at many a place with no clear symptoms. The harmful to lethal effects are seen on all developmental (age) stages of the forest whose image is rapidly levelled (Fig. 1). Due to air pollution the monocultures have to be converted even in the mountains where a mere modification of tree species composition, age and spatial forest reconstruction would do under normal ecological situation (Tesař 1994).

The narrowed biodiversity of the monocultures reduces stability as an autecologically and synecologically given aptitude towards coming to terms with air pollution impacts. A reasonable management will then take into account the potential of the species diversity, thus reinforcing elasticity as an ecosystem potential for a new dynamic balance.

Ecological principles of handling the forest endangered by air pollution

The health condition and vitality of tree species and their stands are given by both autecological and synecological factors. In the global environmental situation of the present time it is the result of synergic action of natural environmental agents and air pollution (Fig.1). Efficient forest management cannot, therefore, neglect basic principles of ecotechniques:

1. Tree species and their stands exhibit a relatively greatest vitality at an optimum constellation of environmental factors. For any forest measures to intervene into an ecosystem of spruce monoculture or of stands with spruce dominance, this means to make all that is technologically “feasible” and at the same time economically “acceptable” in order to create conditions that would be most favourable for the forest. There is a whole range of measures to improve soil conditions (liming, fertilization, hydroreclamations) as well as the stand microclimate and the mesoclimate of larger stand units.
2. An inseparable pre-requisite to fully respect the above principle is to ensure the general stability of trees and stands against typical harmful agents. The system of management should, therefore, also include well-tried methods of stand tending that have been proved by present forest practices.
3. The position of optimum growth conditions will change in dependence on what is being offered to the tree species and the stand by a particular ecotope whose important and sometimes decisive component became the type and size of air pollution load. Much more important than the instantaneous health condition of the stand for the decision-making about the system of silvicultural measures is the dynamics/prognosis of survival – the total vitality of the stand. A basic differentiation criterion is stand vitality and its classification varies in different countries: e.g. a four degree (A to D) danger system of classification by 20-year vitality steps has proven useful in the Czech Republic (Materna and Tesář 1990). The degrees are illustrated by enclosed territorial units which represent the basic frames for planning.

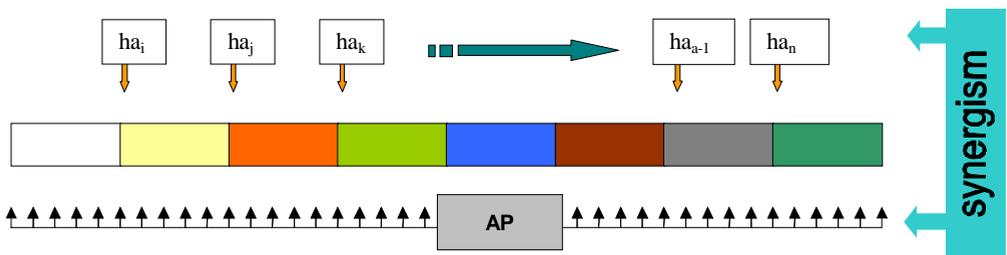


Figure 1. Consolidation management takes into consideration that air pollution (AP) affects the system of even-aged forest both directly and in synergism with current harmful agents (ha). See text for details.

4. Long-term air pollution load caused total extinction of original spruce populations in the Krusne hory Mts. (Erzgebirge) and the process of gene pool reduction continues at other places.

Based on the autecological and synecological air pollution effects it will always be a process of accommodation. The ecosystem will either be left to processes of the natural regeneration (succession) or the natural processes are entered into intentional forestry activities. The intentional management will range between conservation and reconstruction strategies (Tesar 1988, Thomasius 1989).

Conservation strategy

The conservation strategy is applied at a weak to medium load of forest regions, inducing disintegration dynamics at which the minimum vitality of stands is at least 30 years. Its main steps issue from respecting the relationship between air pollution and the environment being aimed at the improvement of ecological conditions of the forest.

The aim of this type of silviculture, as well as of the whole forest practice, is to keep or to establish again such a stable forest ecosystem that any disturbance of the stand cannot turn into the phase of destruction. Its application will result in the possibility of keeping the controlled forest management with minimum losses in wood production and minimum disruption of forest ecological functions. In this way, the silvicultural measures are developing the character of preventive activity. The complete set of measures for forest adaptation to the new ecological conditions includes: (1) the building up of a stable stand structure, (2) the intentional arrangement of forest stands to one another, (3) the maintenance of favourable soil conditions, and (4) the conservation of genetic resources for the future. The full effect and results of total management will only be achieved by a strict connection of partial measures and their consistent application.

Let us put aside the care of the gene pool as a specific theme not sufficiently researched out so far to submit concrete proposals for its integration into the management system of spruce monocultures.

Direct reclamation measures into the soil aimed at such improvements in water and soil-aeration regimes that the species can make better use of nutrient reserves and that the growth conditions are created for a wider range of tree species offer the same logic even with the air pollution impact. It was generally accepted that spruce plantations growing in inappropriate sites cause soil acidification and start the whole chain of malfunctions in soils as well as in plant nutrition.

The present acidification of the environment due to acid deposition endangers the species not only by its direct effect on their assimilatory organs, but to a considerable extent also by the above mentioned processes in the soil. It is known with confidence (Grenfelt et al. 1996) that sulfur deposition has increased concentrations of absorbed sulfate in the soil and caused the depletion of base cations on soil exchange sites. The acid deposition to soils has increased leaching of base cations, leading to nutrient deficiency, especially of magnesium and potassium. On most soils, acidification leads to the formation of insoluble aluminium phosphates which may result in phosphorus deficiency. The present acidification of the environment due to acid depositions endangered the species not only by its direct effect on their assimilatory organs, but to a considerable extent also by nutrition disorders and impaired vitality due to their soil effects. Science is concerned with the soil changes, their recovery and their prevention, as can be documented by hundreds of papers (Rehfuess 1989). However, the

results achieved do not guarantee a reliable silviculture in the sense that the chemical reclamations and fertilization can be included in the silvicultural systems with a guarantee of success and without a risk of any negative effects in the future.

There are basically two reclamation goals: (1) the screening of proton depositions and the limitation of their unfavourable effects on the soil; (2) the improvement of conditions for the development of root systems.

The first goal can be achieved relatively quickly and effectively. The fulfilment of the second goal is more difficult. The acidification-induced soil changes reach into the deep layers and affect the rhizosphere in its entire depth. The restoration of optimum or at least acceptable conditions for trees will require a time-consuming process with regard to a slow shift of amelioration materials into the soil depth.

Fertilization cannot be separated from liming. It is carried out from two viewpoints. It should either improve the overall nutritional status and thus increase the species vitality and tolerance or such fertilizers are used to increase the tolerance of particular species to particular stress factors.

Although the soil environment is inseparable from raising stand resistance, the process of spruce monoculture adaptation is rather focused on the stand itself and its above-ground environment. The dynamics and degree of damage are resulting from the horizontal and vertical constitution of the stand, particularly its crown layer.

Microclimatic properties of the crown layer are of essential importance for the modification of air pollution flow, which can be simplified for an illustration as a multiple of harmful substance concentration and air flow rate. It is the noxious agent itself that is “offered” to the assimilatory organs, from the physiological point of view. The dense stand with the enclosed crown canopy and an active climatic area located in the very top zone of crowns exhibits very low aerodynamic roughness. The penetration of air pollution into the stand interior is hampered and depositions are reduced. The offer of air pollution in this condition of the stand is at its relatively lowest. The positive aerodynamic effect is, however, opposed by the negative ecophysiological effects: the growth space of each tree in the dense canopy diminishes and due to the low light penetration the assimilatory organs are reduced which results in lowered vitality and impropotional growth with serious consequences for the tree statics (Fig. 2). There is a relatively simple recommendation: to prefer dendrophysiological aspects in young stands (up to about 10 m stand height), i.e. to grow them in the open canopy. The security of stands from the mid-age (higher than 15 m) is to be ensured by maintaining the canopy as continuous as possible. As a matter of course, the particular systems of stand tending also take into account the topical damage and the degree of danger (Tesař 1984).

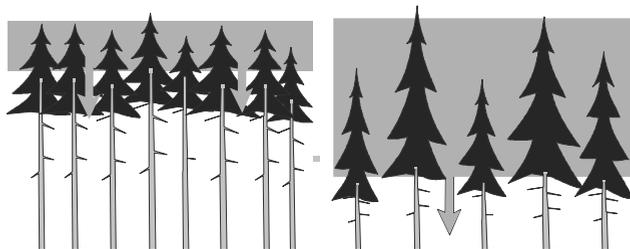


Figure 2. Different structural and ecophysiological situation caused by penetration of air pollution into closed and open canopy.

Positive effects can also be induced on a higher level of forest hierarchy – on the set of stands which manifests itself as a mesoclimatic organic unit. And it is this level where the ‘lateral ecological protection’ is used most often. A situation is induced in which the stands situated on the leeward side of higher stands are relatively protected against the air pollution flow and exhibit less damage. The effect which is well known in the protection against stormy winds shows gradation with the impact of air pollution. This is the right area to fully apply methods that were tested and well-proven in dividing forest complexes into separate small units. An entirely essential and exceptional importance for the spruce monocultures is attributed to stand margins.

Stand margins are sharp microclimatic boundaries and, therefore, they retain and suppress the stress effects which are magnified. Their stability depends on the degree of adaptation to free position. The stand regeneration should proceed from the firm protected edges against the direction of air pollution flux. These edges should eventually be removed. The creation of a stand shield using tree species tolerant to the complex of disturbances is relatively most reliable.

Reconstruction strategy

The strategy of reconstruction is suitable for areas with a particularly dynamic damage where it is impossible to delay the decline of the forest and its accommodation to new conditions in the sense of conservation strategies. It is the only permanent solution for higher mountain altitudes (Tesař and Tichý 1991). The stand cannot be restored in the short time in which it is destroyed. If the stand is cut out on continuous extensive areas, extraordinarily difficult conditions arise for the tree species’ regeneration due to the synergism of air pollution with the microclimate of clear-felled areas – with solar radiation, frost and air flow in the ground layer. Grass and herbal phytocoenoses develop before the stands cease to exist forming strong competition and related zoocoenoses decimate the tree species.

The resistance of the environment to a new forest generation can be treated in two ways (Materna and Tesař 1990). Up to now, a new forest was established at high costs by intensive technologies. Stands of relatively tolerant introduced species have been established by this method in the Krusne hory Mts. (Erzgebirge). Another way consists in the use of natural forest succession to create a preparatory and transitional forest of pioneer species – birch, rowan, possibly also aspen and willow, should this method be enough for ensuring general ecological roles of the forest. For the temporarily and spatially directed regeneration of large units it would be possible to decide where the forest should be entirely left to its own development, and where it would be useful to enter the succession with further control and acceleration due to environmental reasons and goals of forest strategies.

Stabilization of forests growing under the impact of air pollution and its accommodation to changed site conditions induced by the glasshouse effect

Society and forest management focused and tried to adapt their practices in forests growing under the impact of air pollution for several decades. The forest became an example of a complex biotic system occurring in an extreme situation (air pollution or climatic warming caused by glasshouse effect), which opens new horizons for both science and forest practice and forces us to solve them.

Anthropogenic changes of air pollution did not cause the general extinction of forests with the exception of several cases limited to certain localities. However, we should be interested in the well-being of forests for the future. Irrespective of the fact that the glasshouse effect is still more or less only assumed at present and its possible impact only assessed, the

phenomenon should not be neglected. It was shown during recent decades that risks suggested in scientific literature can be underestimated and a critical situation might occur soon, when forestry will have to face a situation in which its regular operations must be accomplished with enormous efforts or it might even be paralyzed.

If the warnings concerning the danger of extensive air pollution were taken seriously some thirty years ago, the economic and social consequences could have been diminished right from the beginning. The present forest is a reflection of not only the incomplete knowledge of forest dynamics due to air pollution and the related chain of events, but also the unwillingness to adopt a system of reconstruction of forestry, sometimes accompanied by chaotic and hot-headed empirical decisions which only deepened the negative consequences.

The toxic air pollution of anthropogenic origin and the glasshouse effect have entirely different mechanisms of affecting the tree species and the whole spruce monoculture forest ecosystem. In the course of time, it has been shown how difficult and limited is the practice of adapting the tree species to the toxic air pollution which it has never experienced in its phylogenetic development. In the post-glacial epoch, the species had to face climatic changes – secular fluctuations of atmospheric temperature, several times. However, the predicted climatic changes should occur so quickly that the existing populations of not only spruce but also of other species determining the present forest composition cannot cope with them since they are missing the genetic outfit to do so (Fanta 1992). The result of the changes will be common to both phenomena: the species will be discarded from the ecosystem. And, the solution core will again consist in the conversion of the species composition.

The culticoenoses of spruce stands for whose management and wood-producing functions management systems prepared some time ago failed under the influence of air pollution and can hardly stand the proof in the future. We should try, therefore, to grow a forest which would be rich in species composition and spatially differentiated. The achievement of age differentiation will depend on the possibilities of the prolonged regeneration period of stands. Also, the diversity of vertical stand structure is going to be conditioned. With air pollution impacts it is impossible to reach more complex vertical forest structure since all shaded stand components (storey, layer) lose vitality. Yet, the maximum filling of the growth space with assimilatory organs would be useful to bind carbon dioxide. Nevertheless, horizontal species diversity is realistic and feasible.

All circumstances offer one direction for the future management: the forest of the future should be capable of a flexible response to possible environmental changes thanks to its internal mechanisms and flexible silvicultural systems have to support this potential of the forest. The highly performing production forest will not be struggled for at all costs. The close-to-nature forest management with its three axioms – (1) optimum utilization of growth production potential by purposefully mixed stands, (2) continual forest regeneration, and (3) utilization of individual properties of trees in each population – is justified, wherever allowed by the level of noxious substances.

Conclusions

Spruce monocultures must also be coped with by future generations of foresters. The methods of transformation will be neither ambiguous nor direct as it is impossible to define them clearly. It is similarly impossible to claim that by establishing a new forest, more tolerant to the existing types of air pollution, we have made all necessary provisions to ensure its future.

The level of acid air pollution has been decreasing recently in Central Europe. However, it would be inexcusable to underestimate this factor for various reasons. The remedy of forest

damage lags behind the trend of decreasing the air pollution level. The disturbed forest stands may respond to any future air pollution episode by new losses. These are laws of plant physiology which are still being made evident every day.

With regard to climatic changes and possible other dangers that cannot even be suspected yet, the forest will have to be further formed. Let us not take it as a defeat but as a challenge to participate in the process of creation, towards our own benefit, together with nature.

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The Possibility of Converting Spruce Monocultures into Autochthonous Stands in Croatia

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Abstract

Spruce monocultures in Croatia are grown only on open sites (meadows, pastures, clearings, non-wooded forest soils), and have a pioneering function in preparing a site for a natural or artificial return of autochthonous forest vegetation. They are grown in rotation periods of 60 to 70 years. In principle, at the end of the rotation period, spruce monocultures result in an autochthonous stand similar to the one that occurs naturally in a given site. This can be achieved artificially by planting or sowing. Shelterwood fellings, usually in two cuts (regeneration and final cut), are conducted in spruce monocultures in such a way that seeds or seedlings are introduced immediately before or after the regeneration cut. In doing this, a stable, biologically diverse pure or mixed stand is obtained which is dominated by autochthonous, mostly climatogenous, tree species. A spontaneous natural occurrence of young autochthonous vegetation is the best indicator that a site under a spruce monoculture is ready for conversion. In this paper, the authors analyse these principles with examples in the Gorski kotar region of Croatia.

Keywords: Picea abies Karst., culture, conversion, autochthonous vegetation

1. Introduction

In Croatia, 95% of the forests have a natural structure, and only 5% are forest cultures and plantations. Common spruce in Croatia occurs in natural stands and in forest cultures. Spruce cultures account for 12 225 ha of the 75 000 ha under conifer cultures. The total growing stock of spruce is 1 950 000 m³.

Despite the fact that cultures of common spruce do not play a significant role in Croatian forestry, their various silvicultural aspects have been studied in depth. Matić and Prpić (1983) write about afforestation with spruce, Orlić (1994; 1987; 1984) Orlić and Ocvirek report on

thinning treatments and the influence of planting distances on the success of common spruce, Orlić et al. (1997) deal with the relationship between thinning operations and mineral nutrition in common spruce cultures, and Orlić et al. (1991) study the effects of initial thinning treatments on biomass production and its chemistry. The growth of common spruce in the cultures on Mount Medvednica near Zagreb is discussed by Oršanić (1995). The growth of local and foreign conifer species including spruce in young cultures growing on heath lands and in bracken-covered areas in Croatia were studied by Orlić and Ocvirek (1993). Matić et al. (1992) give general data on the cultures in Croatia, and these were used as a source for this paper.

Spruce monocultures are grown only on those soils which have lost the properties of forest soils (meadows, pastures, clearings, and non-wooded forest soils). They have a pioneering role in preparing sites for a natural or artificial return of autochthonous forest vegetation. They are grown in rotation periods of 60 to 70 years. Thinning should be applied throughout the rotation period; among other things, this improves the soil and prepares it for the return of autochthonous vegetation.

In principle, by the end of a rotation period, spruce monocultures raised artificially through planting or sowing can be converted into autochthonous stands similar to those that would occur naturally in a given site. For this purpose, shelterwood fellings, usually in two cuts (regeneration and final cut), are conducted in such a way that seeds or seedlings are introduced immediately before or after the regeneration cut. These treatments will result in biologically diverse and stable stands of pure or mixed structures, in which autochthonous and climatogenous tree species dominate.

The occurrence of young autochthonous plants, in our case of silver fir (*Abies alba* Mill.) and beech (*Fagus sylvatica* L.), indicates that a spruce monoculture site is ready for conversion. In case of a less dense monoculture canopy, autochthonous vegetation will occur in greater quantity, and will form a separate storey under the canopy of old spruce trees.

2. Research area and methods

The research dealing with the conversion of spruce monocultures into autochthonous stands was conducted in selection forests of fir and beech in the forest offices of Delnice and Lokve in Gorski Kotar. Gorski Kotar, the most densely forested part of Croatia, is situated in western Croatia. About 100,000 ha of the total 127,000 ha are covered with selection forests of fir and beech and even-aged beech forests. The climate is continental, but with some maritime influences. The average annual air temperature is about 7°C, and the mean annual precipitation is about 2000 mm (Klepac 1997). As Gorski Kotar is part of the Dinaric mountain chain, its relief is characterized by karst forms.

Two experimental plots, each of 500 m² in size, were established in spruce monocultures in the autumn of 1994. Table 1 shows some basic data on the sites and experimental plots. Spruce cultures were established on a limestone geological base, on calcocambisol, in an area in which autochthonous vegetation is represented by a selection forest of fir and beech. In these conditions, adjoining autochthonous selection forests have 470 m³/ha of wood volume, 35 m²/ha of basal area and 8 m³/ha of annual volume increment.

Seeds of common fir were sown in each of the plots on 10 November 1994. In each subplot (100 m²), a quantity of 200 g, or 20 kg/ha, was sown. The soil was previously lightly loosened with hand tools. In the autumn of 1995 and in the spring of 1998, young fir plants were inspected for their exact numbers in such a way that each subplot was divided into 5 strips placed either perpendicularly (Plot 1) or parallel (Plot 2) to the longer plot side, as

Table 1. General data on experimental plots, site and spruce cultures.

	Plot 1 - Delnice	Plot 2 - Lokve
Plot dimensions	50 x 10 m (500 m ²)	50 x 10 m (500 m ²)
Subplot dimensions	5 x 100 m ²	5 x 100 m ²
Geological base	Limestone	Limestone
Soil	Calcocambisol	Calcocambisol
Exposition	SW	SW
Altitude (m)	800	800
Potential vegetation	<i>Abieti-Fagetum</i>	<i>Abieti-Fagetum</i>
Age of culture (years)	20	20
Establishment method	Planting seedlings	Planting seedlings
Planting density (plants/ha)	3,000	3,000
Tending up to date	No	No
Number of trees (plants/ha)	1660 (1460 spruce, 200 beech)	2060, spruces
Basal area (m ² /ha)	25.4 (24.2 spruce, 1.20 beech)	29.80
Volume (m ³ /ha)	124.2 (120.8 spruce, 3.4 beech)	147.2
Max. spruce height (m)	14.3	14.2
Mean spruce height (m)	10.1	9.8
Mean spruce dbh (cm)	14	13

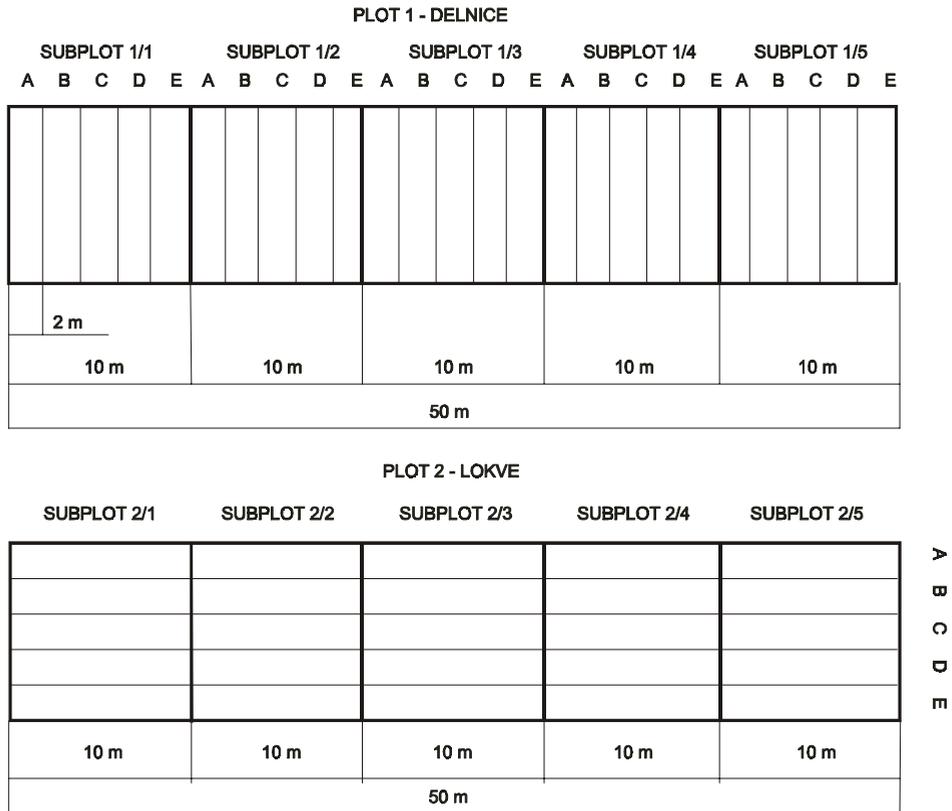


Figure 1. Experimental plots and subplots.

shown in Figure 1. The same principle was used to assess the quantity of light in the stand. The structural indicators of spruce monocultures (breast diameter, total height, the bottom crown height, horizontal crown projection) were also measured.

3. Research results and discussion

Table 1 shows the results of the research on the structural properties of the spruce monocultures in the two experimental plots. It is important to note a spontaneous and natural occurrence of autochthonous beech among the spruces in Plot 1. Its presence indicates that the site in the monoculture is ready to accept seeds of autochthonous climatogenous tree species (common fir and European beech). In order to re-establish a future autochthonous, natural, climatogenous association of beech and fir, we sowed fir seeds in the site of a selection forest of beech and fir, which is currently under a spruce monoculture acting as a pioneer tree species.

Figures 2 and 3 show height curves in the monoculture of common spruce and tree distribution per diameter class in both experimental plots (Delnice and Lokve).

The quantity of young growth of common fir in the plots (1-Delnice and 2-Lokve) and subplots is shown in Table 2 and Figure 4. According to Table 2, there were 966 young fir plants in 500 m² in Plot 1, or 19 320 plants/ha, and 1169 plants, or 23 380 plants/ha, in Plot 2.

Figures 5 and 6 show the following research results in Plots 1 and 2:

- horizontal profile in spruce monoculture,
- horizontal crown projection,
- the plan of plots and subplots with evaluation of quantities of young growth and assessment of light,
- the plan of assessment of light,
- results of evaluating young growth of fir per plots, subplots and evaluation directions.

The quantity of young fir plants depends on the crown cover of common spruce, and light values in the stand. In areas in which light quantity exceeds 6%, either because the soil is

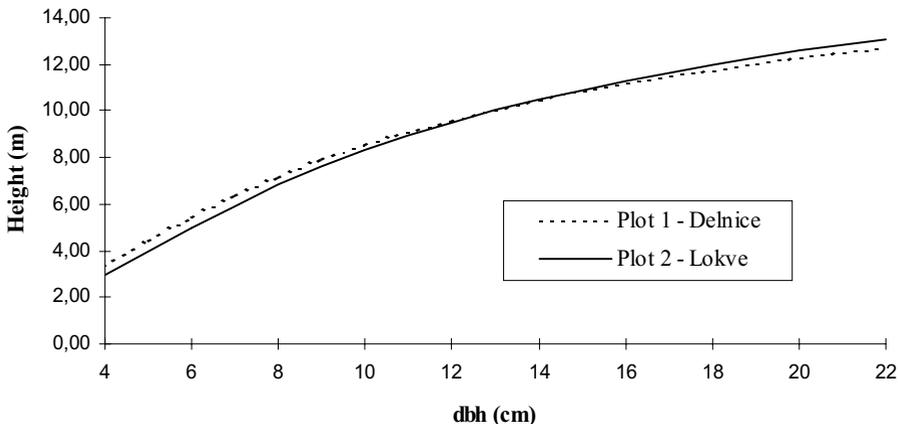


Figure 2. Tree height as to diameter breast height.

covered with weeds or exposed to frost and heat, the number of young firs is the lowest. Light quantity ranging between 2 and 6% in these stands is optimal for the occurrence and survival of young firs. The minimal light intensity of under 2%, or between 1 and 2%, barely enable young fir plants to survive.

The obtained data on the number of young firs and the light in a stand necessary for the young growth to survive, correspond to insights into the biological properties and ecological requirements of common fir (Matić 1979).

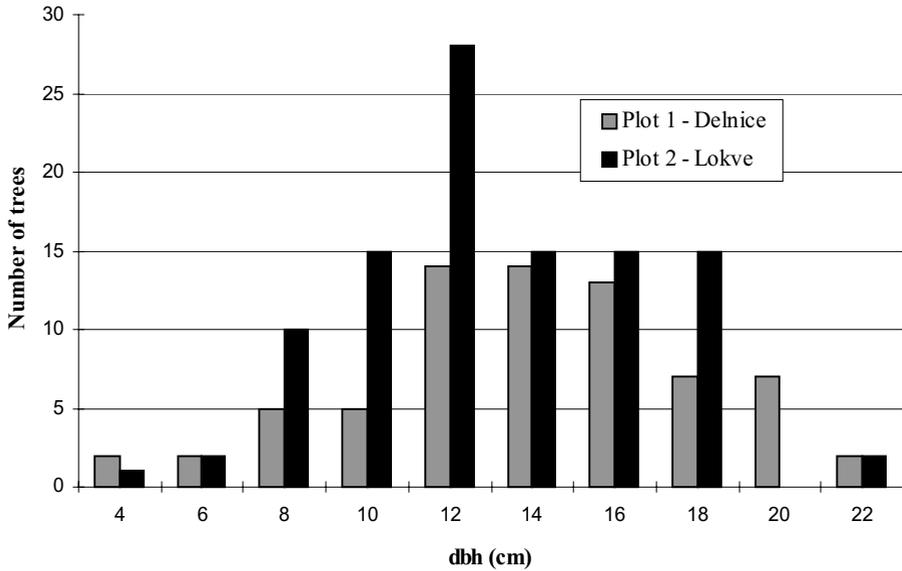


Figure 3. Frequency distribution of diameter breast height.

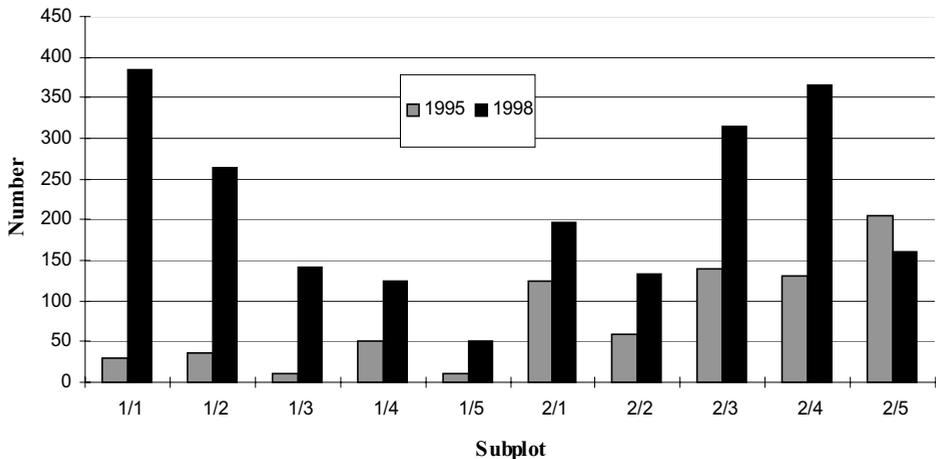


Figure 4. Number of new growth of *Abies alba* in 1995 and 1998.

Table 2. Number of young growth as to plots and subplots.

Plot	1 - Delnice					Total
	1	2	3	4	5	
A	38	45	50	8	12	153
B	64	58	30	25	9	186
C	114	44	25	48	5	236
D	96	61	26	13	10	206
E	72	57	11	30	15	185
Total	384	265	142	124	51	966

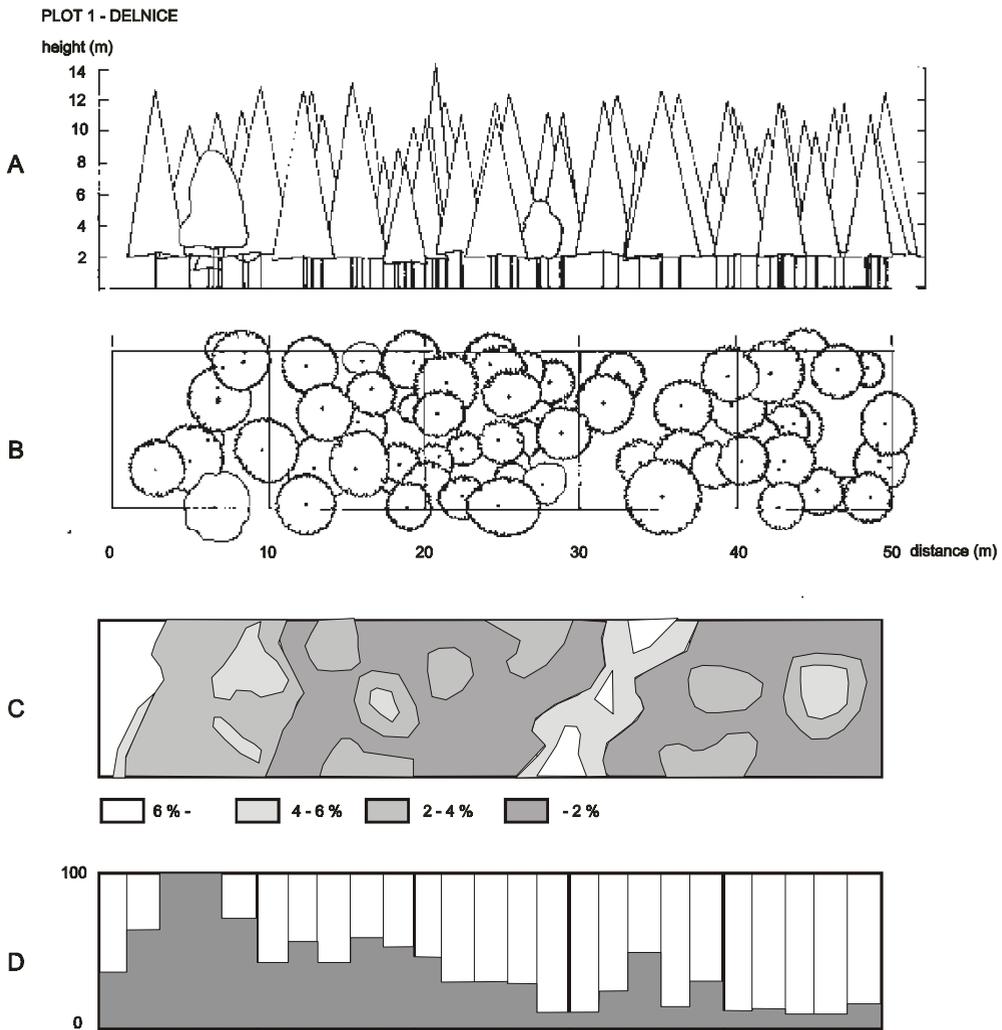


Figure 5. Profile of spruce culture (A), horizontal crown projection (B), relative light quantity in the stand (C), and a number of young plants (D).

Table 2 continued. Number of young growth as to plots and subplots.

Plot	2 - Lokve					Total
Subplot	1	2	3	4	5	
A	22	29	4	13	6	74
B	0	27	2	29	0	58
C	8	20	13	101	10	152
D	59	26	155	135	75	450
E	107	31	140	88	69	435
Total	196	133	314	366	160	1169

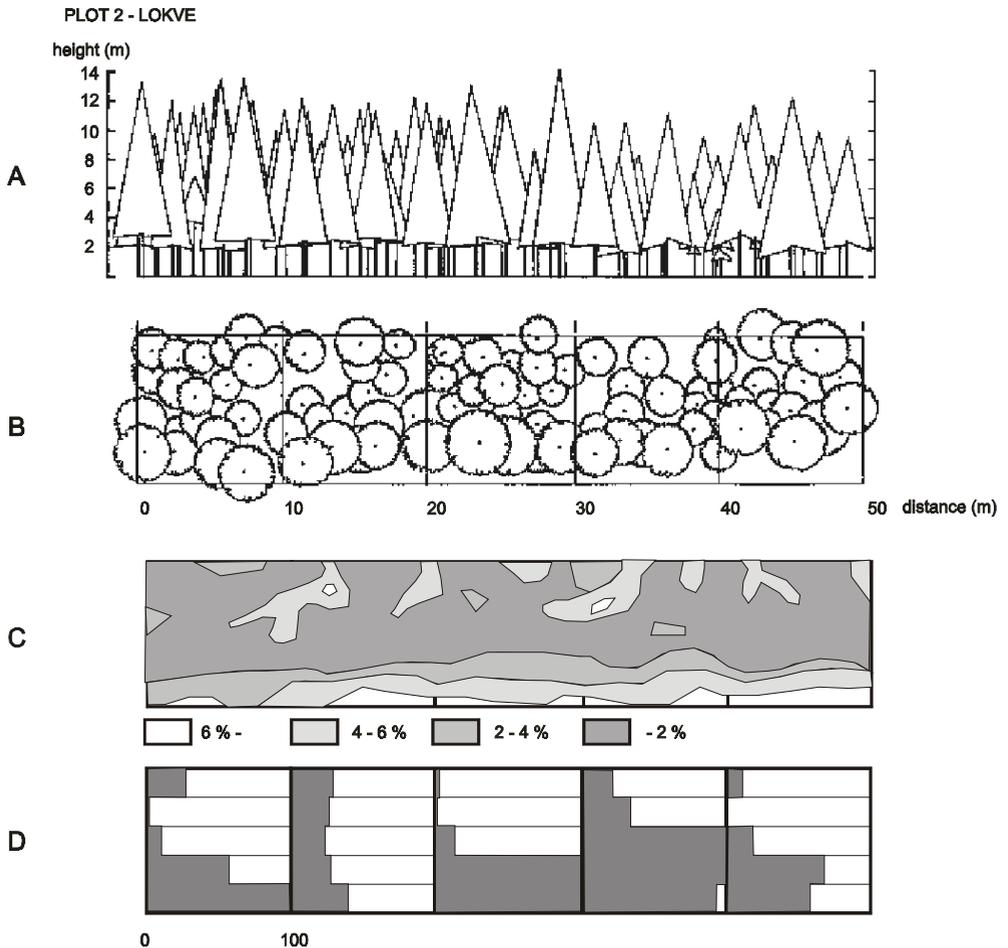


Figure 6. Profile of spruce culture (A), horizontal crown projection (B), relative light quantity in the stand (C), and a number of young plants (D).

4. Conclusions

Our research on the possibility of converting spruce monocultures into autochthonous stands of beech and fir selection forests in Croatia has shown the following:

1. In spruce monocultures established as pioneering stands in potential sites of beech and fir selection forests, it is possible to achieve their conversion into beech and fir stands by sowing fir seeds and by beech seed occurring naturally.
2. Due to its good shade tolerance, common fir is more suitable for conversion than beech. At a light intensity of between 2 and 6%, young firs grow well. Light values of under 2% are the minimal quantities at which young fir plants still survive, while those above 6% are unfavourable for the growth of fir.
3. By regulating the quantities of light with cleaning and thinning operations, and by felling in two cuts (regeneration and final cut), it is possible to achieve better conditions in the soil (an increase in microbiological soil activity), and more favourable conditions for the occurrence and survival of young firs, beeches and other tree species which appear in natural, autochthonous, and climatogenous selection forests of beech and fir. This is the ultimate goal in converting spruce monoculture.

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The Research Program for the Restoration of Forest Ecosystems in Austria¹

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Abstract

In July 1997, the Forestry Section at the Universität für Bodenkultur Wien, Austria launched a ten-year research program to study forest ecosystem restoration processes and to evaluate stability and resilience during the restoration phase into mixed species stands. The need for forest restoration was noticed during the early 1980s, when research emphasized that the symptoms of forest decline can be considered as a mixed effect of both air pollution and historical changes in land use. Twenty-three scientists, covering research fields from ecology to socio-economics, participate in the program. Forest ecosystem modeling and the development of a meta data oriented information system will link data and research results. Funding comes from the Austrian Science Foundation, the Ministry of Science and Traffic, the Ministry of Agriculture and Forestry, and the City of Vienna.

Keywords: forest restoration, Norway spruce, forest ecosystem, Austria

1. Introduction

During the 1970s, researchers expected a forest decline in Europe due to air pollution (European Commission 1994). Research programs were initiated (e. g. in Austria: FIW = Forschungsinitiative gegen das Waldsterben) to search for and quantify factors that would cause the expected “forest dieback” or “Waldsterben”. One important result of these research programs was that air pollution, nitrogen deposition (Katzensteiner and Glatzel 1997) and

¹ The following institutes and scientists of the Forestry Section, Universität für Bodenkultur Wien, participate in the program: Institute of Forest Ecology (Gerhard Glatzel, Torsten Berger, Herbert Hager, Klaus Katzensteiner, Marian Kazda), Botany (Hanno Richter, Peter Hietz), Torrent and Avalanche Control (Wolfgang Weinmeister), Forest Growth Research (Hubert Sterba, Hubert Hasenauer), Silviculture (Raphael Klumpp, Alfred Pitterle), Forest Entomology, Pathology and Protection (Erwin Führer, Axel Schopf, Christian Stauffer, Rudolf Wegensteiner, Peter Baier, Jutta Mattanovich, Erhard Halmschlager), Wildlife Biology and Game Management (Friedrich Reimoser), and the Institute of Forest Economics and Forest Policy (Wolfgang Sagl, Max Krott, Peter Glück).

climate change may affect forest ecosystems directly as well as indirectly due to favoured insect outbreaks and/or fungi infections etc. (Kilian and Fanta 1997). Such detected primary, secondary or even tertiary causes changed the research objectives from monocausal hypotheses testing towards a “multiple stress hypothesis” focusing on stress scenarios and stress profiles of forest ecosystems (Führer 1994).

For centuries, Central European forests have been exposed to severe human impacts resulting in a tremendous reduction of forest covered land area, changes in forest distribution, and particularly changes in species composition and soil conditions (Glatzel 1991; Fanta 1997). Fast growing tree species such as Norway spruce (*Picea abies* L. Karst) or Scots pine (*Pinus silvestris*) were promoted in large areas beyond their natural range to increase commercial timber growth (Güde 1960). These secondary coniferous stands mainly in areas below 1000 m in elevation turned out to be extremely sensitive to environmental stress factors and are highly susceptible to progressive loading by air pollution and potential climate change (Führer 1990). Thus, the renewal of such forest ecosystems is an important challenge within forest ecosystem research (Fanta 1997).

The Special Research Program (SRP) – Restoration of the Forest Ecosystems launched in July 1997 addresses this issue. The mission of the SRP is to study and quantify processes of forest ecosystem restoration and to evaluate stability and resilience during the restoration phase. Twenty-three forest scientists at the Universität für Bodenkultur Wien, participate in the program. In this paper, we will introduce the scientific concepts and objectives of the program as it was developed in a joint effort by all the participating scientists according to their research interests (see section 3.2.). Funding for our work comes from the Austrian Science Foundation, the Ministry of Science and Traffic, the Ministry of Agriculture and Forestry and the City of Vienna. The program is expected to run for 10 years, until the year 2007.

2. Scientific concept and objectives

2.1 Ecological rehabilitation

Predisposing factors combined with increasing stress factors due to air pollution suggest that activities on ecological rehabilitation have to operate on two different levels (Führer 1994):

1. the reduction of air pollution and
2. the renewal of devastated forest ecosystems.

While the reduction of air pollution is mainly a political issue, the development and implementation of strategies to repair disturbed forest ecosystems is an important challenge within forest ecosystem research (Sterba 1994; Fanta 1997). Such ecosystems often suffer from severe heat and water stress (primary causes) as well as biotic and/or abiotic impacts (secondary causes), etc. Stand stability and resilience to additional stress factors (e.g. air pollution, climate change etc.) may be extremely limited within these stands because usually a major decline in biodiversity is evident (Emmer et al. 1998). Thus, modern forestry has to aim towards an increase in resilience of such forest ecosystems by reducing management induced stress factors.

2.2 Working hypothesis

The Austrian National Environmental Plan (NUP) states that “Secondary spruce stands as a result of monocultures and selection through browsing by wildlife and cattle grazing, are

prone to large scale collapse due to storm and snow damage, insects and fungi”. Consequently, diversity is considered a main factor in maintaining or regaining resilience and stability of forests. We assume that forest ecosystems close to old growth stands represent the optimum scenario because they are less susceptible against stress factors versus secondary coniferous stands. Sustainable forest ecosystems are supposed to:

1. increase soil fertility or at least keep it stable,
2. be resilient, i. e. to regain the “original complexity” without too much human interference,
3. be stable in terms of being less susceptible to physical and/or biotic disturbances.

The instability of forest ecosystems affects forest owners as well as public interests because of the increasing risk of commercial timber growth and, e. g. water quality may decrease (Sonderegger and Enzenhofer 1994), respectively. According to Division 1 of the IUFRO “Natural forest ecosystems appear more resistant to wind damage than forest plantations, and this requires investigations” (Quine 1994), we propose that mixed-species stands are more stable, more resilient, keep soil fertility in better conditions, decrease the runoff, danger of erosion, and nitrate flow to the groundwater in comparison to secondary coniferous stands beyond their natural range.

2.3 Restoration hypothesis

An important challenge in ecosystem restoration is the selection of proper restoration scenarios for secondary coniferous stands. However, even devastated coniferous stands have reached certain equilibrium. During restoration, processes will be initiated which may result in a temporary decline of resilience and stability depending on the restoration scenarios selected. Silvicultural treatments change stand structure, and, thus, the growing conditions as well as the stress situation for the remaining trees. As a result, the competition level for light, nutrition, water, etc. changes as well as the microclimate, which may be important for biotic damages. Furthermore, habitat quality and quantity for wildlife, which may alter the possibility of natural regeneration with autochthonous tree species will vary. The way in which forests and their vicinity change affect the distribution patterns of wildlife within forest ecosystems and their impact. Successful ecosystem restoration has to address these issues by evaluating and quantifying the risk during the different stand phases. We are currently investigating three different restoration scenarios:

1. Change in species composition: Secondary coniferous stands may suffer from a significant lack of nutrition. Humus conditions, soil hydrology and soil biology, etc. are disturbed. Thus, planting of broadleaf species will induce soil processes, which may improve site conditions.
2. Fertilization: Nutrient input affects soil processes. However, additional nutrients may have positive as well as negative side effects. For example, the positive impact is that susceptibility of stands for phloem feeders as well as fungi infections are reduced (Neumüller 1994). Negative side effects include possible contamination of groundwater due to leaching and runoff (Katzensteiner and Glatzel 1997).
3. Stand treatment: Generally, it is assumed that decreasing stand density will increase tree vigor, stability, etc. of the remaining stand. The negative side effects include decreasing stand stability immediately after treatment and higher run off rates etc.

2.4 Research objectives

Based on the working and restoration hypotheses our research interests can be summarized as follows:

1. What stages are important during forest ecosystem restoration?
2. The risk factors during forest ecosystem restoration (e.g. level of resilience, stability and susceptibility).
3. How does fertilization affect restoration processes and what are the risk factors (e.g. ground water contamination with nitrate).
4. Socio-economical implications such as restoration costs but also changes in commercial timber output due to changes in species composition. In other words, increase in resilience due to changes in species composition may have negative side effects on the expected commercial timber output versus coniferous stands.
5. Forest policy implications, such as public funding strategies and the implementation of expected research results within forest management plans. How do we transfer scientific knowledge into forest management plans!

An important concern within our program is to approach forest ecosystem restoration in a quantitative way. This implies that the processes during restoration have to be integrated into models that study and evaluate possible restoration scenarios. Currently, we plan to use two different modeling techniques: (1) statistical and (2) biogeochemical modeling concepts.

3. The structure of the program

3.1 Administration

Five scientists, including the chairman (Hubert Sterba) and the deputy chairman (Erwin Führer), represent the panel of the SRP. Because successful research needs professional management and administration, we established a central management. The central management comprises the activities of the chairman, one scientist who assists the chairman and an office manager and includes the joint data collection, the maintenance of research plots, contacting land owner, agencies, and public relations in addition to the budget, bookkeeping and accounting. The central management organizes workshops, meetings and guest lectures.

The next level of administration includes 12 different projects covering the research fields within our program (see Figure 1). Each project is led by one or more project leaders. Currently, 23 scientists (see section 3. 2.) of the Forestry Section, Universität für Bodenkultur Wien, Austria plus about 20 Ph.D. and master students work within the program.

3.2 Research areas: projects and their leading scientists

1. Soil: (Leader: G. Glatzel, T. Berger) – deals with soil fertility and nitrogen and carbon storage, turnover and release as they result from the measures to change species composition, to change soil fertility by fertilization and to change stand structure through thinning.
2. Ecophysiology: (H. Richter, P. Hietz) – how restoration will affect tree water conditions and the frequency of water stress symptoms, which may influence the tree's susceptibility to phloem feeders and fungi infections as well as tree growth.

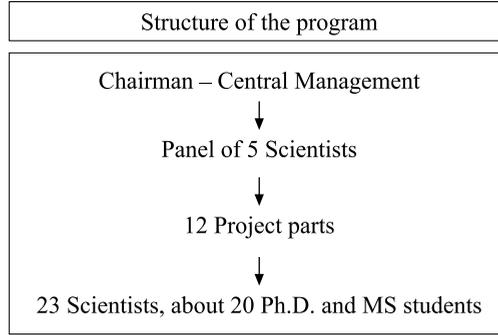


Figure 1. The histogram the research program Forest Ecosystem Restoration.

3. Hydrology and Climate: (W. Weinmeister, H. Hager) – measures of forest ecosystem restoration, stand climate and forest hydrology. Furthermore, stand structure, litter layer, humus type, soil structure, biomass in the soil and soil chemistry will change and consequently influence runoff processes. Stand climate and soil water balance during restoration is modeled for different stages of ecosystem restoration.
4. Modeling: (H. Sterba, H. Hasenauer, K. Katzensteiner) – comprises statistical and biogeochemical modeling concepts to link research output and develop restoration scenarios. Existing individual tree and stand growth models will be adapted to project forest growth and biogeochemical modeling concepts will be developed to describe the ecophysiological processes within forest ecosystems.
5. Regeneration: (R. Klumpp, A. Pitterle) – works on regeneration possibilities and conditions as well as the influence of restoration measures on the genetic structure in treated stands. Allelic and genotypic structures are analyzed and compared with data of autochthonous populations regarding diversity measures. Area-specific markers will serve to assess the consequences for silvicultural treatments.
6. Phloem feeders, Insects: (E. Führer, A. Schopf, C. Stauffer, R. Wegensteiner, P. Baier, J. Mattanovich) – evaluates susceptibility of trees to phloem in differently restored stands. The complex tree-host relationships between structural, chemical and biological characteristics are important for resistance against insects.
7. Fungi: (E. Halmschlager) – deals with the effects of restoration on the susceptibility to twig fungi (and later on to root fungi). In particular, the relationships between *Sirococcus strobilinus*, *Pezicula livida* and *Macrophoma sp.* and their interactions with the nutritional and stress level of host trees will be investigated.
8. Stability: (M. Kazda, G. Glatzel) – works on stand stability effects during restoration, especially against wind and storm. Root development depends on structural changes in the canopy and is strongly affected by silvicultural treatments.
9. Wildlife: (F. Reimoser) – deals with habitat quality for wildlife (mainly roe deer in the first phase) and, thus, the susceptibility of stands to browsing.
10. Economics: (W. Sagl) – evaluates the restoration measures and concepts based on economic and social welfare aspects by studying the awareness of forest owners and forest managers concerning the endangering of forests and by discussing the costs and benefits of forest ecosystem restorations.
11. Policy analysis: (M. Krott, P. Glück) – studies the interaction of recent knowledge on forest ecosystems and the implementation practice of the forest authorities concerning forest ecosystem restoration. Information deficits of the land owner and the information level of programs for forest protection and restoration will be evaluated. In the second

phase it will study the implementation of forest ecosystem restoration in a chain of case studies.

12. Central management: (Leader: H. Sterba, H. Hasenauer) – Besides book-keeping and coordinating the SRP activities, the activities of the central management include the establishment of the information system MORIS (Monitoring Research and Information System) to integrate and provide information across all research groups. The underlying concept of MORIS (Mirtl and Schentz 1995) was developed by the Austrian Agency of Environmental Science and will be adopted for our research needs.

3.3 Level of integration

Although all the groups work within the same area, there are tremendous differences in the level of abstraction and integration of data. Generally speaking, some groups follow the bottom up approach while others are interested in a top down approach, respectively (see Figure 2).

Typical examples for the top down approach include the wildlife, socio-economics, and policy analysis groups (projects 9, 10 and 11), which work on a regional and/or landscape-level. All other projects (PPT 1–8) will mainly work on a tree and/or stand level and follow the bottom up approach. Restoration processes studied and investigated on a small sample or area will be used to quantify processes during restoration. Essentially, these groups are interested in generalizing restoration processes so that they can be implemented in restoration scenarios.

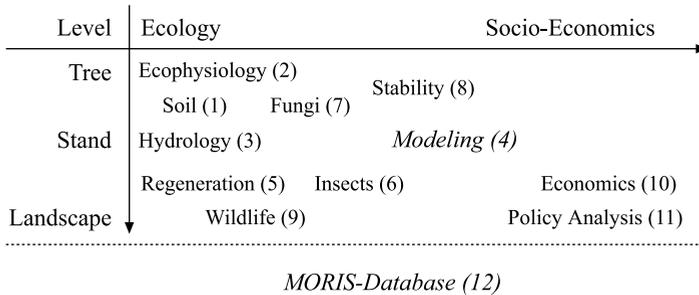


Figure 2. Summary of the project parts within the research program Forest Ecosystem Restoration. The numbers in parenthesis refer to the project part. Please note the different levels of integration and the interactions between the different subject areas of interest. The information system MORIS (12) and the Modeling (4) part are key projects in terms of the joint data collection and to provide access to the data as well as to link research results and develop restoration scenarios, respectively.

5 Data

5.1 Data needs

An important problem in studying forest ecosystem restoration is time. It is almost impossible to experimentally disturb systems and wait until they have recovered. Furthermore, such

restoration phases may be strongly affected by random impacts, which would require a number of replications before generalized implementation strategies could be driven. To circumvent this problem we decided to work on two different time schedules:

1. temporary plots and
2. long term research plots.

The basic idea of the temporary research plots is to explore possible restoration scenarios within the restoration areas of interest. During the Screening which we started in July 1997 different types of stands were selected ranging from the expected worst case scenario (poor secondary spruce stands) to the hypothesized optimum scenarios covered with mixed species stands. Each restoration phase comprises different stand ages to ensure a wide variety of possible stand features. Data recorded cover soil and stand parameters as well as vegetation types.

Based on the results of the Screening we have selected a limited number of permanent research plots for long term observation. Data from these plots will allow us to systematically shift from a “growth series concept” (Assmann 1961) to time series analysis of forest ecosystem restoration covering different restoration stages as they are observable on given sites. In the first stage of our research, we have only access to data from different levels of disturbed forest ecosystems expressed by their relative mixture with broadleaf species (mainly beech). These data consist of stands with comparable site conditions but different age classes (brush stage, thicket, pole stage, mature stands, old timber stands) and stand densities (in terms of thinning).

Besides the terrestrial tree measurements from our research plots, additional information on a landscape level is required. Particularly the projects 9 to 11 need maps, inventories and polls, etc. for the subjects of interest. Remote sensing as well as areal photographs are used and connected to terrestrial measurements (Kusche and Banko 1998). Furthermore, some groups are interested in different land use scenarios (parts 9 and 10), patterns in forest distribution and the surrounding areas as well as different forest ownership (part 11). To address these issues our selected study areas had to cover different forest patterns and sizes of forest ownership.

5.2 Research areas

Two regions with different bedrock were selected to study forest ecosystem restoration. While Region 1 consists of pseudogley soils over flysch located at the northern edge of the Austrian Alps, Region 2 covers the Kobernauberwald with poor podzolic soils over tertiary gravel (see Figure 3). According to Mayer (1971), the natural forest types for both regions are mainly mixed Norway spruce – common beech stands. Both areas are between 300 and 800 m in elevation and have been heavily influenced by historical land use changes and significant changes in species composition towards secondary Norway spruce monocultures. The first results of a survey based on satellite data (Kusche and Banko 1998) showed that the two research areas together cover 280, 000 ha with forests. 68, 000 ha of the 280, 000 ha consist of secondary Norway spruce stands.

Furthermore, the regions selected differ by the structure of land ownership. While our study sites in Region 1 belong to the Austrian Federal Forest Company, the biggest forest owner in Austria, study sites in Region 2 consist of a large number of small private land owners. This ensures that our data will cover different interests in forest management and its impact on socio-economic and policy analyses.

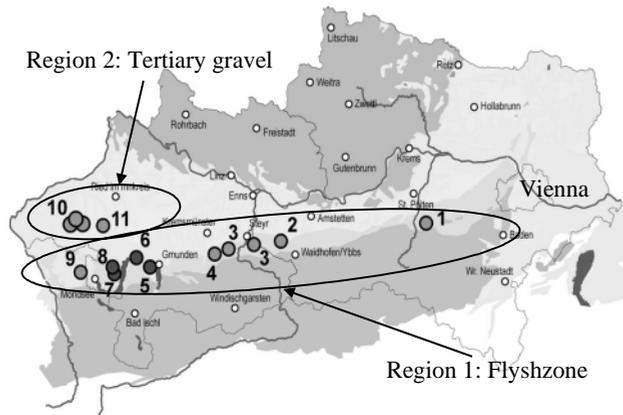


Figure 3. Research areas of the Special Research Program (SRP) – Ecosystem Restoration. Each number indicates one land owner with established study sites. In summary 60 temporary plots (34 in Region 1; 26 in Region 2) were selected.

5.3 Screening

During the first step of our research (Screening) we selected 60 temporary sample plots, 34 in Region 1 and 26 in Region 2. The criteria for selecting a particular location was that for each secondary Norway spruce stand a mixed species stand with comparable site conditions had to be available nearby. Mixed species stands were defined as stands with more than 40% beech and/or white fir trees. Furthermore, research plots selected had to cover three different stand phases (young, middle, and old stands) and had to be located within homogenous stands of at least 1 hectare in size. 1/3 of the plots show natural regeneration. Our plots cover different stand densities, had no treatment during the last 5 years, show no or only minor bark peeling and storm damages, no plots are located on recultivated agricultural land, and finally the steepness of the slope had to be less than 30%.

6. Building links and restoration scenarios

Besides the joint data collection, the synergetic effect will be that the output of one project will be the input for others. Researchers of the different working groups collaborate across their scientific fields in terms of data collection, analysis, etc. to ensure that the complex interaction during ecosystem restoration can be properly addressed.

For example, the expected results of the soil group (project 1) will be an important input to nearly all other projects in order to interpret water stress indicators from soil parameters (see project 2), runoff scenarios (project 3) and regeneration scenarios as they may depend on soil processes (project 5). Soil parameters in combination with the soil water conditions and the nutritional status are particularly important for projects (6) and (7) because these stress factors are hypothesized to be a main predisposing factor for the susceptibility of fungi and/or phloem feeder. In project (8), for example, the anchoring effect of the roots and root growth will depend on soil parameters, silvicultural treatment etc. Similar interactions can be driven for any project.

In addition to the collaboration across different fields, all groups work within the same research area, same plot, stand or even tree. Essentially, the idea is that if research output of one group is the input for another the data have to be compatible with each other. Thus, joint data collection on the same subject of interest is required. If information is collected from different groups, an important problem appears: how do we make the data available for all project members? To ensure this important link within our program we established the information system MORIS (Monitoring and Research Information).

MORIS is a meta-data oriented relational client server system. Meta-data refers to the description of how information was collected, the instruments used, etc. so that the history of the data is clearly documented and available for all potential users. It follows an object oriented design to ensure that errors and unreasonable measurements can be easily detected. MORIS is implemented in Oracle, the development tool is Developer 2000. The system is maintained by a professional data base specialist and each member of our research program will have access to all kinds of data stored. Furthermore, MORIS is particularly designed to be user friendly in terms of data input and output needs, to ensure its key role within the program.

Another important key role within our program is modeling (see project 4). The main purpose of this project is to integrate and quantify results, develop and evaluate restoration scenarios and detect future research needs. We plan to adopt existing statistical models such as the individual tree models MOSES (Hasenauer 1994) and PROGNAUS (Sterba and Monserud 1997). Furthermore, biogeochemical models (see Running and Coughlan 1988) are being developed to study the transport and transformation of energy, carbon water and nitrogen as it may affect different restorations phases.

7. Conclusion

Profit-oriented wood production, grazing, litter raking, and game management have changed and degraded large areas of Austrian forests. Meanwhile, the endeavor to protect sustainable resources has become more popular. Since the first symptoms of air pollution were detected mainly in secondary man made coniferous forests, it became evident that human interference had resulted in a dramatic lack of resilience. Consequently, it is expected that additional stress factors resulting from air pollution, deposition and expected climate change will particularly affect such devastated stands unless proper management strategies are implemented to protect and restore fragile forest ecosystems.

During the next 10 years, we will investigate and evaluate restoration processes and develop restoration scenarios. Socio-economical and policy analyses should provide the proper framework to develop implementation strategies. Besides the scientific challenge, we are particularly interested in transferring an expected research output into forest management plans that support forest managers and public agencies.

Acknowledgments

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Transformation of Spruce Monocultures to Mixed Stands with Heterogeneous Structure on Nutrient Poor Soils in Denmark

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Abstract

Monocultures of Norway spruce (*Picea abies* L. Karst.) are the dominating forest type on nutrient poor soils in Denmark and cover more than 50% of the total forest area at these sites. The background for the profound use of this non-native species includes historic, climatic and economic aspects. The silvicultural flexibility of the Norway spruce stands decreases with increasing height which causes server problems in relation to regeneration and introduction of new species in old stands. Results from regeneration experiments under canopies of young and middle-aged Norway spruce stands are presented and it is concluded that the shelterwood system is a primary tool for transforming the Danish heath plantations into mixed forests.

Keywords: Norway spruce, monocultures, transformation, mixed stands

Reforestation in the western part of Denmark

The Weichsel glaciation, which took place 15 000 years ago resulted in a relatively sharp division of the central and southern part of Jutland into an eastern undulating and hilly part with sandy to clay-like till deposits and a western part dominated by plains with sandy, nutrient poor soils. The following succession eventually covered almost all parts of Jutland with mixed deciduous forest.

After centuries of deforestation, the forest cover was reduced to c. 3% of the total land area around 1800 which resulted in a loss of forest climate, soil erosion and a loss in productivity. These conditions led to the formation of 1 mill. ha. of heath areas, especially on poor sandy soils in the central and western part of Jutland.

During the following 200 years, enormous resources were engaged in an effort to reforest these heath land areas. In the beginning, numerous techniques were tested including different soil preparation techniques, liming and fertilisation, seeding and planting, use of nurse trees and N-fixing herbs, all in an attempt to develop cheap and safe methods of reforestation. A wide range of broad leaved species and conifers were used in these trials but due to the harsh growing conditions and, in some cases, lack of adapted genetic material (provenance) only Norway spruce (*Picea abies* (L.) Karst.) and *Pinus mugo* proved to be usable for large scale reforestation. *Pinus mugo* was often used as a nurse tree for Norway spruce and in mixtures with one of these species Silver fir (*Abies alba* Mill.) also proved successful to some extent (Tøttrup 1997; Løfting 1949). Since the end of the 18th century c. 300 000 ha were successfully reforested in Denmark of which c. 2/3 lies in the central and western parts of Jylland. As Norway spruce proved to be the economically most valuable species, it was favoured during thinning operations and it has, therefore, become the dominant species covering c. 50% of the forest area (Miljøministeriet 1994).

Transformation of monocultures

Norway spruce is not well adapted to the Atlantic climate in Denmark which is characterised by strong winds and relatively warm winters. The plantation system based on even-aged monocultures has therefore led to large windthrow catastrophes and loss of silvicultural flexibility due to biotic and abiotic damages which results in clear-cut situations. As illustrated in Figure 1, the microclimatic conditions on clear-cut areas limits the choice of species to the most frost resistant and fast growing ones which usually leads to the establishment of new Norway spruce dominated stands. However, even when using frost resistant species it has often been necessary to replant more than 100% of the planted trees (Løfting 1949). With regard to the regeneration of first and second generation spruce plantations, the challenge is to establish and maintain a forest cover and develop techniques

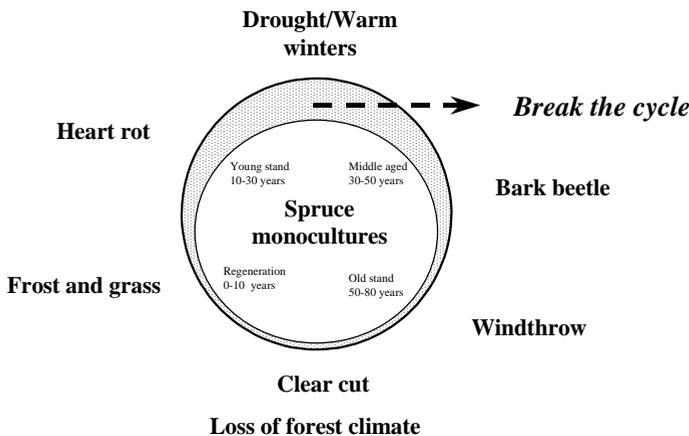


Figure 1. Cycle of spruce monocultures. Illustration of the problems of a plantation system. The thickness of the black area illustrates the silvicultural flexibility of the stand. Flexibility is low in an old stand due to the risk of windthrow and on clear-cut areas due to the microclimatic conditions. The introduction of site adapted species demands a medium to long term forest climate and so the best possibility of breaking the circle is to use the young or middle-aged stand as shelters.

that will secure a successful transformation of the plantations into stable forests by using the protection and forest climate provided by the existing stands. Due to the wind climate in Denmark, with frequent storms the possibilities of establishing stable shelterwoods are limited. Experience shows that the mechanical stability of Norway spruce monocultures primarily depends on the thinning history and the height of the stands (Neckelmann 1992). The most stable stands are those where no thinnings have been carried out or where more than 50% of the basal area have been removed at a young age whereas increased thinning density at a high age destabilises the stands severely. However, Norway spruce stands are relatively stable when the height of the trees does not exceed 12–14 meters (Neckelmann 1992) and it is therefore recommended that shelters should be established at this height in order to obtain long term stability. On better sites this means that it is necessary to establish the shelter at a young age in order to obtain a stable stand while a height of 12–14 meters is first reached at an age between 45 and 60 years on poorer sites.

Transformation of Norway spruce stands admixed with one or more (more or less suppressed) other species

During the last 100 years silver fir has been the preferred species in mixtures with Norway spruce. It has proved resistant to heart rot and has a long term stability and long rotation age (Neckelmann 1986). Experience shows that shelterwood transformation is the most promising approach for establishing Silver fir and that it can perform well under a canopy of Norse spruce.

This is also supported by the results of an experiment which was carried out in the period from 1965–1995 comparing the following transformation strategies:

- clear-cut of a former stand (Norway spruce) followed by different kinds of soil preparation and planting of species mixtures
- strip wise clear-cut system followed by soil preparation and planting of species mixtures in the clear-cut strips partly protected from the remaining old stand along the strips, and
- shelterwood cutting of former stand (Norway spruce, 15 m high) followed by soil preparation and planting of species mixtures (Neckelmann 1995).

Silver fir was the only frost sensitive species included in the experiment. The results were very clear regarding the survival and growth of silver fir, as the shelterwood treatment proved clearly superior to all the other treatments in terms of survival and growth of silver fir (see Figure 2 and Figure 3).

Due to the frost sensitivity and slow initial growth of silver fir, it has often been suppressed or even eliminated in the regeneration phase which has lead to stands dominated by Norway spruce with an under storey of Silver fir. The transformation experiment described above was recently turned into a long-term experiment on how to utilise such suppressed admixtures of silver fir in the process of transformation. The experiment includes two sites, each of 4 plots according to the treatments of Neckelmann (1995). The plots are dominated by Norway spruce in the upper storey admixed with larch (*Larix káempferi* (Lamb.) Carriere) and scots pine (*Pinus sylvestris* L.) and with smaller or larger numbers of more or less suppressed silver fir (*Abies alba* Miller) in the under storey. Two different thinning strategies will be followed in the experiment:

- a) Aims at a relatively homogeneous stand of only spruce and fir. Cuttings will favour fir, while pine and larch successively will be removed from the stand.
- b) Aims at a heterogeneous mixed stand of as many species as possible. Cuttings will favour fir, while spruce will be cut in favour of larch and pine.

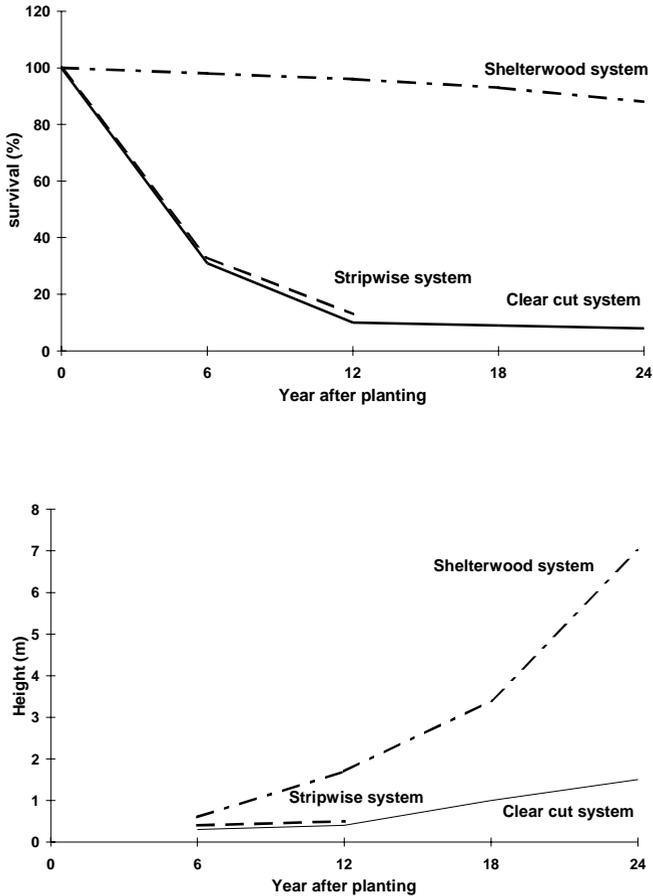


Figure 2. Survival rate and mean height of silver fir seedlings by different regeneration systems (see text). Gludsted. Redrawn from Neckelmann (1995).

As the stands develop different structures according to the different thinning strategies, different regeneration strategies will be implemented. The A-plots will be regenerated by shelterwood regeneration, preferably by natural regeneration, but by means of planting if necessary. The B-plots will be regenerated in groups by natural regeneration only. It is planned that the forest structure and microclimatic factors will be followed intensively along with the regeneration of the stands. Already after the first thinning, considerable differences in forest structure have evolved.

Test of six tree species for regeneration under a Norway spruce canopy

In accordance with the above mentioned recommendations, shelterwoods were established at three different sites in Jylland in the spring of 1992. The 1995 stand characteristics and soil properties are shown in Table 1. The average precipitation in the period from 1993 to 1997

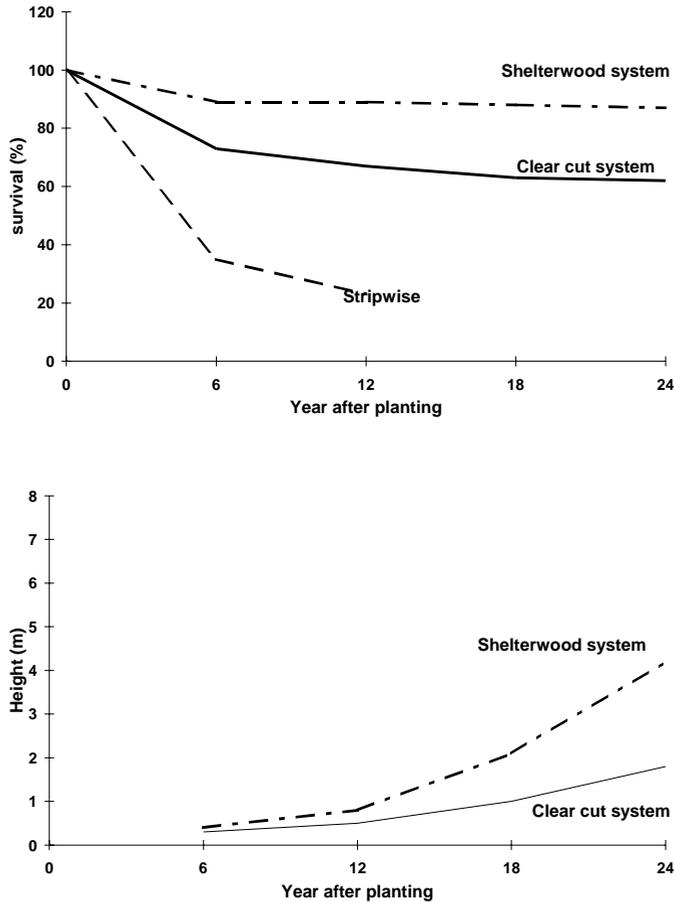


Figure 3. Survival rate and mean height of silver fir seedlings by different regeneration systems (see text). Feldborg. Redrawn from Neckelmann (1995).

was 564 mm at Løvenholm, 736 mm at Feldborg and 874 mm at Lindet. Norway spruce often has a very shallow root system and so a strip-wise soil preparation technique can damage the roots and destabilise the stand. In order to avoid this risk, techniques that prepare single plant holes have been developed (Köpsell and Steinbrich 1989). In the experiment this technique was copied by planting in holes of $25 \times 25 \text{ cm}^2$ made by removing the litter layer and mixing the O-horizon and the mineral soil to a depth of approximately 25 cm by the use of a spade.

Dolomite lime (10% Mg) and PK-fertiliser were applied to one half of the plant holes. The lime (49.1 g) was mixed with the mineral soil while the fertiliser (1.25 g Potassium, 0.50 g phosphorus) was placed on the soil surface of the plant holes. Analyses of the exchangeable cations in the plant hole soil were made in the autumn of 1996. They showed that the amount of exchangeable calcium and magnesium had increased significantly in the plant holes at all three sites and that the aluminium content was reduced leading to a significant raise in pH and base saturation.

As part of the fertilisation and liming program at Feldborg the following nutrients were applied. In spring 1988, 520 kg ha^{-1} 23-3-7 NPK fertiliser with Mg, Cu, and B were applied with

Table 1. Soil properties (0–50 cm) and stand characteristics for the three experimental sites before and after the thinning in the spring of 1995.

Site and age (year)	Løvenholm, 24		Feldborg, 58		Lindet, 25	
	Before thinning	After thinning	Before thinning	After thinning	Before thinning	After thinning
Stems per ha	731	624	747	610	826	427
Basal area (m ² /ha)	14.3	11.9	17.6	13.5	17.2	10.2
Diameter (cm)	15.8	15.6	17.3	16.8	16.3	17.5
Height (m)	12.4	12.3	13.6	13.5	11.3	11.7
pH (CaCl ₂)		3.8		4.0		3.7
C/N ratio		30.6		42.1		44.1
Texture ¹ %						
Clay		6		3		6
Silt		6		2		3
Fine Sand		52		21		38
Coarse sand		36		74		52

¹ Clay <2 µm, Silt 2–20 µm, Fine Sand 20–200 µm, Coarse sand 200–2000 µm

a Moteska fertiliser-distributor. In spring 1992, agricultural lime and dolomite (3 tons ha⁻¹ of each) were applied and in October 1994 300 kg ha⁻¹ 0-7-18 PK fertiliser with Cu and Mg and 400 kg ha⁻¹ triple phosphate were applied. In 1992 and 1994 the distribution of the lime and fertiliser was carried out with a machine that blew the fertiliser and lime over the area.

In spring 1993 seedlings of beech (*Fagus sylvatica* L.), pedunculate oak (*Quercus robur* L.), small-leaved lime (*Tilia cordata* Mill.), sycamore (*Acer pseudoplatanus* L.), european silver fir (*Abies alba* Mill.) and douglas fir (*Pseudotsuga menziesii* var. *viridis* Mirb. Franco) were planted in the plant holes at the three sites. At the time of establishment the heights of the seedlings were as follows: oak 50–80 cm, beech 30–50 cm, lime 30–80 cm, sycamore 40–60 cm and douglas fir 30–50 cm. The initial height of the silver fir was not recorded but is estimated to have been 15–20 cm. The objective was to improve our knowledge regarding growth and survival of different species under a Norway spruce canopy and the possibilities of improving regeneration success by fertilisation.

The canopy density towards south ($\pm 45^\circ$) was measured with two Li-cor LAI-2000 Plant Canopy Analysers (one above and one below the canopy) in spring 1995, 1996, 1997 and in autumn 1997. Since the thinning in 1995 the canopy density has been significantly higher at Løvenholm than at the two other sites resulting in an average relative PAR of app. 18%, while the values for Lindet and Feldborg was 25% and 28% respectively.

Survival rate

The overall survival rate in 1997 for all species and sites was 81% which is satisfactorily in relation to establishing a complete regeneration. There was, however, significant differences between sites and species (see Figure 4). 89% of the seedlings were alive in the fifth growing season at Lindet while 82 and 72% were alive at Løvenholm and Feldborg, respectively. The variation between sites is due to significant differences in the survival rate of silver fir, oak and douglas fir at the three sites. Liming and fertilisation have had a positive effect on the survival of sycamore and lime at all three sites and on the survival of silver fir at Feldborg

and Løvenholm, whereas no clear effect was found for beech, oak and douglas fir.

A statistical model with canopy density (LAI) as a covariant was used to analyse the effect of the canopy density. At Feldborg, the 1995 survival rate of oak and silver fir had been negatively effected by increasing canopy density whereas no significant effect was found for other species and sites. As increasing canopy density is correlated with reduced near ground light intensity and throughfall (McLaughlin 1978) and increased upper storey fine root intensity (Nielsen and Mackenthun 1991), the canopy density does not only effect light conditions but also soil water content. This factor has not been measured in this study. Hence, it is impossible to conclude whether the increasing mortality of oak and silver fir with increasing canopy density is due to one or both of these factors.

Height

The mean height in autumn 1997 of the seedlings is shown in Figure 5 for the two treatments at the three sites. The combined fertilisation and liming has had a limited effect on the height growth of silver fir, beech and oak but a positive effect on the height growth of douglas fir, sycamore and lime at Lindet and Løvenholm, whereas only a small or no effect can be seen at Feldborg. Thus, the fertilisation and lime applied to the plant holes has only had a marginal effect due to the fertilisation in 1988, 1992 and 1994 at Feldborg. The size differences shown in Figure 5 is partly due to differences in initial size at the time of planting.

In Figure 6, the height growth from spring 1995 to spring 1998 (three growing seasons) is shown for all species relative to the height growth of silver fir. At all sites, beech, douglas fir and oak have had a larger height growth than silver fir. Lime also performs better than silver fir at all sites but only when it has been fertilised and limed whereas sycamore has only grown faster than silver fir at Løvenholm. At Løvenholm, the vertical canopy density has had a significant effect on the height of all species, except oak, whereas no significant effect was found at the two other sites.

The height differences between the species found in this experiment are in accordance with the results of an experiment established in 1927 in a heath plantation where the height development of different conifers and beech under a shelter of *Pinus mugo* (5 m high) was recorded (Løfting 1945). After 16 years, silver fir had reached a height of 1.9 meters, beech was 2.25 meters while douglas fir had reached a height of 5.5 meters.

Conclusions

Conversion of spruce monocultures in Denmark has been carried out on a small scale for decades with Silver fir as the dominant species used for regeneration. From these experiences it is known that the protection provided by a Norway spruce shelter prevents damage from late spring frost and *Hylobius* to the seedlings of frost sensitive species like Silver fir.

Under wind climates with frequent storms, it is usually necessary to establish shelters at an early age in order to prevent large windthrows and thereby damage to the seedlings. The height growth of the seedlings plays an important role in relation to the rate by which the upper storey can be removed and, so, the choice of species for underplanting should be closely linked to the expected long-term stability of the stand. The use of silver fir for transformation requires a long-term shelter (20–25 years) due to its slow growth and frost sensitivity. Under most soil conditions beech and douglas fir would be good alternatives as they grow faster in the early stages and have a higher survival rate.

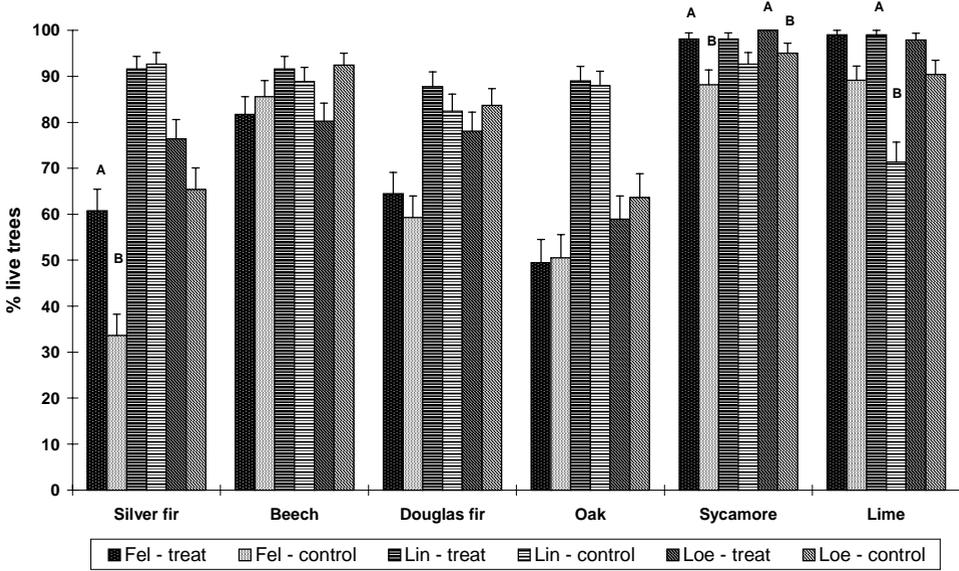


Figure 4. Survival ratio in the fifth growth season, 1997. The error bars shows the standard error of means. Different letters indicates significant differences ($p = 5\%$) between fertilised and unfertilised seedlings

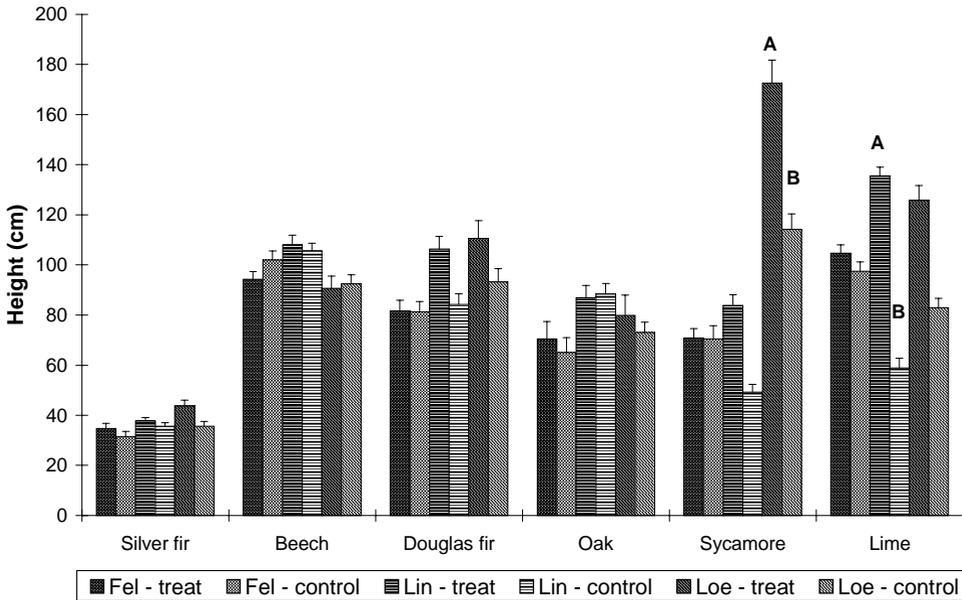


Figure 5. Mean seedling height after the fifth growth season (autumn 1997). The error bars shows the standard error of means. Different letters indicates significant differences ($p = 5\%$) between fertilised and unfertilised seedlings.

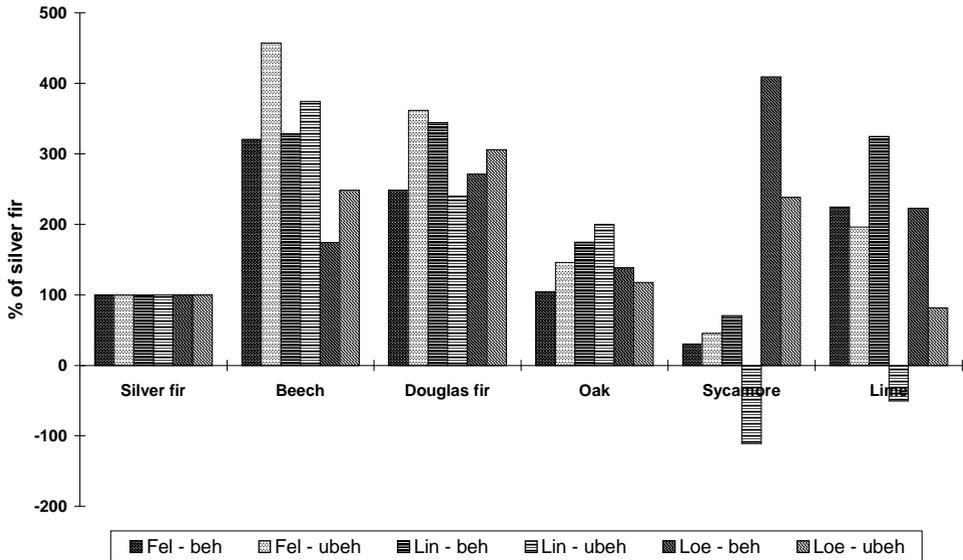


Figure 6. Relative height growth during three growth seasons (1995–1998). Silver fir = 100.

Experiments in mixed stands of Norway spruce and suppressed silver firs have recently been established in order to document the range of silvicultural flexibility obtained by breaking the “monoculture-cycle”.

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Photosynthetic Performance of *Quercus petraea*, *Fagus sylvatica* and *Acer pseudoplatanus* Planted under the Canopy of a Coniferous Forest

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Abstract

Advanced planting under the canopy of mature stands requires comprehensive knowledge about light requirements of the planted species. To supply such knowledge, *Quercus petraea*, *Fagus sylvatica* and *Acer pseudoplatanus* were planted on several plots from the forest edge up to 35 m inside the closed canopy of a Norway spruce/Scotch pine mixed forest in 1996. One additional plot with *Fagus sylvatica* was supplied with a calcium/magnesium fertiliser. The photosynthetic response was measured as a function of photon flux density *in situ* using a CO₂/H₂O porometer on 12 plants from each species in 1996 and 1997. In the year of planting, the light compensation point (LCP) was twice as high for *Q. petraea* than for the other two species. The photosynthetic capacity per unit leaf area was the highest in *Acer pseudoplatanus*. These species which related differences in photosynthetic performance had, however, changed substantially in the second year. No differences in LCP were found between the plants. *Quercus* and fertilised *Fagus* had significantly higher photosynthetic capacity than *Acer*, which declined its maximum photosynthesis from 15.1 to 5.8 μmol CO₂ m⁻² s⁻¹. The differences in photosynthetic performance were found to be related to nitrogen nutrition and to magnesium content on a leaf area basis. However, *A. pseudoplatanus* can theoretically still compensate for its low maximum photosynthesis by its highest total leaf area per plant. Thus, the ability of a plant to enlarge its total leaf area may be very important for plant survival in a low light environment.

Keywords: light compensation point, nitrogen, magnesium, photosynthetic performance

1. Introduction

Advanced planting of broadleaf species is being used increasingly to change the species composition in potentially unstable coniferous forests. It is, therefore, important to know both the species' light demand necessary for regeneration, and also the light distribution within the forest (Kazda 1997). The quantity and the quality of light vary significantly under the plant canopy. Figure 1 schematically displays the light intensity in the open area and on the forest floor. The light response curve of photosynthesis drawn across light intensity shows a sharp increase at low light level, and saturation at high light intensity. It is obvious that a substantial amount of carbon can be gained only during longer periods of direct solar radiation reaching the forest floor. Most of the time plants under the canopy have to cope with low light intensities rather close to the light compensation point of photosynthesis. As a consequence, leaves of light demanding plants will not receive sufficient light for carbon gain during a significant part of the day (Schmid et al.; this volume).

The acclimation of plants to a low light environment results in thinner and/or larger leaves, i.e. in a lower leaf mass per unit area (LMA) (Abrams and Mostoller 1995; Niinemets 1996). In a previous evaluation of this experiment, the LMA decreased from about 60 g m⁻² at the forest edge to about half that value at 35 m distance inside the forest for all trees, whereas the LMA of oak leaves was about 10 g m⁻² larger than that throughout the transect; this shows the low acclimation capacity of this species (Kazda et al. 1999). The development of thinner leaves makes it possible to distribute nitrogen across a larger area, thus optimising the light harvesting (Niinemets 1997).

Minimum relative light intensities of 1.6, 1.8 and 4–5% may be sufficient for the natural regeneration of *Fagus sylvatica*, *Acer platanoides* and *Quercus robur*, respectively (Walter 1960 in Mayer 1980), but must be considered as too low for advanced planting. Paci and Ciambelli (1996) have found relative light intensities between 4 and 50% as optimal for *Fagus sylvatica* regeneration. Drought stress (Grassi 1996) and nutrient shortage (Madsen 1995) can be limiting at higher light intensities. *Acer pseudoplatanus* showed rather high plasticity in experiments by Röhrig (1967); it survived at relative light intensities as low as 1%. The regeneration of light demanding *Quercus petraea* requires at least 20% of the light intensities in the open (v. Lüpke 1982).

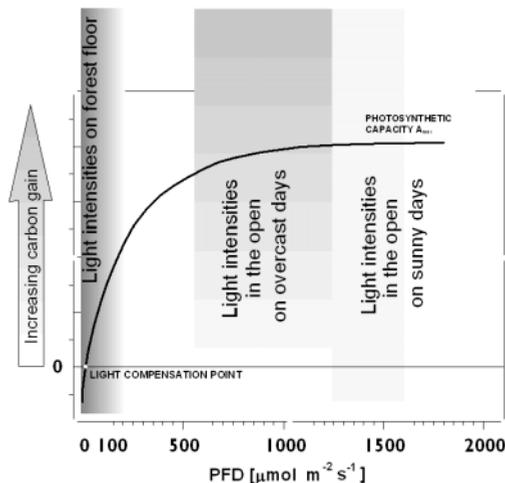


Figure 1. Typical light intensities and the light response curve of photosynthesis

The investigations just mentioned were based on integrative variables such as plant dry mass, height increment etc. The ability of plants to grow in different light environments can also be expressed using photosynthetic response to increasing light supply (light response curve) and the acclimation capacity of the individual plant species to prevailing light conditions. Then, linking data on photosynthetic performance with data on light conditions in the forest should make it possible to recommend threshold light conditions for planting broadleaf species under the canopy of coniferous forests.

The aim of this study is to evaluate light response curves of photosynthesis measured in an advanced plantation of *Quercus petraea*, *Fagus sylvatica* and *Acer pseudoplatanus* in terms of light requirements for regeneration of these species under a spruce canopy.

2. Methods

The experimental area is located in north west Austria near the German border in the Castell-Castell Forest Administration (12° 50' E, 48° 05' N). A mean annual temperature of 8°C and an annual precipitation of about 1000 mm would make the area very suitable for broadleaf species; in actual fact, however, large man made Norway spruce monocultures prevail in the area. To test the possibility of stand conversion through advanced planting, three-year-old saplings of *Acer pseudoplatanus*, *Fagus sylvatica* and *Quercus petraea* were planted in lines from the forest edge into the mixed spruce/pine forest in a block design in April 1996. An additional block was fertilised with 3000 kg ha⁻¹ of a Calcium/Magnesium fertiliser, consisting of MgO, MgCO₃, CaCO₃ (13.5% Mg and 11.5% Ca) and of organic material, two months later.

The photosynthetic response to photon flux density (light response curve) was measured on 12 plants per species along the line at every 3 m distance from the forest edge up to 35 m inside the stand. Photosynthetic measurements were performed on one leaf per plant using a LI-6400 CO₂/H₂O porometer with integrated light source (Licor inc. Nebraska, USA). The photosynthetic response to increasing light intensity (0, 50, 150, 450, 900 and 1500 μmol photon m⁻² s⁻¹) was measured in adjusted internal conditions at vapour pressure deficits between 0,5 and 1,2 kPa and at leaf temperatures between 19 and 21°C during July 1996 and 1997. After the measurement of each plant the number of leaves, leaf dry mass, leaf area of 20 leaves was assessed. In the laboratory, leaves were dried, homogenised and analysed for leaf nutrient content of N (after Kjeldahl), Ca, Mg and K (HNO₃ digestion followed by atomic absorption spectrometry). Statistical evaluations were performed using the Statistica package (StatSoft inc., Tulsa, Oklahoma, USA) to test for significant differences between the means by the Tukey Honest Significant Difference Test and to calculate multiple regression models.

3. Results

The light response of the plants investigated shows remarkable differences between the two years, and between species (Figure 2). In the year of planting (1996), photosynthetic capacity of *Acer* was twice as high as that of *Fagus* and of *Quercus*. Remarkably, no differences were found between the latter two species. Species properties were substantially different in the following year. The decline of photosynthetic performance of *Acer pseudoplatanus* from 15.1 to 5.8 μmol CO₂ m⁻² s⁻¹ was unexpected. The photosynthetic capacity in 1997 was

significantly higher in *Quercus* and fertilised *Fagus* plants than in *Acer*. Calcium and magnesium addition (Table 2) is likely to have an effect upon this parameter, though the differences in the maximum photosynthesis between fertilised and control beech plants are not yet significant (Table 1).

Light compensation points of photosynthesis (LCP) indicate differences between the light demanding *Quercus* and the shade tolerant *Fagus* and *Acer* in 1996 (Table 1). But one year later, these differences had disappeared, and the leaves of all unfertilised plants started with carbon gain at the same light threshold. Nutrient addition had obviously improved the shade tolerance in beech plants (Table 1). This is also expressed by a multiple regression model:

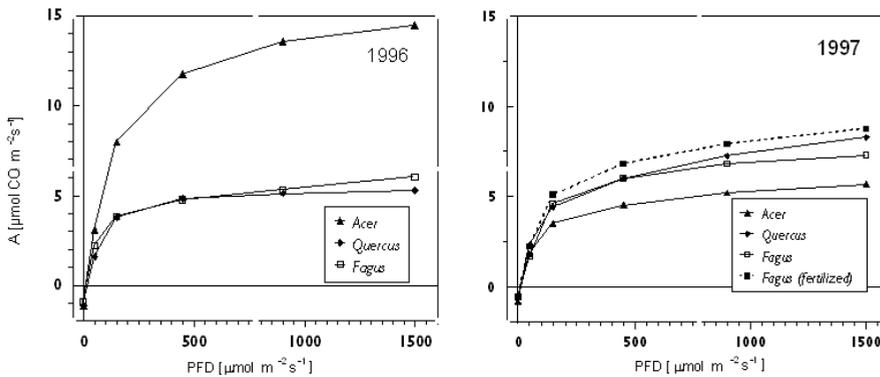


Figure 2. Photosynthetic light response curves of the investigated plants (means from 12 plants per species) for measurements in July 1996 and 1997.

Table 1. Mean photosynthetic parameters of the investigated plants (12 plants per species) for the years 1996 and 1997 (Letters behind the means indicate significant differences between the plants at $p < 0.05$ in HSD test.)

Species	Light compensation point [$\mu\text{mol Photon m}^{-2} \text{ s}^{-1}$]	Photosynthetic capacity A_{MAX} [$\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$]
1996		
<i>Acer pseudoplatanus</i>	11.9 a	15.12 b
<i>Quercus petraea</i>	23.9 b	5.75 a
<i>Fagus sylvatica</i>	14.9 a	7.14 a
1997		
<i>Acer pseudoplatanus</i>	18.7 b	5.84 a
<i>Quercus petraea</i>	18.0 b	8.37 b
<i>Fagus sylvatica</i>	18.3 b	7.62 ab
<i>F. sylvatica</i> (fertilised)	11.1 a	9.21 b

LCP [$\mu\text{mol Photon m}^{-2} \text{s}^{-1}$] = $16.3 + 20.3 \text{ DIFN} - 2.23 \text{ Mg} [\text{mg g}^{-1}]$ ($R^2 = 0.34$; $N=42$; $p < 0.001$),

where DIFN is the canopy transmittance (0–1) estimated by LAI 2000 Canopy Area Meter (Schmid et al., this volume). Thus, improved magnesium nutrition decreases the light compensation point, but increased canopy transmittance towards the forest edge (DIFN) increases it.

The differences in photosynthetic capacity can be explained, in part, by differences in leaf nutrients (Table 2). Especially in the case of *Acer*, mean leaf nitrogen content declined by 10 mg g^{-1} to 17.7 mg g^{-1} from 1996 to 1997. In the second year after planting (1997), *Fagus* exhibited significantly higher nitrogen contents for both treatments. Nitrogen, on a leaf area basis, is the highest in *Quercus* (1167 mg m^{-2}), followed by fertilised and control *Fagus* (990 and 926 mg m^{-2} , resp.) and *Acer* with the significantly lowest contents of 821 mg m^{-2} . The differences in leaf nitrogen are reflected in the photosynthetic capacity (Table 1). The photosynthetic capacity in 1997 was modeled using a multiple regression model, which also indicated a positive magnesium effect:

$A_{\text{max}} [\mu\text{mol CO}_2 \text{ m}^{-2} \text{s}^{-1}] = -1.35 + 0.50 \text{ N} [\text{mg g}^{-1}] + 0.35 \text{ Mg} [\text{g m}^{-2}]$ ($R^2 = 0.33$; $N=42$; $p < 0.001$).

The photosynthetic carbon gain has been given per unit leaf area. Table 3 combines these numbers with the total leaf area of each plant in order to show the theoretical maximum photosynthesis of the whole plant (last column in Table 3). The low photosynthetic capacity of the *Acer* plants is outweighed by the largest total leaf area. Thus, they can be as efficient as the fertilised *Fagus* plants. In contrast, the low total leaf area of *Quercus* plants restricts its carbon gain potential.

Table 2. Mean nutrient contents [mg g^{-1}] in the leaves of the investigated plants (12 plants per species) (Letters behind the means indicate significant differences between the plants at $p < 0.05$ in HSD test.)

Species	N		Ca	Mg	K
	1996	1997	1997		
<i>Acer pseudoplatanus</i>	27.7 b	17.7 a	2.67 a	1.90 a	7.21 b
<i>Quercus petraea</i>	21.7 a	20.7 a	4.48 b	2.36 a	5.58 ab
<i>Fagus sylvatica</i>	23.1 a	22.6 b	4.83 b	2.16 a	4.01 a
<i>F. sylvatica</i> (fertilised)	—	22.6 b	4.36 b	2.55 a	4.07 a

Table 3. Theoretical maximum carbon gain of the whole plant calculated from 1997 data (12 plants per species).

Species	Specific photo-synthetic capacity, A_{MAX} [$\mu\text{mol CO}_2 \text{ m}^{-2} \text{s}^{-1}$]	Total Plant leaf area [cm^2]	Maximum total plant photosynthesis [$\mu\text{mol CO}_2 \text{ s}^{-1}$]
<i>Acer pseudoplatanus</i>	5.84 a	2286 c	1.31 b
<i>Quercus petraea</i>	8.37 b	761 a	0.62 a
<i>Fagus sylvatica</i>	7.62 ab	1278 b	1.04 b
<i>F. sylvatica</i> (fertilised)	9.21 b	1469 b	1.27 b

4. Discussion

The light demand of plants has generally been classified in relation to the minimum relative light intensity below the canopy (Mayer 1980). One would expect that these numbers for minimum relative light intensities reflect the light compensation point of photosynthesis, i.e. that the threshold light intensity at which the leaf starts to gain carbon is higher in light demanding than in shade tolerant species. Indeed, we found this expectation to be true in the year of planting, when the light compensation point (LCP) was twice as high in *Quercus* than in the two other species under study. Identical light compensation points of unfertilised plants in the second year indicate, however, that all species have adapted their photosynthetic apparatus in a similar manner. But improved base cation nutrition has lowered this parameter and has enabled fertilised *Fagus* plants to start with positive net photosynthesis at lower light intensities. Differences in light compensation points are very important for plant survival in shade, since the light intensities below the canopy are often only slightly above LCP values (see Figure 1 and Schmid et al. this volume).

In the first year, the high photosynthetic capacity of *Acer* can be attributed to its excellent nitrogen nutrition as found for other forest species by Oren et al. (1986) and Reich et al. (1995). For the same reasons, photosynthetic capacity has declined in the following year. The light demanding *Quercus* leaves have high leaf mass per unit area (Kazda et al. 1998) and thus increased nitrogen levels per unit leaf area. That enables high photon gain in oak in comparison to maple (Reich et al. 1995) despite no significant differences in leaf nitrogen content in mg g^{-1} . The multiple regression analysis for photosynthetic capacity indicated that better magnesium nutrition enhances photosynthetic performance. The finding by Niinemets (1995) that magnesium allocation in shade leaves is important for the light harvesting complex, is in accordance with our results. In addition, Küppers et al. (1985) improved photosynthetic performance through magnesium addition to deficient pine plants. Thus, better magnesium nutrition increases the chance for survival for plants in low light environment by changing both the light compensation point and the photosynthetic capacity.

The interpretation of photosynthetic capacity per unit leaf area can lead to biased estimates of plant growth potential. This is obvious from the data for *Acer*, where the high total leaf area compensates for the low photosynthetic capacity. For survival and growth on the forest floor, it is crucial for the plants to adapt their photosynthetic apparatus *and* to build large and thin leaves in order to absorb light on an area as large as possible. In this respect, the investigated *Quercus petraea* is a typical example of a light demanding species that has the lowest total carbon gain under shade conditions due to a small total leaf area.

5. Conclusions

Because of several unknown factors, such as the acclimation of photosynthetic apparatus (Brooks et al. 1994) and the influence of plant nutrition, we cannot yet decide upon light threshold values for advanced planting. Whereas in the year of planting, the plants were still largely influenced by the light and nutrient conditions of their previous three years in the nursery, the results from the second vegetation period after planting suggest that the adaptation of different plant species to low light environment is driven more by such a simple reaction as the enlargement of the total leaf area than by a species specific acclimation of the photosynthetic apparatus. The latter is further determined by nutrient availability, that enables better supplied plants to start with a positive net photosynthesis at lower light intensities. Thus, for practical forestry, it is crucial to maintain (and to protect against game damage) a

large leaf area of the young plants and to improve their nutrition, if necessary, to ensure a successful forest regeneration.

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Conversion of Norway Spruce (*Picea abies* L.) Stands into Mixed Stands with Norway Spruce and Beech (*Fagus sylvatica* L.) – Effects on the Stand Structure in Two Different Test Areas

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Abstract

16% of the Bavarian State forests consist of Norway spruce (*Picea abies* L.) stands, which are critical from the ecological point of view and are very susceptible to abiotic and biotic damages.

With regard to nature-orientated forest management one aim is to transform pure needle monocultures into stands with deciduous tree species. Mainly, it is previewed to see if it increases the stand structure and biological diversity. To test this hypothesis within a short research period, it was necessary to examine different stages of the conversion process. With the help of different structure elements, the differences between the conversion stages are demonstrated and discussed according to the following aspects:

- models of three-dimensional structure,
- tree species composition of the old stand compared to the young regeneration beneath a shelter, and;
- a combination of natural regeneration and artificial reproduction

The results demonstrate a striking change within the stand structure from the monotone control areas to the conversion stands with beech (*Fagus sylvatica* L.) groups. The results lead to conclusions for practical silviculture.

Keywords: nature orientated forestry, stand structure, biodiversity, silvo-ecological analysis, “biological rationalization”.

Introduction

With regard to the present discussion of “a greater degree of nature protection in the forest” environmental protectionists criticise the fact that monotone and, from the ecological point of view, invaluable spruce monocultures are still growing on a large area of the Bavarian forests (Bode 1994, Ammer 1988, Hanstein 1984).

At the moment, 16% of the Bavarian State Forests consist of pure stands of *Picea abies* (with mixtures less than 10%). In total, this species covers about 50% of the Bavarian forest area, which used to be occupied by mixed stands with mainly beech (*Fagus sylvatica* L.).

According to the opinion of the nature conservation monocultures with Norway spruce (*Picea abies* L.) which are not adapted to their specific surrounding show less faunistic species and are responsible for the decrease of species listed in the so-called red lists (Blab 1995).

Moreover unnatural needle monocultures are very susceptible to different biotic and abiotic calamities: The hurricanes Vivian and Wiebke proved that Norway spruce (*Picea abies* L.) monocultures show a low stability: 23 mill. m³ of wood have been victims of two of the strongest storm events ever noticed in Bavaria. 80% of the timber mass thrown at that time consisted of spruce timber (BayStMELF 1990).

In the mid-seventies, the Bavarian State Forest Administration started emphasizing the conversion of spruce monocultures into mixed stands by underplanting, especially with beech (*Fagus sylvatica* L.) and silver fir (*Abies alba* Mill.) (Arenhövel 1996, Burschel 1985, Weidenbach 1985). In relation to the long regeneration phases and the system of selective group-wise cutting, this development often receives little attention from the public because of the long period the deciduous trees and the firs spend beneath the shelter of the old trees (Ammer 1988).

Hypothesis

According to the introduction and the problem described above the following hypothesis were examined:

Although the conversion stands still look like pure needle stands at first sight, the species composition of the young regeneration beneath the shelter will result in mixed stands with *Picea abies* and mixed tree species (especially *Fagus sylvatica* L.) in the next generation.

It is expected that the conversion process will lead to an increase in the biodiversity only a few decades after its beginning. This positive development can be demonstrated with the help of the horizontal and vertical stand structure.

The silviculture treatment of the conversion stands favour different illumination situations below the canopy and consequently provides ecologically diverse habitats.

It is forecasted that the conversion process will also have positive effects on the remaining old trees.

It was the aim of the research project to quantify and qualify the described process. For this purpose the Bavarian State Ministry for Nutrition, Agriculture and Forestry funded an interdisciplinary research project to deal with the effects of the conversion in different parts of the ecosystem, as there are, for example, the stand structure, soil fertility, nutrient fluxes, herbaceous vegetation and diversity of arthropods.

In the following part of the project it was the aim to investigate the effects of the conversion on the stand structure and biodiversity.

Methodology

An important aim of the conversion of pure spruce stands into mixed stands is to increase the stand structure and biological diversity.

To prove the hypothesis within a short research period, it was regarded necessary to examine different stages of the conversion of Norway spruce stands which already exist in a forest environment on similar soil types. This “space for time substitution” is a methodical approach to replace the long-term study of a real stand development (Pickett 1989). Therefore different stages of the development existing at one site at the same time have been analysed.

Two test sites have been selected: Biburg and Schernfeld; in each of the two test sites the following three conversion stages were chosen for closer investigation:

- a 90-year-old (Schernfeld) respectively 110-year-old (Biburg) spruce (*Picea abies* L.) monoculture without any or only with first signs of young regeneration trees as a control area in order to characterise the stage before beginning with conversion,
- a 120-year-old spruce monoculture with a 20-year-old beech group beneath its shelter as a first conversion stage and
- a 120-year-old (Biburg) respectively 140-year-old (Schernfeld) spruce monoculture enclosing a 40-year-old beech (*Fagus sylvatica* L.) group as a second conversion stage

Each conversion phase was represented by a test area of the size 40 m x 20 m. The design of the test area is shown in Table 1.

In each test unit the stand structure was analysed by various structural elements including different variables for the investigation of the horizontal and vertical stand structure (Spellmann 1995).

In order to characterise the old stand, its coordinates, the height, the extent of the shelter-effect (crown radius in eight directions and crown beginning) and the diameter have been investigated by manual measurement.

Within the regeneration plots, the number of species has been counted and the height of each tree and their vitality have been ascertained.

The variables mentioned above enable us to describe the horizontal and vertical structure of the specific stand with the help of different structure elements. The horizontal structure can be divided in distribution (regular – accidental – heaped), density (crowded – light – spatial), diversity (poor – two species – several species), mixture and edge effect (single – group – by row). The vertical structure can be described by the following specific indicators (Füldner 1995):

- relative height structure (the height of a single tree compared to the height of the neighbours in the regeneration plots)
- absolute height structure (the height of the single tree related to defined absolute height classes)

Table 1. Design of the test units.

Test units	Size/number of plots
Size of the test area	40 m x 20 m
Number of regeneration plots	128
Size of the regeneration plots	2.5 m x 2.5 m
Soil vegetation	10 m x 10 m

Results

3-dimensional models

3-dimensional models (Figure 1), containing the real data of the stands, can be regarded as an excellent method of visualising the stand structure (Nagel 1996). The regeneration is represented by the highest tree of each regeneration plot.

These models compare the structure of the different regeneration phases. The chronosequence shows a group selection cutting regime. Although the second conversion stage in Biburg is similar to a single cutting regime, the shelterwood has to be conducted to group-wise cutting, because the beech (*Fagus sylvatica* L.) was planted within a tree-fall-gap, which was caused by a storm.

The regeneration stages can be described as follows:

- control area: high stand density of the old trees, only one layer existing, long but narrow shelter-effect; natural regeneration containing spruce and a few deciduous tree species, the regeneration is concentrated on the eastern and southern part of the test unit.
- first regeneration phase with beech (*Fagus sylvatica* L.): reduced number of old trees, increased tree distance, wider shelter-effects and a greater roughness of the canopy, two tree-layers; growth advantage of the planted beech compared to the spruce regeneration; several deciduous tree species made by natural regeneration within the beech group.
- second conversion phase: decreasing number of old trees surrounding the beech (*Fagus sylvatica*) group, old trees with long and large crowns; beech trees have a growth advantage of several meters to the spruce regeneration; this means an enormous potential for the development of a multi-stagial stand.

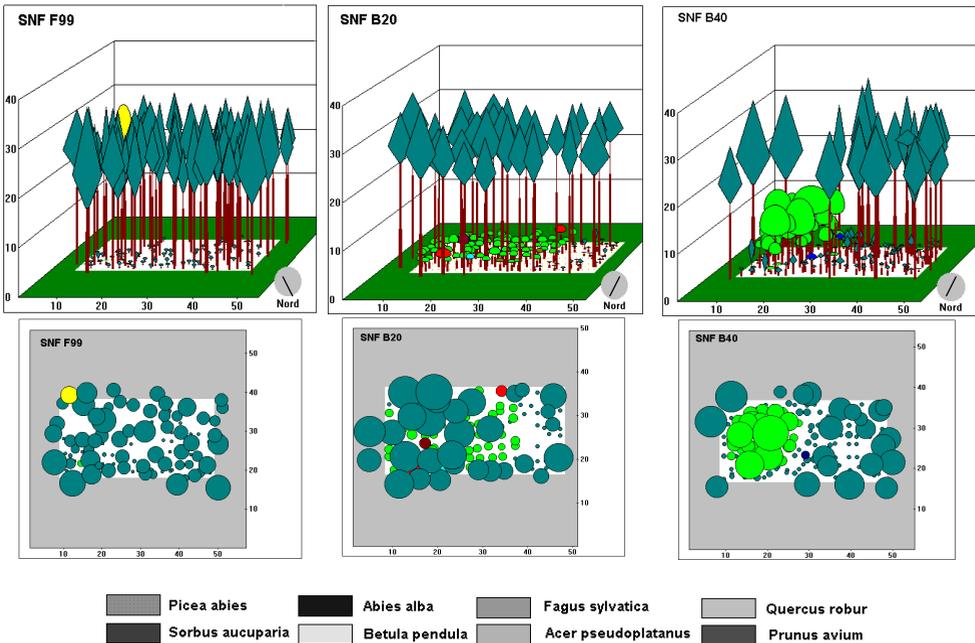


Figure 1. 3-dimensional models of the horizontal and vertical stand structure of the different conversion phases in the test area “Scherfeld” (SNF).

Effects on the old trees

First of all, the effects on the trees growing in the adult stand were analysed: to judge the stability of the old trees the relation between height and diameter (so called h/d-ratio) was investigated Figure 2. The calculated quotient for the old spruce trees is better in the two conversion phases and below the value of 80 whereas the trees of the control areas have a h/d-ratio of 90. The quotients further show that it even seems possible in older stands to improve the h/d-ratio during the conversion process.

Secondly, the reduction of the number of trees during the conversion indicates a higher timber mass of each remaining single tree (Table 2): a correlation between the number of stems and the timber mass of the remaining single tree can be detected; in Biburg this effect can be due to the group-wise cutting regime, in Schernfeld, of course, this effect also depends on the age-class of the old trees, as shown in the chronosequence. To understand the conversion process in Biburg, it must be taken into account that the 2nd conversion stage was created by a small gap caused by a snow breakage. This gap was covered by planting beech trees without any thinning in the following forty years. This explains the relatively high number of old stems, e.g. compared to the number of stems in the 1st stage.

Table 2. Characteristic values of the old trees.

Characteristic values	Schernfeld			Biburg		
	Control area	1 st conversion stage	2 nd conversion stage	Control area	1 st conversion stage	2 nd conversion stage
age of the old trees (years)	79	108	118	110	100	105
number of remaining old stems (n)	44	25	11	40	19	33
stock of timber mass (m ³)	1.3	2.1	2.5	1.8	2.4	1.9

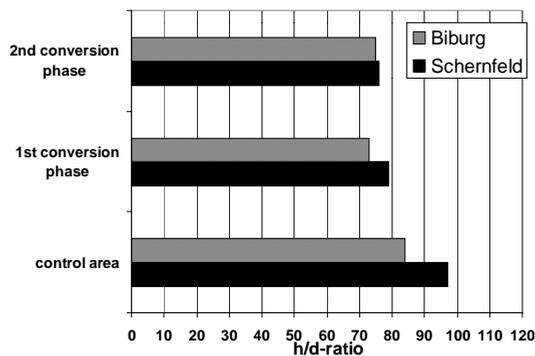


Figure 2. h/d-ratio of the remaining old trees as an indicator for the stability of the different conversion phases.

Illumination situation for the young regeneration

Ecologically, it is very important that different illumination situations exist beneath the canopy of the old trees. The variation of illumination beneath the shelter is the presupposition for the development of a heterogeneous stand structure and creates ecological niches (Johnson 1996, Canham 1988). To quantify the variety of the shelter-effect, the crown size was measured by the crown radius in eight directions. Thus, the shelter could be sized for each of the 128 regeneration plots. The values-variance shows the illumination variety of each test unit. Exact radiation measurements would have been too large-scale, because the measurement of the radiation had to be over the young regeneration in the different regeneration plots.

As Figure 3 demonstrates, the illumination variety of the conversion stages with beech (*Fagus sylvatica* L.) groups is higher, so it can be concluded that the treatment of group-wise cutting increases the number of ecological niches (Horn 1981). The high number of old trees in the second conversion phase of Biburg is responsible for the minor variation coefficient.

Change of the tree species composition

The conversion's main objective is to change the tree species composition.

Although only beech and silver fir were planted in the pure spruce stands, between four and eight different species in the young regeneration exist and, moreover, the layer of the young trees show both needle and deciduous tree species.

The result proves the potential for natural regeneration if seed-throwing trees are growing in close surroundings to pure spruce stands (Auclair 1983). An important presupposition for this result is the fencing of the admixed tree species over a period of 15 years. In the surroundings near the beech groups outside the fence there scarcely exists admixed tree species due to natural regeneration.

Due to the number of stems, the deciduous trees are in the minority compared to spruce. The vertical structure, on the other hand, clearly shows that the very important mixed tree species belong to the upper height-classes, thus having an advantage against spruce regeneration.

If the height of a regeneration tree is related to the highest tree of each regeneration plot, an answer can be given to the relative social structure of a test unit. This information is important for the development of the tree species composition and gives hints for silvicultural

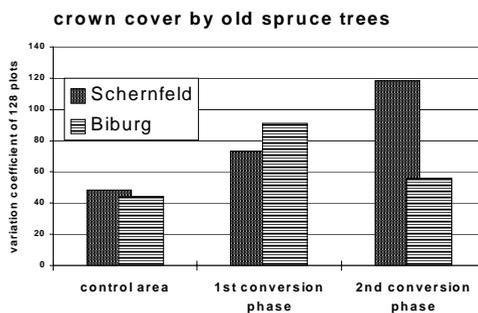


Figure 3. Variation coefficients of the crown cover in different conversion phases. The variation coefficient described above is calculated by the crown cover of 128 regeneration plots per test area.

Table 3. Tree species composition in the regeneration in the upper social classes (in %).

Characteristic values	Schernfeld			Biburg		
	Control area	1 st conversion stage	2 nd conversion stage	Control area	1 st conversion stage	2 nd conversion stage
<i>Picea abies</i>	97.2	26.2	73.6	72.1	27.3	57.9
<i>Abies alba</i>	1.3	0.2	0.8	1.2	0.9	0.0
<i>Fagus sylvatica</i>	0.1	71.1	25.6	2.3	66.1	41.9
<i>Quercus robur</i>	0.0	1.7	0.0	5.2	0.4	0.9
other deciduous species	1.3	0.2	0.0	19.2	1.2	0.2

measurements. Three social classes can be distinguished: first class (more than 80% height of the highest tree of the plot), second class (from 50 to 80% height related to the highest tree of the plot) and third class (below 50% height of the highest tree of the plot). A combination of the first and the second social class leads to the following tree species composition (Table 3).

Although beech (*Fagus sylvatica* L.) and spruce (*Picea abies* L.) are dominating the conversion phases, some deciduous tree species, especially in the first conversion stages, exist. In the second conversion stages, however, the deciduous tree species seem to disappear. As a matter of fact, the development of beech stands with admixed pioneer tree species clearly shows that the pioneer species will be eliminated forty or fifty years after their growth (Nüsslein 1995). Referring to historical data, it seems to be probable that admixed pioneer tree species initially existed in the second conversion stages. In order to maintain the tree species composition of the conversion phases, it is necessary to support pioneer tree species by thinning.

To sum up, the development of the conversion stages can be explained by the irregular shelterwood system, which includes planting and fencing of beech groups. The age-class of the old stands, however, seems only to have a minor influence on the stand structure, as shown by the similar age of the old stands in the test area Biburg.

Although this paper has only given a short introduction to the development of the stand structure at some stage in the conversion process, the following conclusions can be drawn according to the results mentioned above.

Conclusions

The irregular shelterwood system with staggered tending according to growth phases of shade and light demanders is a good technique to convert pure even aged Norway Spruce stands (*Picea abies* L.) into mixed stands with site adapted indigenous tree species. The combination of artificial planting and natural regeneration is a successful way to achieve an intensive mixture of several site adapted indigenous tree species and vertically structured stands. The shelterwood system follows the principles of naturalistic silviculture. Besides the cutting regime, the fencing of the deciduous tree species is necessary in order to maintain the admixed tree species.

Naturally growing deciduous tree species like birch (*Betula pendula* ROTH) or mountain ash (*Sorbus aucuparia* L.) increase the biodiversity (Auclair 1983, Pimm 1995). From an

ecological point of view, in order to conserve the very valuable succession phases it seems to be necessary to support these phases by care measurements, for example by selective and increment thinning.

On the other hand, the conservation of the succession phases as described above is inconsistent with the natural dynamic process. Therefore, it is important that these phases exist respectively and are developing locally, separated at other places in the stands. This requires conversion on a large scale.

The natural regeneration beneath the shelter of old trees offers further advantages:

- artificial planting is no longer necessary by all means for every small patch without forest growth.
- Often the natural regeneration improves the quality of the artificial regeneration (Leder 1992).
- A wider distance between the plants is possible and thus reduces the costs (Mosandl 1996).
- The remaining old trees seem to provide an appreciation in value because of the rising timber mass of the single tree which is combined with the reduced number of trees (Sinner 1997).
- A wide-spread composition of tree species could be an answer to fluctuations on the timber market and also offers a possibility to face the problems of long-term climatic change (Schreyer 1991).

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Restoration of Degraded Central-European Mountain Forest Soils under Changing Environmental Circumstances

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Abstract

Forestry in the Central-European mountains is confronted with a severe forest decline, which is attributed to the combined effects of continued spruce monoculture (borealization) and air pollution. This paper aims at pointing out the distinction between borealization and acid rain regarding their effects on soil acidification, and addresses the role of pioneer tree species in reversing this process.

The effect of borealization on soil pH was established at 0.2–0.3 pH units and a decrease in base saturation at up to 10%. Acid rain has a more pronounced effect on soil chemistry, accounting for a pH decrease of more than 1 pH unit and a reduction of the base saturation of up to 5 times or more over the last four decades. Pioneer broad-leaves exhibit a favourable influence on chemical soil properties, increasing the pH in the organic layer up to 1.3 units and increasing the base cation concentration 3–4 times within about 50 years.

A scenario analysis, using a deterministic soil acidification model, indicated the relative unimportance of soil weathering in counteracting acidification. Given a 50% reduction of acidic compounds in atmospheric deposition by the year 2050, the pool of plant available base cations will not be restored. The results support the idea of converting Norway spruce monocultures into mixed forests.

Keywords: Norway spruce, borealization, scenario analysis, soil acidification, soil restoration

1. Introduction

Forestry in the Central-European mountains is confronted with a severe forest decline, which is attributed to the combined effects of ‘borealization’ and air pollution. Borealization is defined as enhanced soil acidification and litter accumulation, retarded nutrient cycling and changed forest climate, brought about by large-scale continued spruce monocultures (Emmer et al. 1998). Since the late 1980s, air pollution has decreased and nowadays sustainable forestry and self-sustaining forests are topics that rank high on the agendas of Central-European governments. This, in combination with ongoing reductions of state funding and the increasing importance of tourist industries in mountainous areas, provides forestry with an impetus to abandon costly technical large-scale measures and to revert to an approach based on ecological principles.

The Krkonoše National Park (Czech Republic), a UNESCO Biosphere Reserve, is a typical example of the massive loss in biodiversity and forest decline in the Central-European mountains, connected with continued monocultures of spruce. Species and community diversity have considerably decreased over large parts of the Park. Forest die-back started in the 1970s affecting about 8000 hectares.

Though acid atmospheric deposition has already been reduced and will further decrease in the near future, forest restoration will continue to meet serious problems, and biodiversity will remain low, if management in lower mountainous zones continues along the traditional silvicultural lines and does not change into nature-based restoration management aiming at forest restoration and improvement of the ecological stability of these forest ecosystems. Trends in natural vegetation and soil development in declined forests and clear-cuts show that natural development offers very good possibilities for a more passive, low-cost restoration management.

This paper aims at pointing out the distinction between borealization and acid rain regarding their effects on soil acidification. A scenario study indicates the necessity for forestry to adapt to current circumstances characterised by a decreasing (high) pollution stress. We will present the results on the effects of borealization, acid rain and broad-leaved pioneer tree species on soil properties, and a scenario analysis, to show the dynamics of soil acidification from the past and in the future.

2. Materials and methods

2.1 General

For this analysis four sources of information were used:

1. The effect of borealization on soil properties was assessed by comparing monoculture Norway spruce stands with beech stands.
2. The effect of acid rain on soil properties was evaluated from historical information on soil chemistry provided by the Czech state forestry organisation (Lesprojekt, Hradec Králové).
3. A scenario study on the effects of atmospheric pollutants on soil chemistry was conducted using a deterministic computer model.
4. The option for forest management to promote pioneer species to mitigate the effects of borealization and acidification was evaluated on the basis of a comparison of pioneer stands and Norway spruce stands.

The Krkonoše Mts. (51°N–15°E) are part of the Sudetes, with altitudes ranging between about 400 and 1600 m a.s.l.. The mountains are situated inside the ‘Black Triangle’, which

covers the area along the joint borders of former East Germany, Poland and the Czech Republic. Mean annual temperatures range between +6 and °C, depending on altitude and exposition. Precipitation increases with altitude, from about 800 mm on foothills to 1400 mm on summits. There is a permanent snow cover for up to seven months, with a mean depth ranging between 1.5 and 2 m. The Krkonoše Mts. consist of a small granitic core, surrounded by a broad belt of metamorphic rock. The main rock types are granites, schists, gneisses and phyllites, while limestone and dolomitic rock are scarce. The soil pattern is determined by altitude, erosion and parent material. The catena is reflected in the typical up-slope sequence of soil types: Dystric Cambisols – Spodi-Dystric Cambisols or Cambic Podzols – Podzols – peaty gleyed Podzols – Histosols and Leptosols (FAO 1988).

Based on a reconstruction of the natural vegetation of the Krkonoše National Park, five vegetation zones related to altitude can be distinguished. These zones can be described as follows (numbering according to the Czech classification):

- Zone 5 (sub-montane; approx. 600–700 m). Deciduous and mixed forests with European beech, European larch (not indigenous), sycamore, ash, rowan, Grey alder and European fir. The herb layer is dominated by various phanerogams and fern species.
- Zone 6 (montane; approx. 700–900 m). Mixed forests rich in herbals synusia, with fir and beech as the dominant tree species. With increasing altitude a decreasing admixture of indigenous broad-leaves and an increasing share of Norway spruce.
- Zone 7 (supra-montane; approx. 900–1050 m). Predominantly coniferous forests with spruce, mixed with fir and beech. Herbal layer mainly comprises small shrubs and grasses.
- Zone 8 (supra-montane below the timber line; approx. 1050–1250 m). Open coniferous forests dominated by Norway spruce, with an admixture of rowan. Herbal synusia dominated by small shrubs, grasses and, in wet places, ferns.
- Zone 9 (>1250 m). Subalpine belt where the most valuable ecosystems (e.g. subarctic mires) are concentrated, and an alpine belt consisting of isolated mountain summits. The zone lies above the timberline, and mountain shrubs and grasses are the characteristic vegetation. Swiss mountain pine (*krummholz*) and low ericoid shrubs are the main species.

Since the 16th century, the natural composition of the vegetation has been strongly altered, especially in the montane belt (zones 6 and 7). The original stands of beech have practically disappeared, being replaced by stands of Norway spruce, either planted or regenerated naturally. Present day forests are therefore dominated by monocultures of Norway spruce. More information is available in Šýkora (1983).

2.2 Long-term effects of borealization on soil properties

It is difficult to quantify the long-term effects of borealization on soil properties, because historical data covering the past two or three centuries are scarce. However, based on a comparative study of Norway spruce and European beech stands in the Krkonoše National Park, conclusions can be drawn as to the effects of spruce on ecosystem properties, compared to close-to-nature stands.

From the forest stand database of the Krkonoše National Park, 150 stands were randomly selected in 4 strata, including spruce and beech stands in the montane (zone 6) and the supra-montane (zone 7) vegetation belts. For representative soils within 100 m² plots, the organic horizons and the underlying mineral horizon (Ah or E) were described according to Green et al. (1993), sampled and analysed for pH-H₂O and pH-CaCl₂. More details on plot selection, sampling and statistical analyses are given by Emmer et al. (1998).

2.3 Historical information on chemical soil properties

Results of soil chemical analyses in the Krkonoše Mts. since the late 1950s were available from Lesprojekt (Hradec Králové). These data comprise repeated measurements of, amongst others, pH, CEC and base saturation in genetic horizons of forest soils. Horizons distinguished were litter, humus, A, E, B and C horizons, depending on soil type. Sample date, forest stand code (compartment and age class), forest site type, and sample depth for each horizon were also recorded. The sample periods were 1958–61, 1971, 1981, 1986, and 1991. Sample points were mapped on topographic maps with compartment codes. The 1981, 1986 and 1991 dates involved the sampling of permanent soil pits. In all sampling periods, there was a comparable distribution of sample points over altitudes and soil types.

2.4 Scenario analysis

Soil changes in response to changes in atmospheric input of acidifying substances were studied using a deterministic model which has been developed to assess the long-term effects of acid deposition on soils (Smart version 1.3, Posch et al. 1993). The advantages of this model are that it is a) process-oriented, implying that soil processes are explicitly included, b) it is simple, requiring only little input data and making it applicable on a regional scale, and c) it is dynamic, which makes it suitable to analyse the long-term behaviour of soils (De Vries 1994). The model calculates the soil solution in equilibrium with a given deposition rate, while interactions in the soil are accounted for. These interactions are notably growth uptake, soil weathering, Al-dissolution and N-transformations. The parameters required to run the model are:

- Precipitation excess, i.e. precipitation minus evapotranspiration.
- Atmospheric deposition of NO_x , NH_3 , SO_x and base cations (BC).
- Soil characteristics: C, C/N, CEC, $\text{Al}(\text{OH})_3$, and BC, Al, H in the adsorption complex, thickness and bulk density of the rooted zone.

The starting and ending year of simulation were 1900 and 2050. In the Czech Republic, acidifying deposition was relatively small in 1900. Although it had increased already threefold since 1860, it was still about one sixth of the deposition measured in the 1980s (Figure 1). Hence, the situation in 1900 can be considered as more or less undisturbed by acidifying pollution. Simulations were continued until 2050 to assess the effects in the future.

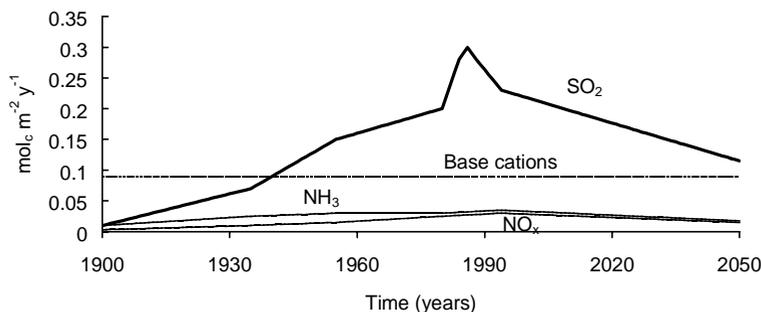


Figure 1. Deposition scenario for the Krkonoše Mts., including sulphur and nitrogen compounds and base cations. (Partly after Hruška et al. 1999.)

2.5 Management option: the ameliorative effect of broad-leaved pioneer tree species

The approach of the research on the ameliorative effect of broad-leaved pioneer tree species on soil was basically similar to that described by Miles (1981). It involved a comparison of soil characteristics of stands of different age bearing more or less even-aged pioneers with adjacent monoculture spruce. Antecedent similarity of soil properties of adjacent plots of pioneers and spruce was assumed, based on their vicinity, in addition to information from forest archives. The effect on the humus form of naturally established stands of pure rowan and of mixed stands of rowan with birch was investigated by comparison of such stands with adjacent pure Norway spruce stands.

The assessment involved 7 plot pairs in vegetation zones 6, 7 and 8, with altitudes ranging from 660 to 975 m a.s.l. According to the forestry archives, these plots have not been limed in the past. Stand ages ranged from about 20 to 50 years for pure pioneer stands, and from about 40 to 120 years for spruce.

3. Results and discussion

3.1 Effects of borealization on soil

Seven forest communities were found on the basis of the botanical inventory of 150 relevés, ranging from species-rich spruce stands to species-rich beech stands, with intermediate species-poorer spruce and beech stands (Table 1, see Emmer et al. 1998).

Species-related indicators which in the current study can be used as evidence for borealization are, particularly, the diversity indices and Ellenberg's R (acidity) and N (nitrogen) values (Ellenberg 1974). On average, the spruce stands exhibited a lower species diversity, and had less nitrogen indicators (lower N value) and more acidity indicators (lower R value) than beech stands. On average, spruce stands had thicker organic horizons, with a lower pH than beech stands (Table 2). In almost all cases, the organic layers under spruce had a much denser packing than under beech, so the differences in terms of organic matter accumulation are likely to be larger. The major humus form in beech stands was Moder (88%). In spruce stands this was 68%, while Mor humus forms were also well-presented (32%) (Emmer et al. 1998).

Table 1. Community grouping of 150 relevés in the Krkonoše Mts.

Group and stand type	Major undergrowth species
1 Species-rich spruce	<i>Athyrium filix-femina</i> , <i>Oxalis acetosela</i> , <i>Senecio nemorensis</i> ssp. <i>fuchsii</i> , <i>Luzula luzuloides</i>
2 Spruce	A dense vegetation of <i>Calamagrostis villosa</i> , <i>Deschampsia flexuosa</i> and <i>Vaccinium myrtillus</i>
3 Species-poor dense spruce	Scarce <i>C. villosa</i>
4 Species-poor beech	A dense vegetation of <i>C. villosa</i> , <i>D. flexuosa</i> and <i>V. myrtillus</i>
5 Species-poor beech	<i>V. myrtillus</i> , juvenile <i>Sorbus aucuparia</i> and <i>Fagus sylvatica</i>
6 Species-rich beech	<i>Polygonatum verticillatum</i> and <i>Gymnocarpium dryopteris</i>
7 Species-rich beech	<i>Galium odoratum</i> or <i>Paris quadrifolia</i> without <i>C. villosa</i> , <i>D. flexuosa</i> and <i>V. myrtillus</i>

Table 2. Mean values of soil parameters by community group (standard deviations between brackets for thickness).

	Thickness in cm			pH-H ₂ O			pH-CaCl ₂		
	L+F	H	Ah or E	L+F	H	Ah or E	L+F	H	Ah or E
Spruce									
1	4.8 (1.6)	3.5 (3.2)	2.8 (3.2)	4.2	4.2	4.0	3.2	3.4	3.1
2	5.4 (1.8)	4.3 (2.8)	3.6 (4.1)	4.3	4.0	3.8	3.1	3.0	3.0
3	3.7 (2.1)	3.0 (3.2)	3.3 (3.3)	4.3	4.0	3.9	3.2	3.0	3.0
Beech									
4	5.1 (2.2)	2.6 (1.5)	4.4 (5.1)	4.3	4.1	3.9	3.2	3.1	3.1
5	4.4 (1.8)	2.4 (1.7)	2.7 (2.3)	4.4	4.1	3.9	3.3	3.1	3.1
6	4.0 (2.0)	2.9 (2.1)	4.1 (3.4)	4.7	4.3	4.1	3.6	3.4	3.4
7	3.3 (1.7)	1.1 (1.1)	2.3 (1.3)	4.9	4.3	4.1	4.0	3.4	3.3
Spruce									
	4.8 (2.1)	3.8 (3.0)	3.5 (3.7)	4.3	4.0	3.8	3.2	3.0	3.0
Beech									
	4.3 (1.9)	2.4 (1.7)	3.4 (3.5)	4.6	4.2	4.0	3.5	3.3	3.3

Major sites indicated on the forest type map of the Czech Forest Management Institute (Lesprojekt) include those which are poor-acidic (with podzolised brown forest soils in vegetation zone 6 or podzols in zone 7) and relatively fertile or with top soils rich in organic matter (both with brown forest soils in zones 6 and 7). Species diversity of beech stands in vegetation zones 6 and 7 was found to be strongly related to site quality in terms of the forest type map (Figures 2A and B, see Emmer et al. 1998), which suggests a quite balanced vegetation-site relationship, i.e. species-richer beech forests on better soils, etc. Spruce stands were mostly located on acidic sites, without a clear differentiation among groups. As in the

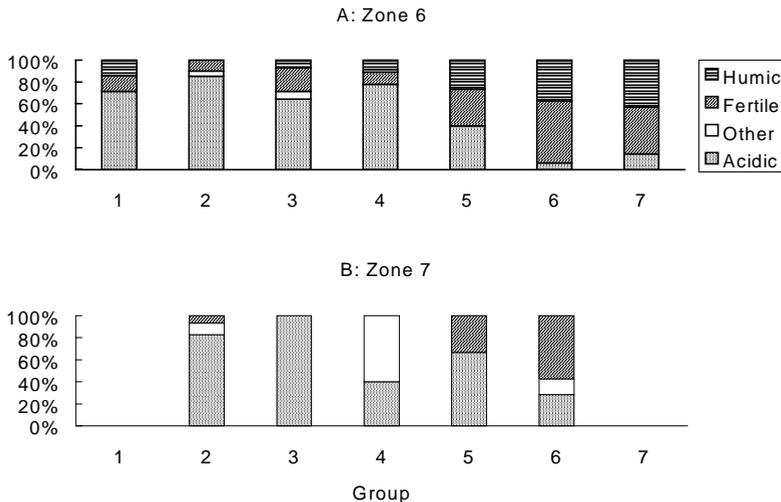


Figure 2. Distribution of map-derived forest types (Lesprojekt) among vegetation communities (Table 1) in zone 6 (A) and zone 7 (B). (Taken from Emmer et al. 1998.)

past, there was no preference to plant spruce on poor sites or to reserve better sites for beech, this pattern is a strong indicator for soil acidification due to spruce monoculture.

Regarding the chemical differences between soils under spruce and beech, as an indicator for the effect of borealization on soil properties, only limited published information was found. Podrázský (1996), in his paper about soil differences between spruce and beech stands in the Krkonoše Mts., only provided information about the mineral soil, unfortunately. The results show that under beech the pH-KCl in the A and B horizons is about 0.25 unit higher than under spruce, while the base saturation is around 10% higher.

3.2 Effects of acid rain on soil

The changes in pH and base saturation since the late 1950s according to the Lesprojekt archive are shown in Figures 3 and 4. Figure 3 shows the change in pH over time for different horizons, while Figure 4 shows the change of the base saturation with depth for different sampling periods. In the late 1958–61 period, the values for the pH varied considerably among the soils sampled. A strong decrease in the soil pH has occurred during the 1960s, followed by a period of stabilisation or small decline during the 1970s and later on. Moreover, the *range* of pH values measured decreased significantly (Figure 3), which indicates the converging effect of heavy acid deposition on soil chemical properties in the area. The phase of decline matches well with what has been observed in the Orlické hory Mts. (Pelíšek 1984).

The base saturation also shows remarkable changes over the time period under consideration (Figure 4). In 1958–61, the topsoil as well as the subsoil vary strongly, with a maximum just over 50%. In 1971, high values in the topsoil have disappeared. In 1981 and 1991, only values below 15% were found in both top and subsoil. This pattern points at an ongoing loss of adsorbed base cations, starting in the topsoil and progressing into the subsoil. These results are consistent with those reported by Pelíšek (1984), Materna and Lochman (1988), Vacek et al. (1994) and Podrázský (1996).

3.3 Scenario analysis

Simulation with the Smart model shows a strong acidification of the soil (Figure 5). The pH decreases, the base saturation approaches zero, and the Al/base cation ratio strongly increases. Once the acidifying deposition decreases again, the pH and the base saturation increase somewhat and the Al/base cation ratio decreases substantially. The changes in base saturation and pH are quite well in agreement with the measurements carried out between 1958 and 1991 by Lesprojekt (Figure 4). During that period the base saturation decreased to values under 0.1, as in the simulation.

3.4 Soil amelioration by pioneer trees

There was a substantial difference in horizon morphology between humus forms under pioneers and spruce (Emmer et al. 1998.). Under pioneer trees, the horizons were much less compact or matted, and showed a considerably higher degree of faunal activity. Under pioneer species, the pH (CaCl₂) in the LF horizon was up to 1.3 units and on average 0.7 units higher than under spruce. For the H horizon the difference was smaller, which must be ascribed to the fact that the H horizons under young pioneer trees were built-up from Norway

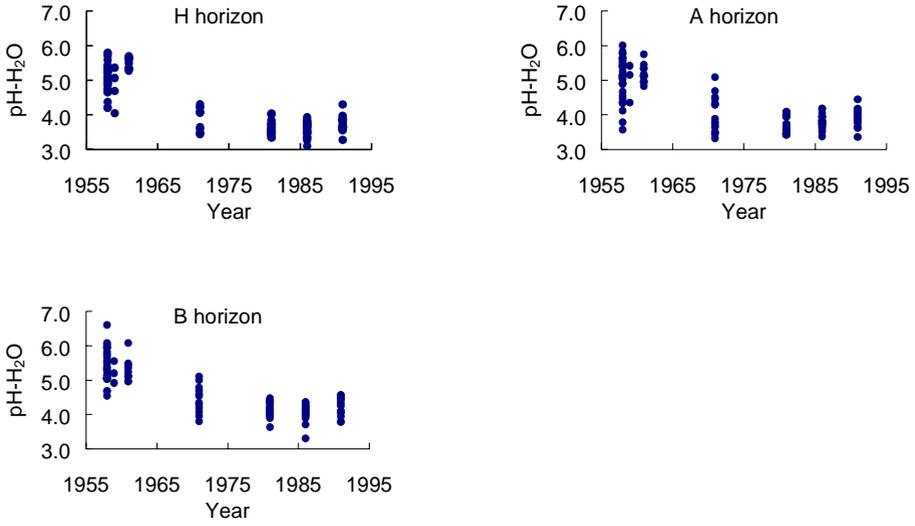


Figure 3. Changes in the pH of forest soils in the Krkonoše Mts. during the period 1958–1991. (Data provided by ÚHÚL-Lesprojekt, Hradec Králové.)

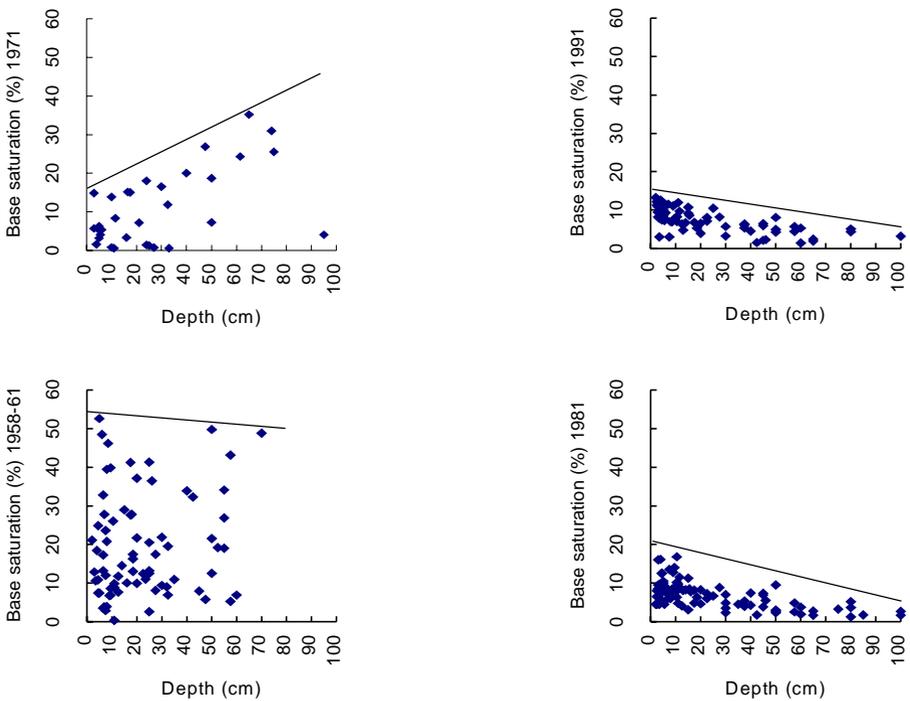


Figure 4. Changes in the base saturation of forest soils in the Krkonoše Mts. during the period 1958–1991. (Data provided by ÚHÚL-Lesprojekt, Hradec Králové.)

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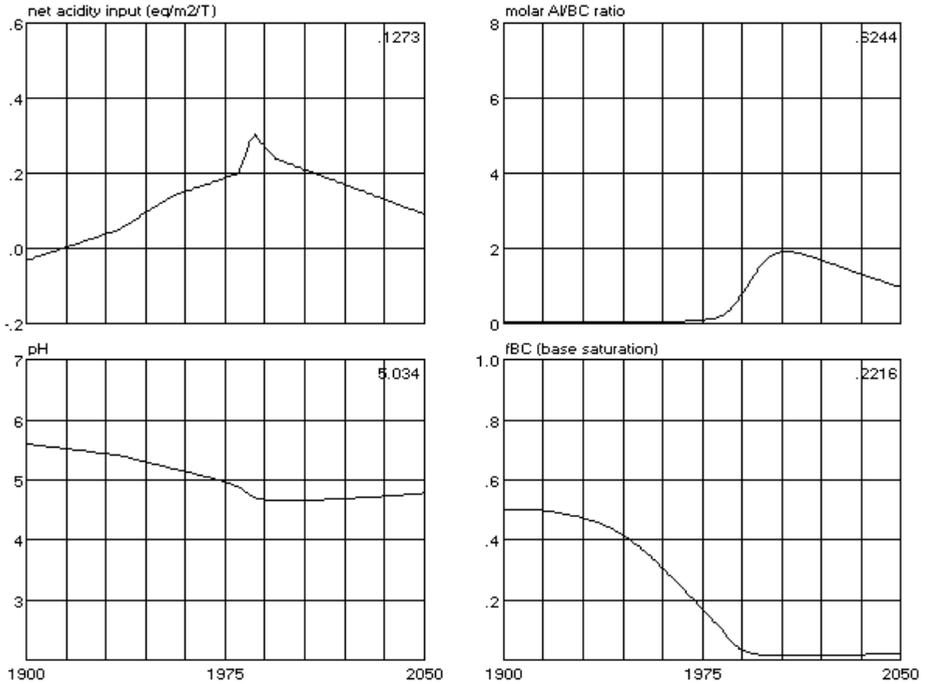


Figure 5. Selected output of the Smart model, showing the deposition scenario over the period 1900–2050 and the course of the Al/base cation ratio, the pH and the base saturation.

spruce litter. Pioneer species, thus, improve growth conditions towards pH ranges which are suitable or optimal to other indigenous tree species: European fir, European beech, European larch: >3 (suitable) and >4 (optimal) (Van den Burg 1981).

The results summarised in Table 3 clearly show that effects on soil organic matter quality by pioneer growth are indeed the case in the soils studied. Concentrations of base elements (of which between 54 and 88% is Ca), Mg and Al in LF horizons under spruce are quite constant, but under pioneers concentrations of bases increase with age. Furthermore, in the LF and H horizons under pioneers higher NH_4 and lower exchangeable acidity were found (Emmer et al. 1998). In the H horizons, total bases and Mg increase with age. Concentrations of total bases and Mg in the LF horizon of pioneers stands are 2 to 4 times higher than under spruce, while Al is lower. Similar features are found for H horizons, where Al concentrations are much higher, and total bases much lower than in the LF.

The results on pH and base elements of ectorganic horizons are in line with those obtained by Podrázský (1995) on soil properties under birch after 25 years of stand development on bulldozed sites in the Krkonoše Mts. Under spruce the availability of Mg is low, in general, as a result of the composition of the granitic and metamorphic parent material. In fact, Mg shortage has been found to be responsible for discoloration of needles throughout the Sudete mountains along the Czech borders (Materna 1989).

Trends in the stock of base cations for the entire organic layer (LFH) are unclear (see Emmer et al. 1998), as they are largely determined by differences in organic matter stock. However, the LF horizon under pioneers shows an age related increase in base elements,

Table 3. Concentrations (mmol_c kg⁻¹) of base elements (sum of Na, K, Ca and Mg), Mg and Al in the LF and H horizon of Norway spruce and pioneer stands (Emmer et al. 1998).

	Age	Horizon	Base cations		Mg		Al	
Spruce	38-118	LF	74	(30)	10	(4)	17	(8)
		H	25	(8)	4	(1)	62	(11)
Pioneers	20	LF	132		24		4	
		H	62		8		33	
	52	LF	262		42		2	
		H	132		26		4	

attributed to its closer relation to above-ground litter dynamics. Other studies (e.g. Fisher 1990) indicate that broad-leaved pioneers strongly affect element pools in organic matter and to a lesser degree amounts of accumulated organic matter, which implies the redistribution of nutrients from poorly to readily accessible pools in the soil. This will depend on the length of time during which pioneers have pursued their influence, with longer time spans related to greater effects on stocks of organic matter. Under pioneers there is a gradual increase in the values for Ca and Mg during the first 50 years.

It can be concluded that broad-leaved pioneer trees significantly affect the chemical properties of the LF horizon within 20 years after their establishment, and these properties continue to improve later on. For the H horizon a longer period seems required for significant changes to take place. It is roughly between 40 and 50 years after pioneer establishment that ecologically significant changes can be observed in the H horizon. This is not surprising, since the residence time of organic matter in the LF layer may be up to several decades (e.g. about 30–40 years for Scots pine stands under climatic conditions more favourable to humification; Emmer and Sevink 1994).

4. Conclusions

As inferred from the results of the beech-spruce comparison and from the literature, the effect of borealization on soil pH can be estimated at 0.2–0.3 pH units. For the base saturation, the literature shows a difference of up to 10%. These are significant but relatively small changes in comparison with the effect of acid rain. Results of field measurements and simulations indicate that acid rain causes more than 1 unit decrease in pH, down to values below 3, and a reduction of the base saturation of 5 times or more for the period 1958–1991.

The scenario analysis indicates the relative unimportance of soil weathering for counteracting the acidification by acid rain. It also shows that, given a 50% reduction of the acidifying deposition by the year 2050, with a prevailing cover of spruce forest, the pool of plant-available metal cations will not be restored.

Soil changes due to broad-leaved pioneer trees involve an increase in pH-CaCl₂ in the LF horizon up to 1.3 units higher than under spruce. The pH increase in the H horizon balances the decrease under spruce between the 1950s and 1980s. Pioneer trees affect the chemical properties of the LF horizon within 20 years and the H horizon roughly between 40 and 50 years after their establishment. The ameliorative effect of pioneer trees on soil properties to reach deeper soil layers will take longer, particularly at higher altitude.

5. Recommendations

The comparison of broad-leaved pioneer and spruce stands reveals that the sustenance of pioneer species may be an effective tool to prevent or even reverse site deterioration, without the need to adopt liming or fertilisation. The introduction of these pioneer tree species in Norway spruce stands or clear-cuts causes an increase in pH, plant-available elements, and biological activity in the humus form, and concordantly a higher variability in humus form properties.

The foregoing is in close agreement with the conclusions of other authors (Gardiner 1968; Perala and Alm 1990a and b, and references therein), who stated that birch and rowan are soil improvers and 'nursing crops', that they enhance decomposition and nutrient release, and that they prevent site deterioration and even improve sites.

Such beneficial effects will be considerably less if pioneers grow in a mixture with spruce. A critical areal cover of pioneers cannot be deduced from the information currently available. Tesar and Tesarová (1996) stated that 50% is a critical canopy density for rowan growing amidst spruce, above which spruce height increment will be significantly reduced. This is, however, only important from the viewpoint of spruce silviculture and much less so in the restoration of a natural forest composition and in nature management in general.

Given the fact that humus form restoration under broad-leaved pioneer trees is a matter of several decades in unmixed stands, a high cover percentage of broad-leaved pioneers should be maintained as long as possible, preferably up to the length of a generation (i.e. about 50–90 years). This has also been clearly stated by Podrázský (1992), who studied soils under broad-leaved pioneer trees in the Krušné hory Mts., the Krkonoše Mts. and the Orlické hory Mts. A high cover percentage of broad-leaved pioneers can be easily achieved in patches of pioneers to obtain age differentiation in new plantations. At sites of good quality, with a high recovery potential under a scenario of reduced air pollution, considerations as to the optimal areal coverage of pioneer trees are less essential. However, as stated by Emmer et al. (1998), allowing a natural development including the establishment of broad-leaved pioneer trees improves site diversity and biodiversity. A cost-effective nature management, therefore, should omit, in any case, the removal of those species by the cleaning of stands.

Of particular importance could be the role of broad-leaved pioneer trees at sites severely deteriorated during the course of air pollution impact and borealization. These sites are particularly found at high altitude (zone 7 and 8), where air pollution is more severe than in lower areas, decomposition of organic matter and weathering of mineral substrate is also slow and growth conditions are poor. The alpine timberline in zone 8 can, however, only be preserved through the conservation of Norway spruce, as less spruce and more pioneers may enhance the development of avalanche tracks.

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The Effect of Sulphur Addition and Liming on Soils in Norway Spruce Stands

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Abstract

Results are evaluated of the simulated input of sulphur *in situ* with the parallel application of dolomitic limestone. Soils of the experimental area are classified as acid Cambisols (developed on granodiorite) with an admixture of eolian materials, light-textured and with a low supply of fundamental nutrients. Saturation with basic cations is lower than 10%, pH value of soil (pH/H₂O) in the surface humus ranges between 3.8 and 4.2, and in the upper mineral layer between 3.5 and 4.3. Surface humus amounts to about 50 t ha⁻¹. Sulphur doses were 0–300 kg ha⁻¹ year⁻¹ and doses of dolomitic limestone were 2500 or 5000 kg ha⁻¹. Soil pH increased significantly in the surface humus within the course of 5 years but was insignificant in the mineral soil. Liming resulted in the decrease of leaching of humic acids and improvement of soil saturation with basic cations. Soil solution showed lower acidity, higher conductivity and higher content of Ca and Mg. Leaf analyses showed a slight increase (but not significant) in the concentration of fundamental bioelements. Norway spruce aged 90–95 years exhibited a significantly higher increment of the assimilatory tissue biomass in the beginning. This trend, however, gradually decreased and, finally, ceased. At present, repeated liming is prepared with the aim to create better conditions for the regeneration of stands.

Keywords: Norway spruce, soil improving measures, soil chemistry, forest regeneration

1. Introduction

In the Czech Republic, high inputs of acids into the soils of forest stands, reaching as much as 2.5–7.0 kmol H⁺ ha⁻¹ year⁻¹ permanently exceeded several times the capacity of soils for their neutralization. Thus, the resistance of forest ecosystems towards other factors (e.g. climatic excess, acidification impacts etc.) gradually decreases. Leaching of cation nutrients

(particularly Ca, Mg and K), release of aluminium ions (as the result of acid inputs) and trends towards excessive nutrition by N (as the result of nitrogen inputs) leading to an absolute or relative nutrient shortage are of particular importance. In association with the need to increase the proportion of broadleaved species or with respect to the conversion of Norway spruce pure stands to 'near-natural forests', the question of soil improving measures appears. Together with a decreasing air pollution load it will be necessary to apply the measures mentioned above. Because the implementation of these measures will require considerable financial expenses it is necessary to obtain strong arguments for decision making authorities. This means that our previous liming experiments have to be evaluated and new experiments established. The new experiments will also include possibilities to apply ameliorants and fertilizers into the soil (rhizosphere) on sites where it will be possible from a technical point of view.

2. Material and methods

In this paper, the results of the application of 2500 or 5000 kg ha⁻¹ dolomitic limestone with the parallel simulated input of sulphur *in situ* at a rate of 0–300 kg ha⁻¹ year⁻¹ are evaluated.

The plot is situated about 40 km NW of Brno at an altitude of 625 m. Original forest stands, mainly beech stands, were gradually replaced by spruce (*Picea abies* Karst.) at the turn of the century. At present, the stands are 90 years old. A detailed description of the experiment and evaluation of the first stage of the project has already been published (Kulhavý 1992).

The region is characterized as moderately humid and moderately warm with mean air temperatures amounting to 6.3°C and mean precipitation 683 mm. Air pollution is on the level of increased background pollution (10–20 µg m⁻³ SO₂ and 15–20 µg m⁻³ NO_x). Atmospheric precipitation is of acid character with values amounting to pH 4.4–4.5. pH values of throughfall are still lower. Sulphur deposition amounts to as much as 60 kg ha⁻¹ year⁻¹, nitrogen 15–20 kg ha⁻¹ year⁻¹ (Klimo 1992). It corresponds to 4.5 kmol H⁺ ha⁻¹ year⁻¹ entering the soil.

Soils of the experimental area are classified as acid Cambisols (developed on granodiorite) with an admixture of eolian materials, light-textured and with a low supply of fundamental nutrients. Saturation with basic cations is lower than 10%, the pH value of the soil (pH/H₂O) in the surface humus ranges between 3.8 and 4.2 and in the upper mineral layer between 3.5 and 4.3. Humus is accumulated mainly in the A horizon (12%) and it markedly decreases to 2–1% in deeper horizons. The ratio between the content of fulvic acids and humic acids is balanced, particularly in the surface layers. In free oxides of iron and aluminium, it is possible to observe a slight increase in the lower part of the Bv horizon. The soils are characterized by small physiological depth and a relatively high percentage of gravel. A typical moder of a depth of up to 6 cm represents the form of humus. Surface humus amounts to about 50 t ha⁻¹ (Klimo 1992).

For the purpose of acidification, pulverized sulphur mixed with fine siliceous sand (1:2) was applied on plots below a spruce stand annually from 1986 to 1994. In 1990, dolomitic limestone was applied on some of the plots. According to experimental design (Table 1), 700 or 2100 kg S ha⁻¹ were applied to the soil during the nine-year period of study and a further approximate 200 kg S ha⁻¹ represented input into the soil in the form of natural deposition. It represents a total input of 205 or 617 kmol of the equivalent amount of protons entering the soil. With respect to the variant, the neutralization effect of the dolomitic limestone was 53 or 106 kmol ha⁻¹. The area of experimental plots was 400 m² and each of the variants was

repeated three times. Changes in the following parameters were evaluated: chemistry of soil solution, mineral nutrition and biomass increment of assimilatory tissue. The characteristics were evaluated in the course of 5 years after application.

The content of total carbon in soil was determined by 'wet combustion' according to Tjurin, total nitrogen (N_t) according to the Kjeldahl method, the pH value was determined by potentiometry with a glass and quinhydrone electrode in an aqueous extract and in 1 N KCl extract (leachate) on a digital OP-211/1 pH-meter of Radelkis Co. Soil/leachate relation was 1:2.5, extraction time 24 hours. The content of macroelements in soil was determined after material mineralization at 400°C and in the leachate of ash by hydrochloric acid. Phosphates were determined by colorimetry with molybdenumsulphuric acid, sulphates by gravimetry in an aqueous extract after precipitation by barium chloride. Sodium, potassium, calcium, magnesium, zinc, iron, manganese and copper were determined using the Varian Techtron atomic absorption spectrometer. The concentrations of NO_3^- -N and NH_4^+ -N was determined by ion-selective electrodes, aluminium by titration from the 1 N KCl leachate, adsorption complex from the leachate according to Mehlich.

The content of Ca, Mg and K in needles was determined after wet ashing using $H_2SO_4 + H_2O_2$, P was determined by spectrometry and S by gravimetry. Fe, Mn and Zn after dry ashing (at 450°C) AAS by flame technique, Al after the same ashing AAS by flameless technique, N_t by coulometry.

Sampling of the soil solution was carried out by vacuum lysimeters of our own design using ceramic tips and 0.6 KPa vacuum in three repetitions for each of the variants. Soil solution sampling was carried out in the spring and autumn months under conditions of sufficient soil saturation by water. Values of pH in water were measured by potentiometry using a combined electrode, conductivity by the OK 102/1 Radelkis conductometer using platinum electrodes, Na and K by atomic emission flame photometry using the FLAPHO 4 device, Ca, Mg and Fe by AAS using the Varian Techtron AA-6 apparatus, PO_4^{3-} by spectrophotometry, Al by spectrophotometry with chromazurol S using the Specol device, NO_3^- by spectrophotometry with sodium salicylate, SO_4^{2-} by gravimetry with barium chloride and Cl by mercurimetry.

3. Results

3.1 Soil chemistry

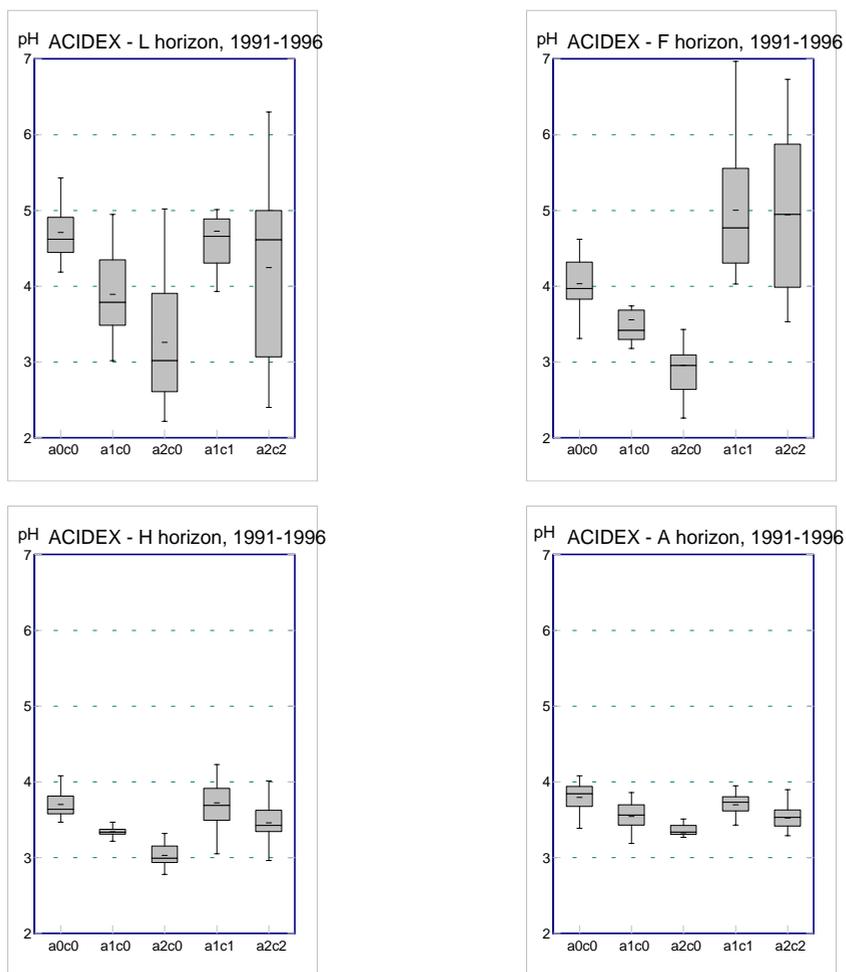
Acidification effects of added S were highly significant in comparison to the control up to a depth of mineral horizons. Mean pH values in the surface humus at a rate of 300 kg S ha⁻¹ year⁻¹ were modified in a range from 2.7 to 3.6 pH and in a mineral horizon A/B of a depth of about 10 cm from 3.2 to 3.6 pH for the whole period. It is necessary to emphasize that the effect was already achieved in the first years of the experiment and the acidification trend did not markedly change in the course of time. The development of exchangeable soil reaction was of similar character and acidity shifted below a limit of pH 2.5. Liming caused a statistically significant decrease in acidity (increase in pH values) in the O_l, O_f, O_h horizons in both variants (3.5 and 5.0 t dolomitic limestone, respectively) as compared with variants where only sulphur was applied. Short time values of pH/H₂O after liming reached as much as pH 6, a slightly higher effect of applied lime being in the variant with lower acidification and lower rate of lime (variant a₁c₁). Mean pH values for the period 1991–1996 are given in Figure 1. The effect of added lime was obvious (although statistically largely insignificant with respect to variants where sulphur was applied only) down to a depth of the surface mineral horizon even in 1996, i.e. 6 years after the application. Sulphur application resulted

Table 1. Soil adsorption complex in mineral soil at the end of the experiment Rájec n. Svit., August 1996. Unit mmol IE kg⁻¹.

Variant	Ca ²⁺	K ⁺	Mg ²⁺	Al ³⁺	H ⁺	CEC	BS %
a ₀ c ₀	7.4	2.4	2.6	76.6	112	200.7	6.1
a ₁ c ₀	6.2	2.3	1.9	88.1	137	235.5	4.4
a ₂ c ₀	4.6	2.0	2.3	72.0	116	207.9	4.2
a ₁ c ₁	8.9	2.3	3.3	88.2	127	229.4	6.3
a ₂ c ₂	9.3	1.7	2.2	84.1	125	222.6	5.9

a₀c₀ = controla₁c₀ = 100 kg S ha⁻¹ year⁻¹a₂c₀ = 300 kg S ha⁻¹ year⁻¹a₁c₁ = 100 kg S ha⁻¹ year⁻¹ + 2500 kg CaCO₃ · MgCO₃ ha⁻¹a₂c₂ = 300 kg S ha⁻¹ year⁻¹ + 5000 kg CaCO₃ · MgCO₃ ha⁻¹

CEC = cation exchange capacity

**Figure 1.** pH/H₂O in different soil horizons 1991–1996.

in changes in the soil adsorption complex (Table 1). Low values of base saturation (BS) further decreased in the most acid variant. The largest proportion belonging to calcium (4.6 mmol IE kg⁻¹ as compared with 7.4 in control). Liming caused a higher proportion of Ca²⁺ in the soil adsorption complex.

3.2 Soil solution

Soil solution (sampling by vacuum lysimeters from B horizon) in the control variant is characterized by high concentrations of H⁺ (pH 3.7). Sulphur application and increase in acidity markedly modified the chemical composition of the soil solution. Soil solution pH in the most acidic variant was significantly lower reaching a value of pH 3.5 (a₂c₀). The highest concentrations due to acidification appeared in Mg²⁺, Ca²⁺, and SO₄²⁻ (Figure 2). Conductivity markedly increased and all these changes were largely statistically significant. The content of Al was higher in acid variants. Liming resulted in the change of solution pH to the level of control, a further increase in conductivity and an increase in the content of Ca²⁺ and Mg²⁺. Nitrification was markedly inhibited in variants with applied sulphur as compared with the control. Addition of lime partly stimulated nitrification (particularly in a variant with the lower rate of sulphur and lime), however, it did not reach the NO₃⁻ values of the control variant.

3.3 Soil respiration

Due to the decrease in soil pH conditions for the decomposition of organic matter were gradually diminished. The C/N ratio was changed only slightly because increased hydrolysis of the surface humus affected both nitrogen and carbon. CO₂ production of soil as an

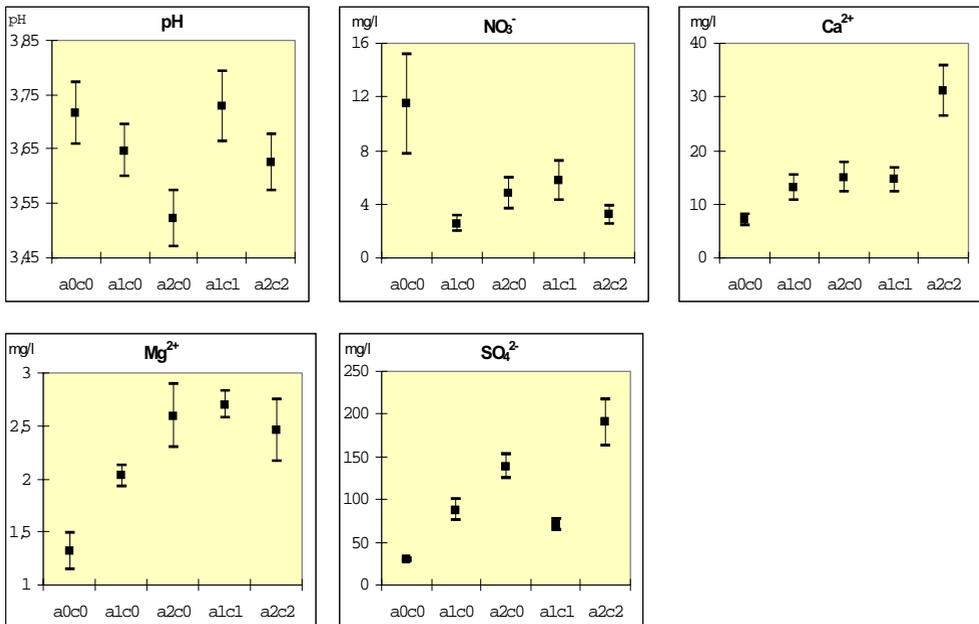


Figure 2. Mean value of pH, NO₃⁻, Ca²⁺, Mg²⁺ and SO₄²⁻ in soil solution, ACIDEX 1991–1996.

expression of the overall activity of microorganisms indicates a slight decrease in values during a short period of the year only when the soil microflora is most active (Figure 3). In the course of the year, changes in the production of CO₂ are on the limit of significance and decrease by a max. of 8% for the whole growth season.

3.4 Mineral nutrition and growth

Leaf analyses were carried out twice in the period 1991–1996. Differences in the content of nutrients are not statistically significant but in the majority of nutrients, a slight trend in their increase is evident in association with sulphur application (Figure 4). Spruce trees responded through increased biomass increment of assimilatory tissues of the 1st and 2nd needle year-classes. The response was positive after the addition of sulphur at the beginning of the experiment but the effect gradually ceased (Figure 5). By means of the simultaneous application of sulphur and limestone in relatively high doses the effect of limestone application was, however, low.

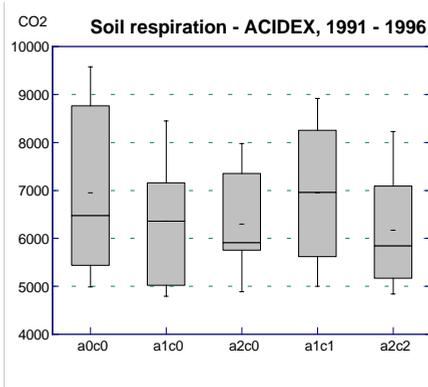


Figure 3. Mean values of soil CO₂ (mg m⁻² day⁻¹) respiration in July and August.

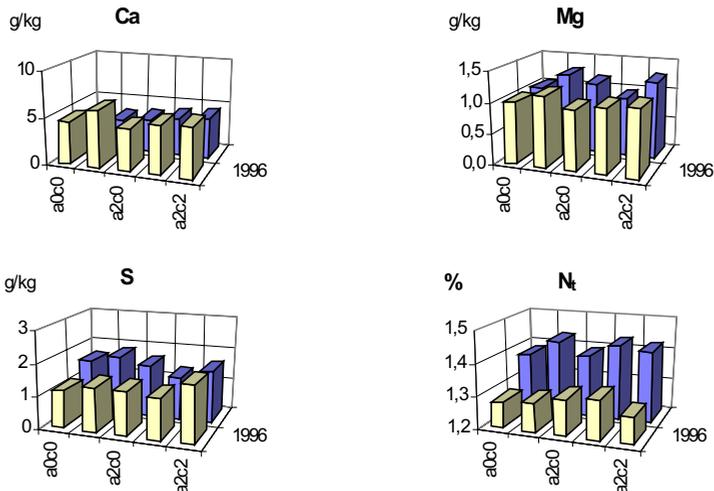


Figure 4. Leaf analysis, 1st year needles, ACIDEX 1991 and 1996 (1 and 6 years after liming).

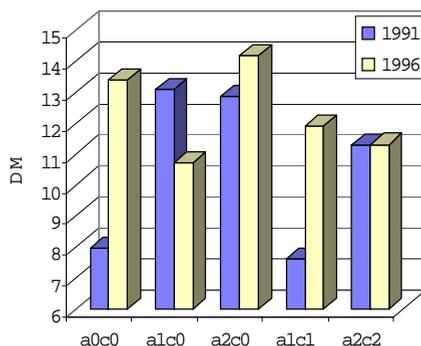


Figure 5. Needle biomass in g of DM per metre of shoots in 1991 and 1996, ACIDEX.

4. Discussion

The study site is a Norway spruce stand situated in the 4th vegetation zone at an altitude of 625 m. Spruce stands were established here at the turn of the century replacing mixed stands with the predominance of beech.

The present state of acidification originated in the locality under study by the combination of natural and anthropogenic factors as a result of the change in the vegetation cover in Holocene and in the last century due to high levels of acids in the atmospheric deposition. The establishment of the experiment and its long-term evaluation at one site enabled us to assess the condition of soil better than using a method based on the comparison of impact and reference regions which often differ in their conditions. In the experiment, an increase in soil acidity was achieved corresponding (according to pH/H₂O in the upper mineral horizon) to the Al/Fe buffering zone. Proton neutralization proceeded mainly by the decomposition of Al and Fe minerals and bonding into organic complexes. Chemical composition of the humus layer is seldom considered because nutrients in the humus layer are viewed as becoming available during mineralization (Meiwes et al. 1986). The changes in soil acidification manifested themselves by a significant increase in the concentration of SO₄²⁻ ions and bases but also C and Al in the soil solution.

Liming at a rate of 2500 or 5000 kg ha⁻¹ dolomitic limestone had marked effects on the change in soil reaction in the surface humus (particularly O₁ and O_h) but small effects on the upper mineral horizon. A significant change occurred, however, in the saturation of the soil adsorption complex by Ca and Mg in surface mineral horizon. The increase in base saturation in mineral soil after liming was also observed by Abrahamsen (1994), Kreutzer et al. (1989), Ingerslev (1997) and others. The effect of liming here was evident even after a longer period (about 6 years). The buffer capacity of soils under the presence of water-soluble humic substances was relatively high. This is proved by a relatively rapid return to original pH values after the cessation of sulphur input into the soil.

Spruce responded through the increased biomass increment of assimilatory tissues in soils with higher acidity in the first stage of the experiment, however, later on the trend of increment increase ceased. Accelerated growth is often attributed to the account of the increased input of N by atmospheric deposition (Eriksson and Karlsson 1996). However, it is probable that in regions with a high level of acid deposition other nutrients are also available in the soil. No changes were found in the uptake of nitrogen. Application of sulphur or

sulphur + lime change the production of CO₂ from soil only partly. This is a rather surprising result because, generally, the inhibition of biological activity is expected with increasing soil acidity and, vice versa, an increase in biological activity after liming. In spite of the fact that soil microflora responded to the sulphur application by decreasing CO₂ respiration, simultaneous sulphur and dolomitic limestone application did not cause any response. Our findings correspond with similar results offered by Alexander (1980), Lohm (1980) and Francis et al. (1980).

5. Conclusions

Sulphur application into the Cambisol soil type under the spruce stand (*Picea abies* Karst.) markedly modified soil pH and the chemistry of the soil solution. Application of sulphur + lime resulted in the decrease of leaching of humic acids and an improvement of soil saturation with basic cations. Of the exchangeable cations, it is Ca²⁺ which exhibits the highest proportion. Liming increased the total content of Ca²⁺ and Mg²⁺ both in the surface humus and mineral horizons, while the content of nitrates did not increase. Soil solution showed lower acidity, higher conductivity and higher content of Ca²⁺ and Mg²⁺ after liming. Production of CO₂ from soil did not change significantly. Leaf analyses showed a slight increase (but not significant) in the concentration of fundamental bioelements. Norway spruce aged 90–95 years exhibited a significantly higher increment of the assimilatory tissue biomass. The trend, however, gradually decreased and, finally, ceased. At present, repeated liming is prepared with the aim of creating better conditions for the future regeneration of stands.

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Crown Structure Transformation and Response of Norway Spruce Forests to Multiple Stress Impact

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Abstract

The intensity and quality of the crown and branch structure transformation (the formation of secondary shoots in successive series) is a sensitive indicator of a long-term tree damage on the one hand, and of the subsequent regenerative processes on the other hand. The response of montane Norway spruce forest stands to multiple stress impacts has been estimated since 1992 on four permanent research plots in the Krkonose Mts. (Giant Mts.). The results obtained enabled us to estimate the multiple stress impact on forest stands in the past and to predict their subsequent development.

Keywords: multiple stress, branch structure transformation, Norway spruce

1. Introduction

Forest decline is a complex multifactorial problem caused by natural and anthropogenic global environmental change imposed by acute climatic and pollution stress events (Ulrich 1994). Stress can be defined as a “state in which increasing demands made upon a plant lead to an initial destabilization of functions, followed by normalization and improved resistance. If the limits of tolerance are exceeded and adaptive capacity is overtaxed, permanent damage or even death may result” (Larcher 1987). Within the broad scale of intensities and the duration of pollution impacts upon trees, chronic and acute stress effects can be considered. Montane forests have been under a long-term synergistic chronic effects of nature and anthropogenic stress impacts, imposed from time-to-time by acute climatic and pollution stress events.

Proventitious shoots (secondary shoots according to Lesinski, personal communication) are always formed if the correlation between branching (a total mass of active assimilative

organs) and outer (light income) or inner conditions (starting carbohydrates, water and nutrient supply) is out of balance. They are initiated by promoted root growth (above average production of cytokinin) and needle loss (below average production of auxin). They can serve as substitutes for insufficient crown parts, play a role in the crown regeneration, are an adaptation of the crown in developing an optimal form for the given environmental conditions, and also exploit light in favourable growth phases. Therefore, increased formation of secondary shoots should not be considered as a specific symptom of spruce response to pollutant effects (Gruber 1994).

Periodic investigations of defoliation, needle damage and regenerative processes in the crown can detect changes in forest stands due to fluctuating environmental impacts, including atmospheric deposition. Branch structure transformation (shoot turnover) is a very sensitive and distinct indicator of the long-term damage of assimilative organs on the one hand and of subsequent regenerative processes on the other hand.

Causes (damage to the tree) and consequences (regeneration processes) of multiple stress impact are not distinguishable using classic dendrochronological methods. Acute stresses (frost, drought, pollution) result in a small ring increment diameter; however, the cause of this increment (shoot mortality) cannot be determined at the time. Chronic climatic and/or anthropogenic stress impact caused small ring increment diameter but its cause cannot be detected in the past, either. The same situation is valid for exhaustion of the tree during the process of shoot turnover. These above-stated reasons are why we studied branch structure transformation.

The aim of this paper is to introduce our method of branch structure transformation analysis as a basis for studies of stress response history of a forest stand, to demonstrate this with the example of four montane forest stands in the Krkonose Mts. and to propose this approach for other ecological applications. Data obtained using this method, which estimates the decline rate and endangerment of individual forest stands, could be very useful for priority determination for transforming spruce monocultures to mixed stands.

2. Methods

2.1 Permanent research plots

The response of Norway spruce (*Picea abies* [L.] Karst.) assimilative organs to multiple stress have been studied in four permanent research plots (50 x 50 m) which were established in 1992 in the Krkonoše Mts., one of the most valuable and endangered national parks in Europe (Cudlín et al. 1995). The basic site characteristics are briefly described in Table 1.

Table 1. Basic site characteristics for the permanent research plots in the Krkonoše Mts.

Site	Altitude [m]	Exposition [angle]	Slope [°]	Age [years]	Tree / number 2500 m ² [pcs]	Mean diameter [cm]	Height [m]
Pudlava	1140	144	17	102	84	29.9	18.8
Modry dul	1237	174	22	121	101	43.5	23.4
Slunecne udoli	1241	154	31	154	86	39.7	21.7
Paseracky chodnicek	1317	222	18	145	140	25.7	13.3

2.2 Crown status estimation

All trees on the permanent plots were monitored each autumn for mean defoliation, defoliation of the primary structure, percentage of secondary shoots, crown transparency, and types of defoliation, using a modified approach of Lesinski and Landman (1985). These parameters were determined only for the middle (production) part of the crown, i.e. exclusive of the upper, juvenile, bottom, and shadowy part. Afterwards, five progressive degrees of crown transformation were derived:

- Degree 0: small defoliation of the stem and/or mosaic type (estimated for branches of the second order), percentage of secondary shoots less than 20%.
- Degree 1: defoliation of the stem and/or mosaic type (estimated for branches of the second order), counteracted by scattered secondary shoot formation, percentage of secondary shoots from 21 to 50%.
- Degree 2: incipient peripheral (ends of primary branches) injury, occasional sub-top injury, often in combination with stem and/or mosaic type, percentage of secondary shoots from 51 to 80%.
- Degree 3: peripheral injury prevailing, occasional top injury, often in combination with previous injury types, percentage of secondary shoots from 81 to 99%.
- Degree 4: peripheral injury occurring by all branches of the middle part of the crown, occasional top injury, often in combination with previous injury types, percentage of secondary shoots 100%.

In addition, we distinguished five types of the shape of the upper (juvenile) part of the crown (modified after Lesinski, non-published data):

1. normal shape, without either vertical or horizontal increment reduction;
2. wide shape, with vertical increment reduction but with normal horizontal increment;
3. narrow shape with both vertical and horizontal increment reductions;
4. dry top;
5. broken top.

These types informed us about the rate and length of the growth process reduction in the last years.

2.3 Branch analysis

Branch sampling

One branch (age of 30 to 40 years) from 5 to 10 trees, representing the most frequent degrees of branch transformation, was cut for analysis below the juvenile part of the crown (Gruber 1994), mostly from the border of the fourth and fifth sections of the crown length. The windward side of the crown, which is supposed to be the most exposed to airborne pollution, was preferred.

Sample preparation

Cookies from the base of the sampled branches (the place where the branch is joined to the stem) were sanded with a 600 grit sand paper and scanned. Images of the cookies were analysed by DendroScan software. Missing annual rings and other disproportionateness were corrected by cross-dating methods.

In addition, cookies of perpendicular sections from all small shoots (thicker than 5 mm), which can be supposed to be of subsequent order, were cut and their annual rings were

counted and measured for ring width under a microscope in two perpendicular directions. From these sets of data, shoots were categorized as regular or secondary shoots of single orders, regular shoots being those from the one year older branches and secondary shoots from two or more years older branches (Gruber 1994).

Dendrochronological analysis

We suppose that assimilates flow on the basis of a glucose gradient, from the needles to the stem. In every live needle set, a certain percentage of the assimilates is utilized in the annual increment of wood during the year (formation of wood cells and cell wall development is accomplished in each part of the tree at the relatively same time – spring – and late-wood formation). Therefore, the level of assimilates produced by the shoots in successive series of particular structure orders of the branch could be an indicator of growth activity (health) of the assimilative apparatus during recent years.

Because different amounts of assimilates are needed to form annual rings of equal width at different ages (older annual rings require higher amounts of assimilates), the width of an annual ring is substituted by annual wood production. This is equal to the area between two subsequent growth ring boundaries, supposed to be approximately circular, which is measured in two perpendicular directions.

The annual wood production of a particular structure order was obtained by the sum of the annual net wood production of all shoots of the same order during their whole life. Part of the annual increment, formed due to support from assimilates which originated from a shoot of the subsequent structure order, must be eliminated. Time series of annual wood production of regular and, in particular, secondary structure orders formed in successive series, were compared (Cudlín et al. 1999).

If the annual wood production of the secondary structure order is greater than the annual production of wood of regular shoots for some period, the annual production of wood at the branch base is maintained mainly by the import of assimilates from the secondary shoots. This phenomenon can be called “secondary shoot prevailing”.

The contribution of the active assimilative apparatus of the branch to wood production at the branch base (and the trunk) is shown by comparing the annual wood production of the whole branch (sum of all primary and secondary shoots) to that at the branch base.

Statistical analysis of the time series of annual wood production at the branch base and of the whole branch

For modelling of trends of the time series of annual wood production at the branch base and of the whole branch after stress exceedance starting time, the second degree (quadratic) polynomial equation ($Y = \beta_0 + \beta_1 \cdot t + \beta_2 \cdot t^2$) and modified exponential equation ($Y = \beta_0 \cdot \beta_1^{\beta_2 \cdot t}$) were chosen. Kendall's tau test was used to determine if the computed trend models of both time series were stationary (Farnum and Stanton 1989). We determined whether the trends of annual wood production of the whole branch and at the branch base are upward (+), downward (-) or stationary (0).

Morphological analysis of foliated shoots

The partitioning of the foliated shoots between primary and secondary shoots of single orders (formed in successive series) was visually estimated using results from tree ring counting of shoots thicker than 5 mm. The number of needle sets of single orders of secondary shoots in individual years was counted to reveal the rate of shoot turnover (number of all structure orders formed).

3. Results

The results of this paper consist of the selection of an indicator set to classify Norway spruce trees according to their stress response history to multiple stress and of their demonstration on selected trees from permanent research plots. These indicators, derived from studies on crown and branch structure transformations (described in Table 2), were selected to recognise the following critical stages of the stress response history: “stress exceedance starting time” (time of exceedance of multiple stress impact over tree resistance), “significant harmful effect time” (time of significant injury to assimilative organs), length of “secondary shoot turnover period” (period of equilibrium of defoliation and regenerative processes) and period when either degradation (exhaustion phase) or regenerative processes (recovery phase) prevail. Characterisation of the above-mentioned indicators using branch and crown transformation analysis is presented in Table 2.

Selected branches, sampled from trees, representing the most widespread crown transformation degree in four permanent research plots in the Krkonose Mts., are described in details using these indicators (Table 3). Such type of tree selection resulted in a large variability of indicators, estimated by trees from one permanent research plot, especially on plots with less progressive crown transformation. On plots with long-term progressive crown transformation, there was a decreased heterogeneity in relation to the dead, less tolerant trees. The comparison among plots is, therefore, possible only using crown status parameters, measured by several tenths of the trees on the plot.

In Table 3, we can see a relatively strong dependence of the significant harmful effect time on the length of the secondary shoot turnover period, however, dependence of these parameters on the prediction of prevailing of exhaustion or regeneration processes was relatively weak. It proved how different single tree strategies respond to similar type and length of multiple stress impact. For example, the tree PUD2 has been stressed for many years, it is considerably transformed, however, it is regenerating at present. On the contrary, the tree PAS3 has been stressed much shortly, it is transformed shortly, however, it seems to be exhausted.

The reconstruction of a hypothetical stress response history for individual Norway spruce trees, subjected to multiple stress impact of different duration and intensity, was performed from the experimental data, obtained from several years observation (Fig. 1). The stress response history of each tree can be described (Table 3) and visualized using this scheme. It is possible to distinguish three different types of stress response behaviour:

1. The stress response history of trees, where the multiple stress impact exceeded “stress exceedance starting level”; the recovery phase succeeded the tree injury after a short time (curve A).
2. The stress response history of trees, where the multiple stress impact exceeded “stress exceedance starting level”; the recovery phase almost compensated for the tree’s injury after a shorter or longer “secondary shoot turnover period” (curve B).
3. The stress response history of trees, where the multiple stress impact exceeded “significant harmful effect level”; a long-term “secondary shoot turnover period” (curve C_0) may result in the prevailing of exhaustion (curve C_2) or regeneration processes (curve C_1) of the tree.

Percentual representation of crown structure transformation degree for single permanent research plots, obtained by ground observation, is summarized in Table 4. This degree for each tree, sampled for branch structure analysis, is given in the last column of Table 3. It enables us to obtain relatively good overview about stress response history of single forest stands.

Table 2. Indicators of critical phases in branch and crown structure transformation (see Figure 1) as a response of Norway spruce to multiple stress impact.

	Stages of response to multiple stress impact	Indicators at branch level Indicators at tree level
Stress exceedance of tree resistance to multiple stress	Distinct, several years decline of annual wood production at the branch base, caused by primary shoot injury, and followed by increased formation of secondary shoots ^{*)}	Defoliation of primary structure $\geq 50\%$
Significant harmful effect of multiple stress on assimilative apparatus	Termination of annual wood production of primary structure ^{*)} Complete defoliation of primary structure at sampling time ^{**)}	Dry top of the major part of branches outgrowing from the stem (defoliation of the whole primary structure)
Shoot turnover period (continual replacing of defoliated shoots by secondary shoots)	Number of secondary structure order prevailing in annual wood production / number of secondary structure orders formed ^{*)} Number of secondary structure order prevailing in quantity of foliated needle sets / number of secondary structure orders formed ^{**)}	Tree with significant harmful effect, without considerable regeneration or exhaustion evidence (see below for explanation)
Tree exhaustion (loss of ability to replace defoliated shoots)	Significant reduction of annual wood production both of the branch base and of the sum of all lateral shoots of branch investigated in last growth period ^{*)} stage 4 (100 % of secondary shoots)	Tree with significant harmful effect, with total defoliation $> 35\%$ and simultaneously classified as crown structure transformation
Tree regeneration (prevailing of processes over defoliation)	Significant increase of annual wood production both of the branch base and of the sum of all lateral shoots of branch investigated in last growth period ^{*)} stage 3 or 4 (secondary shoots $> 80\%$)	Tree with significant harmful effect, with total regenerative defoliation $\leq 35\%$ and simultaneously classified as crown structure transformation

^{*)} characteristics derived from dendrochronological analysis of the branch

^{**)} characteristics derived from morphological analysis of the branch

Table 3. Description of branch structure transformation processes of Norway spruce on the Krkonose Mts. permanent research plots (sampling time September 1996) from the stress concept point of view (see Table 2).

Plots and No. of sampled tree	Age of branch [yrs]	Stress exceedance starting time	Significant harmful effect time	Secondary shoot turnover period [orders] ¹⁾		Exhaustion or regeneration processes B/W ²⁾ [+/-] ³⁾	Stress response history reconstruction ⁴⁾	Degree of crown structure transformation ⁵⁾
PUD1	28	1980	1993	2/3	3/4	0/+	C ₀	3
PUD2	55	1967	1970	3/5	5/7	+/+	C ₁	4
MOD1	29	1978	–	1/3	2/4	0/0	BII	2
MOD2	34	1985	1992	2/3	2/5	-/0	C ₀	3
MOD3	33	1982	1986	2/3	3/6	+/+	C ₁	3
MOD4	40	1982	–	1/2	2/5	0/0	AII	2
MOD5	29	1982	1992	3/3	3/4	-/+	C ₀	4
SLU1	38	1972	1984	2/3	3/5	0/+	C ₀	4
SLU2	36	1972	–	2/3	2/6	-/+	BII	2
SLU3	50	1968	1983	3/3	3/6	-/0	C ₀	4
SLU4	40	1971	1971	3/5	3/6	+/+	C ₁	3
PAS1	48	1973	1993	4/5	5/8	+/+	C ₁	4
PAS2	31	1975	1991	3/3	3/5	0/0	C ₀	4
PAS3	33	1975	1990	2/4	3/5	-/0	C ₀	3

PUD – Pudlava, MOD – Modry dul, SLU – Slunecne udoli, PAS – Paseracky chodnicek

1 Left column: prevailing order of structure of assimilative organs / total number of orders, determined using the dendrochronological approach; right column: prevailing order of structure / total number of orders, determined using the morphological approach.

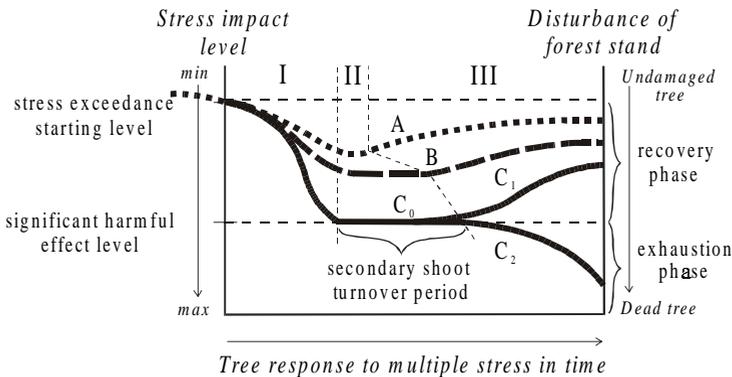
2 Type of time series: B – annual wood production of the branch base; W – annual wood production of the whole branch (sum of all primary and secondary lateral shoots).

3 Trends of time series of annual wood production of the branch base, of the whole branch after stress exceedance time: + upward trend; – downward trend; 0 no trend.

A Ax, B_x, C_x (types of the stress response history curves from Fig. 1) – if both values B and W are plus P x = 1; if both values B and W are minus P x = 2; if values B and W are plus and minus or 0 P x = 0. For further explanation see Fig. 1.

Table 4. Representation of crown structure transformation degree of Norway spruce on the permanent research plots in the Krkonose Mts.

Site	Degree of crown structure transformation					Average
	0	1	2	3	4	
Pudlava	0	30	33	26	11	2.2
Modry dul	0	25	30	37	8	2.3
Slunecne udoli	0	8	17	58	17	2.8
Paseracky chodnicek	0	2	10	38	50	3.4

**Figure 1.** The hypothetical stress response history reconstruction of Norway spruce trees subjected to the multiple stress impacts of different duration and intensity.

- A: The stress response history of trees, where the multiple stress impact exceeded the “stress exceedance starting level”; the recovery phase succeeded the tree injury after a short time.
- B: The stress response history of trees, where the multiple stress impact exceeded the “stress exceedance starting level”; the recovery phase almost compensated for the tree’s injury after a shorter or longer “secondary shoot turnover period”.
- C: The stress response history of trees, where the multiple stress impact exceeded the “significant harmful effect level”; the long-term “secondary shoot turnover period” may result in the exhaustion (C_2) or partial regeneration (C_1) of the tree.
- I: The period of the tree response to the multiple stress impact, exceeding the “stress exceedance starting level”, when degradation processes temporarily prevail upon the regenerative processes.
- II: The “secondary shoot turnover period” – a period when the degradation processes are in equilibrium with the regenerative processes.
- III: The period of tree response to the multiple stress impact, when either the regenerative processes (recovery phase) or degradation processes (exhaustion phase) prevail.

4. Discussion

Our results showed the need to estimate crown features (defoliation and secondary shoot occurrence) only from the central, production, part of the crown, where the primary structure (regular shoots) is continuously transformed to secondary structure through secondary shoot

formation. This part represents most of the crown, excluding the top, juvenile part, with prevailing air space colonization function (Gruber 1994) and the bottom, shaded and, therefore, photosynthetically less active part. Photosynthesis is most prominent in the production part of the crown.

The representativeness of sampled trees to whole forest stands is always questionable. To investigate a larger quantity of trees and branches, and to statistically process the obtained data is undoubtedly the best method. However, this current method of branch structure analysis is very time consuming. Therefore, the comparison of forest stands according to the crown transformation degree was proposed. Detailed branch structure transformation analysis can serve to obtain more precise data about the stress response history of the trees with high representation in degree of crown transformation. The correlation between crown transformation degree and tree stress response history, derived from branch structure analysis, seemed to be sufficient. However, different possible strategies of the tree to counteract crown injury and some methodological problems (e.g. different age of sampled branches) can be causes for an occasional decrease.

In relation to the time and labour consuming branch structure studies, indicators of the same processes in the crown of the sampling trees have been developed (Table 2). Comparison of the indicators, describing branch structure and crown transformation, showed relatively sufficient correspondence with the exception of the determination of significant harmful effect. The estimation of the occurrence of this indicator in tree crowns (complete defoliation of primary structure in major part of branches outgrowing from the stem in the production part of the crown) is sometimes difficult in relation to the breaks of dry branches and progressive secondary shoot formation (e.g. trees SLU 4, MOD 3). Another cause can be the different age of branches under study; the primary structure of older branches had more time to defoliate (Table 3).

The proposed approach for stress response history analysis of montane Norway spruce forest stands can be a useful tool to approximately describe tree response to long-term multiple stress impacts. It can be used for more precise predictions of the subsequent development of these forest ecosystems, estimation of zones of forest endangerment, and for the evaluation of loss in wood production of trees, caused by repeated replacement by secondary shoots of damaged assimilative organs (including branches).

For these purposes, the possibilities to increase the number of analysed branches to a level satisfactory for mesoscale monitoring are currently being tested. This method consists of the time series analysis of annual wood production at the branch base and of visual estimation of secondary structure prevailing, primary structure decline, and the length of the secondary shoot turnover period.

5. Conclusion

Crown and branch structure analyses of Norway spruce trees enabled us to reconstruct stress response history on four permanent research plots in the Krkonose Mts. The representation of crown structure transformation degree obtained by ground observation allowed to range these forest stands according to the rate of defoliation and regeneration processes (Table 4). The least transformation was observed on the plots of Pudlava and Modry dul, higher transformation on the Slunecne udoli and the highest transformation was found on the Paseracky chodnicek plot.

The branch structure transformation study on trees, representing the most frequent crown transformation degrees enabled us more detailed stress history reconstruction (Table 3). A big

variability among trees was estimated on plots with less progressive crown transformation (Pudlava). On plots with long-term progressive crown transformation (Paseracky chodnicek) the heterogeneity decreased regarding to the considerable share of dead, less tolerant trees. The comparison among plots is therefore possible only using parameters of crown status, measured by several tenths of trees on the plot.

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Assessment of the Predisposition of Spruce-Abundant Forests to Various Disturbances

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Abstract

With the increasing limitation of personal and financial resources in forest management, the role of preventive forest protection becomes more and more important. Aiming at the improvement or the warranty of special forest functions and the reduction of production risks, a wide range of tools reaching from mechanistic to statistical models can be used. Referring to the goal of the present study, a system with widest possible applicability (primarily for spruce-abundant forests in Austria) has been established, which belongs to the category of mechanistic models. This model is to derive the predisposition of a given stand or a larger forest unit for various biotic and abiotic destructive agents. It contains a set of indicators – found by an intensive literature analysis – which are presumed to be essential for the prediction of predisposing site and stand situations. The final system will combine singular predisposition-models of special damaging agents such as storm, snow, hoarfrost and air pollutants as well as phytophagous insects or important fungi. The prediction-system for each impairing factor consists of an award-penalty-point system with facultative knock-out-criteria, where a list of relevant impacts is made up. These lists contain indicators such as altitude, slope or soil type for the site-related assessment as well as tree species, stand density or developmental phase, for example, for stand-related assessment. The indicators have been split into classes in order to establish a scale, where a specific score is assigned to every scale level corresponding to its contribution to the overall-predisposition. In consideration of the predisposition-increasing or -decreasing effect of those very scale levels, positive or negative signs have been put to each score. Applying the system to a given site or stand, the specific scores of each correct scale level of the indicator list are summed up to an actual total amount. The result is related to a pessimal total amount and this percentage can be interpreted as a relative predisposition.

Keywords: assessment of predisposition, award-penalty-point system, biotic and abiotic damages

1. Introduction

Staff reductions and an increasing wage-cost factor clearly indicate a decreasing availability of personal and financial resources for curative forest protection in the near future. As a matter of fact, the detection of potentially endangered areas as well as any other preventive protection tools will attain outstanding importance by means of concentrating limited resources mainly on spatial zones or stands with a high potential for severe forest injuries. Furthermore, knowledge about circumstances that pave the way for destructive agents may be essential for evading such conditions. The assessment-system for the identification of various predisposition-statuses of spruce-abundant stands, respectively, forest sites presented in the following should be seen as a first attempt in developing supporting tools for forest management decision processes. It should provide the basis for an objective and operational handling with the constituent facts of relevant threats for forests.

Moreover, the predisposition-models could be regarded as a potential part of an integrated pest management system, which combines the study and evaluation of all aspects of a pest-host system to provide the resource manager with an information base for decision-making (see Stark and Waters 1985). Details about the goals, the conceptual and organisational structure as well as the development and practical application of such an integrated pest management system (IPM) can be drawn from Waters et al. (1985).

2. The system

At the beginning, it is essential to lay particular stress on the fact that the model does *not* provide information about *risks* of forest injuries but only about the conditions that may favour pest outbreaks or other damages. Injuries may occur if high to low predisposed sites and/or stands coincide with the appearance of lowly to highly aggressive destructive agents. Only the combination of those two pathways will result in the derivation of risk-predications. The assessment of predisposition stresses the importance of long-term impacts that pave the way for severe forest protection problems and triggers by that the preventive part of forest protection. Before the system will be explained, a short synopsis of the underlying goals is given in order to justify the methodical fundament of the tool. The first aim was to derive a model, which can be adapted to any relevant destructive agent occurring in (spruce-dominated) forests, regardless of whether it refers to biotic or abiotic injuring factors. Moreover, a widest possible spatial applicability was required with a preliminary concentration on forest stands and sites within Austria. In addition, the model should point out as many important impacts on the predisposition of forests as possible and be useful in supporting peoples' conscious content for anthropogenic and naturally determined risks. With respect to the extremely varying quality and quantity of data-sets existing for different forest administrations, a system had to be found that could deal with rather different data-bases concerning size and scale level. On the one hand the system should work as a checklist of impairing factors, on the other hand it should allow simple derivations of danger potentials. Furthermore, a clear differentiation between site- and stand-dependent predisposition was required in order to illustrate site- and stand-related possibilities for interference by forest management and to allow mapping of high to low endangered spatial areas. Finally, the concept of the model should allow current adaptations to the latest scientific findings, which should guarantee permanent improvements in its predication quality. This is thought to be especially important for damaging agents, which are not well investigated at all.

All the above mentioned requirements seemed to be met by an “award-penalty-point-system” cited by Speight and Wainhouse (1989) or Berryman (1986). In the present context of predisposition-assessment this very system belongs to the category of mechanistic models, which trigger general applicability and implementation of basic knowledge at the expense of accuracy and precision. The model is to derive the predisposition of a given stand or a larger forest unit for various biotic and abiotic destructive agents such as storm, snow, hoarfrost and air pollutants as well as phytophagous insects or important fungi. Each single model (i.e. storm-model, snow-model, etc.) contains a set of indicators – arrived at by an intensive literature analysis – which are presumed to be essential for the prediction of predisposing site and stand situations. As for biotic disturbances, especially for insect pests, much less intense and useful investigations in comparison to abiotic threats exist that could be incorporated into the system. This circumstance is reflected in the number of indicators assumed to be relevant for the assessment, which amounts to 29 criteria for the site-related identification of storm-predisposition compared to 16 site-related criteria for *Cephalcia abietis* L. (Hym., Pamphiliidae). Table 1 shows an exemplary list of criteria used for the assessment of predisposition for storm-damages.

After a first grouping of relevant impact factors (see Table 1), their relative strength of influence on the predisposition was represented by allocating a certain weight-number to each single criterion (compare Table 2). Impairing factors with overlapping influence orbits were assigned to lower weight-classes to avoid false predication patterns.

Table 1. List of some criteria for the assessment of storm-related predisposition.

site-related criteria	stand-related criteria
soil type	tree-species composition resp. portions
presence and functioning of artificial forest drainage	predominant mean height
water table, dynamic of stagnic conditions	stand age structure, vertical forest crop structure, canopy density
soil compaction, soil texture, coarse fragments, outcropping bedrock	plant number at stand formation status
relative site quality	tending operations, stem number curve
N-input	shelter, wind mantle, etc.
slope, topography	visible root damages, stem wounds, damages caused by air pollution
site-related predisposition to relevant disturbant factors (bark beetles, root rot, etc.)	stand-related predisposition to relevant disturbant factors (bark beetles, root rot, etc.)

Table 2. Examples for the allocation of criteria to different weighting-classes.

weighting-class	criterion
1	water table; humus; thickness of A horizon soil compaction; soil texture, etc.
2	forest drainage system; dynamic of stagnic conditions; podzolization
3	topography
5	gley soil, gley-like soil

Table 3. Example for the assignment of predisposition-points.

critereon	indicator-scale	score
water table	> 120 cm	+ 2
	61–120 cm	+ 4
	31–60 cm	+ 6
	16–30 cm	+ 8
	≤ 15 cm	+ 10

In the next step, each indicator has been split into classes in order to establish a scale, where a specific score was assigned to every scale level corresponding to its contribution to the overall-predisposition. The assignment of scores was oriented on the principle form of the relationship-function between the destructive agent and its target, directly or indirectly described in the special literature. To avoid the impression of an incorrectly high level of accuracy a maximum score of 15 points was taken as a standard allocation. In consideration of the predisposition-increasing or -decreasing effect of those very scale levels, positive or negative signs have been put to each score. This was especially done due to the intention of demonstrating possibilities for interference by forest management. Table 3 contains some examples of such a differentiation process.

Indicators of outstanding influence on the predisposition were defined as knock-out-criteria, where a further determination of other indicators becomes superfluous. As a matter of fact, the assessment process can be shortened by the use of knock-out-criteria. Since no knock-out-criteria exist for all impairing factors, they have been termed “facultative”. Applying the described system to a given site or stand, the specific scores of each correct scale level of the indicator list are summed up to an actual total amount. The result is related to a pessimal total amount and this percentage can be interpreted as a relative predisposition. Knock-out-criteria automatically lead to the highest possible predisposition-number of 100% or, the other way round, to a minimal predisposition-number. Since the availability of datasets will significantly vary among different forest administrations, a minimum standard of indicators has been defined for every particular model. Hence, certain flexibility concerning the data-basis is guaranteed. Local site or stand particularities can be taken into account by changing the respective weight-numbers or predisposition-points.

3. Conclusions

The higher the deduced status of the predisposition is, the higher will be the possibility of severe injury for the respective site or stand. Strongly predisposed stands on sites with marginal danger may be endangered to a minor degree than less predisposed stands on highly threatened sites. As the predisposition-related point of view mainly takes into consideration the victim-related pathway of damage, stands may evade harm only because of the (probably random) absence of destructive agents. That clearly indicates that the validity of the system is not always simple to be proved. Principally, the distribution-pattern of damaged sites or stands should represent a right-skewed curve with an increasing predisposition level and the other way round for undamaged stands or sites. Attention must be paid to the circumstance that according to the limited number of criteria and indicator scales only certain predisposition levels can be reached and that “validation”-calculations must consider that fact

in the form of using appropriate predisposition-classes. By means of the system an assessment of the actually existing predisposition can be obtained, furthermore future predisposition states can be derived by varying the indicators (e.g. by changing the tree species composition or the predominant mean height). Thus, the model represents a first approach to an additional tool in forest management decision processes.

As the recent state of knowledge partially contains major gaps (as mentioned especially for biotic impacts), an urgent need for further investigations can be pointed out during the establishment of such a predication-system. Referring to the observed uncertainty of knowledge in the domain of predisposition-assessment the presented system should be regarded as a first step along a difficult path.

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Implementing a Decision Support System for Silvicultural Decision Making in Low-Elevation Norway Spruce Forests

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Abstract

Silvicultural decision making in damaged off-site Norway spruce stands is a multiple-objective and multiple-attribute decision making problem. To support the decision maker in analysing such complex decision problems DSSs (decision support system) can provide valuable help. In this contribution a comprehensive outline of a DSS for silvicultural decision making with Norway spruce stands is presented. Selected components of a DSS are described and demonstrated for the evaluation of silvicultural treatment options and growth stock objectives. In this contribution, we apply (a) a static model for site requirements of tree species to assess species suitability under different climatic conditions, (b) the analytic hierarchy process (AHP sensu Saaty 1977) to determine preferences for different silvicultural treatment options as well as for growth stock objectives. The trade-off between contrasting preferences is modelled with a multiple-attribute utility function.

Keywords: decision support system, stand conversion, analytic hierarchy process, silviculture, Picea abies.

1. Introduction

Extensive areas supporting broad leaf species in warmer and drier lowlands have been transformed to conifer plantations dominated by Norway spruce. Under these site conditions Norway spruce is particularly vulnerable to drought, windthrow and an array of insect and disease organisms. Depending on site conditions multiple rotations of pure Norway spruce may lead to soil compaction, increased soil acidification and decoupled nutrient cycling. Scenarios of a possible climate change with higher temperatures and more frequently occurring drought periods increase the risk of such "secondary" spruce stands. To reduce

economic and ecological risks the conversion of Norway spruce stands into mixed-species stands which are better adapted to particular site conditions is recommended. In multiple-purpose forestry, a decision maker usually has to consider other objectives besides timber production. Thus, in the silvicultural planning process the decision maker faces multiple-objective and, in view of the extensive array of site and stand attributes involved, multiple-attribute decision making problems. Due to the complexity of the problem, it is obvious that for the development of stand conversion programmes or treatment plans neither intuitive nor schematical solutions are appropriate planning approaches. For such decisions, a formal decision analysis is strongly recommended. According to Keeney and Raiffa (1976), four phases of decision analysis can be distinguished:

1. structuring the decision problem,
2. assessing the impacts of each possible solution
3. determining the preferences of the decision maker, and
4. comparing the decision alternatives.

To support the decision maker decision support systems can be employed. Decision support systems (DSS) can be a valuable tool in solving complex real-world decision problems by generating aggregated information on a particular decision problem. In general, DSS are computer based systems which utilize available knowledge, i.e. facts, expert rules and models which have been found useful in solving specific problems. As DSS are based on formalized knowledge, their application in the decision making process facilitates the making of decisions which are reproducible and as rational as possible. In silvicultural planning, quite often the consideration of spatial information is necessary. If mechanisms for the input and use of spatial information as well as for the output of maps are provided, such systems are called SDSS – spatial decision support systems. In Central European forestry the application of DSS in silvicultural decision making is widely unknown. In this contribution we (1) outline the general structure of a DSS, and (2) present and demonstrate the application of selected components of a SDSS which is currently being developed at the Institute of Silviculture for decision making in damaged Norway spruce stands.

2. Some fundamentals on decision support systems

There is no universally accepted definition of a decision support system (Fedra and Reitsma, 1990). Almost any computer-based system, from database management or information systems via simulation models to mathematical programming or optimization models can support decision-making. Though these instruments and methods can be of valuable help they do not represent a DSS in a strict sense. Recent definitions (e.g. Densham 1991) suggest that decision support systems have the following distinguishing characteristics:

- they are designed to solve ill-structured problems
- they have a user-interface that is both powerful and easy to use
- they enable the user to combine data and models/methods in a flexible manner
- they help the user to evaluate the decision space/the available options
- they can be adapted to specific situations.

In Figure 1, the general structure of a DSS is shown. Four main components can be distinguished: the information base, the tool box, the implementation of the system and the decision model. The information base contains all information which is available to solve the

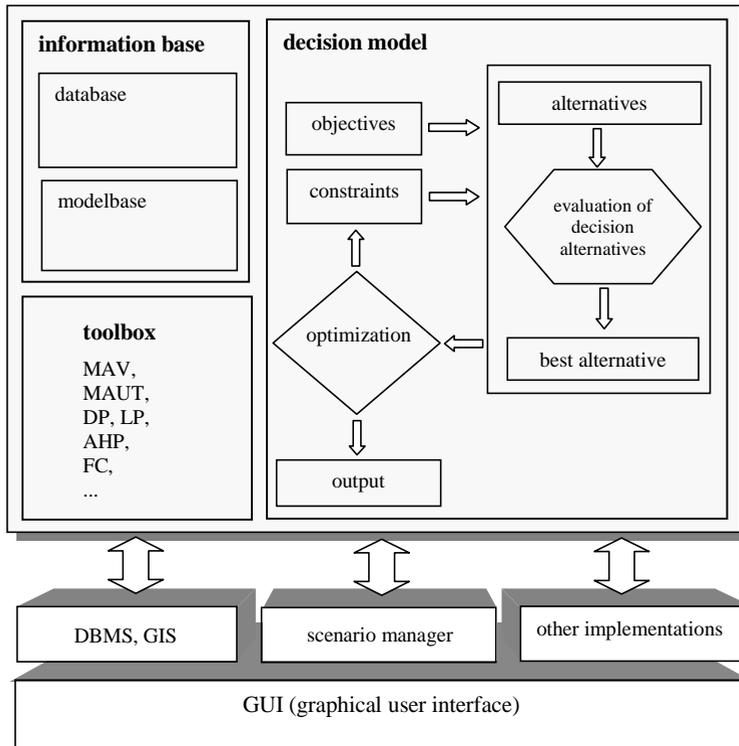


Figure 1. General structure and main components of a spatial decision support system (SDSS). MAV = multi-attribute value methods, MAUT = multi-attribute utility theory, DP = dynamic programming, LP = linear programming, AHP = analytic hierarchy process, FC = fuzzy logic control, DBMS = data base management system, GIS = geographical information system.

decision problem. The information consists of data either directly obtained from measurements of the decision objects or generated by models. The tool box may contain various methods for optimization and evaluation such as linear programming (LP), dynamic programming (DP), multi-attribute value (MAV) and multi-attribute utility techniques (MAUT) either as implemented applications or as algorithms which are defined via the user interface. Based on the contents of the tool box and information base the decision model is realized. Essentially a decision model consists of goals, constraints and decision alternatives which can all be defined via the graphical user-interface (GUI). The decision alternatives are evaluated or optimized with methodologies or algorithms from the tool box. The implementation of the DSS can be seen as the framework for the construction of the decision model where data, models and methods are linked. It always includes the scenario manager and a data-base management system (DBMS). In case of a spatial decision support system (SDSS) a geographical information system (GIS) is included. However, the expectation that all involved applications of a DSS are fully integrated is somewhat unrealistic. The current state of technology is, that though data formats are already interchangeable, the administration and coordination of application tasks still has to be coordinated by the user.

3. An example: Evaluating silvicultural treatment options and growth stock objectives for damaged Norway spruce stands

3.1 Site and stand data

In the following sections, some of the concepts and components of a decision support system which are currently already implemented in a beta version are applied to analyse the decision space for a silvicultural decision problem quite typical for secondary Norway spruce forests. In our example, the forest comprises some 250 hectares of almost pure Norway spruce stands and is located in the very south of Austria at 24.5° longitude east and 46.3° latitude north at altitudes between 540–640 m a.s.l. On a subsoil of silicatic fluvio-glacial gravelly deposits mainly brown earths and podzolic brown earths have developed. At sites where silty soil layers do occur gleyic soils can be found. On some hilltops dolomitic bedrock appears. Multiple rotations of Norway spruce and intensive litter raking in the past have had a substantial impact on soil acidity. Some 54% of the forest area shows pH(H₂O) values between 3.8 and 4.2, a smaller portion even yields pH-values below 3.8. The regional climate is characterized by an average precipitation sum of 778 mm per year and an annual average temperature of 8.3 °C with low winter temperatures due to temperature inversion. According to Kilian et al. (1994), the potential natural vegetation (PNV) would mainly consist of associations of the *Pino-Quercetum* and *Luzulo-Fagetum*. Old forest records report on gradations of *Lymantriacha dispar* in the period 1927–1933, and of *Pristiphora abietina* in 1949–1950. Damage by bark beetle infestations occurred periodically during the 1960s and 1970s. Although for decades the reintroduction of admixed tree species, mainly broadleaves, has been among the most prominent management objectives, the current stands still consist of almost pure Norway spruce. The decrease in annual precipitation during the last 10 years in combination with ongoing discussions on a possible climate change with higher temperatures and precipitation eventually shifted to the cold season causing increased interest by the forest owner in stand conversion strategies. In February 1996, a severe damage was caused by a snow breakage event.

3.2 Structuring the decision problem

After the salvage operations had been completed and data on the remaining stands had been sampled in the course of an inventory, the decision analysis started with an array of remaining Norway spruce stands of different damage intensities, where each stand was characterized by a set of site and stand attributes. The questions to be answered were:

- What is the most appropriate silvicultural treatment for the remaining stands?
- What alternate or admixed tree species are suitable for the site?
- Where and how can they be introduced?
- What is the overall best solution with respect to the owner's objectives?

In our example, the general objectives of the owner were (a) income from timber production, (b) a reduced risk of management through the establishment of mixed species stands, and (c) ensure sustainable site productivity. One task was to decide on appropriate further silvicultural treatment alternatives (STO) for the individual stands some of which had been severely damaged by snow. The general frame for this decision problem was to determine:

- a) the loss from reduced volume increment in case a damaged stand is further grown
- b) the volume loss from premature cutting of stands

Given the premise that timber production is the only management objective the conceptual decision model would schedule a stand for "final cutting" (STO = 4) and, subsequently, "afforestation" (STO = 3) if the expected volume loss from premature cutting is lower than the expected loss from reduced volume increment due to reduced stocking. Otherwise, an appropriate silvicultural treatment option has to be selected from the alternatives "do nothing" (STO = 5), "regenerate by advance planting" (STO = 2.1–2.4) and "refill blanks" (STO = 1.1–1.2). However, facing additional objectives, a trade-off between different aspiration levels for the set of objectives has to be considered. Thus, the range of possible treatments for given stand conditions was broadened substantially (Table 1). STO = 9 was either assigned in the case of missing information or in the case of unclear situations, such as reasonable degree of stocking but very few crop trees. To determine appropriate treatment options for each stand, 11 rather broad stand categories with respect to the stand attributes age, degree of stocking and number of crop trees per hectare had to be defined. Possible silvicultural treatment options (STO) were assigned to each stand category based on recommendations given by Thomasius (1973), Rottmann (1985) and Pollanschütz (1980) and on results of simulation experiments with a single-stem growth simulator (Hasenauer 1994). Each stand of the forest was assigned to a stand category (Table 1).

To select the most preferred silvicultural treatment for given stand conditions the objectives of the owner had to be considered. In the course of discussions with the forest owner, the minimization of management risk and of financial investment respectively, a low silvicultural and organizational know-how level for the implementation of further stand treatment options and as the utilization of a stand's inherent yield potential were identified as relevant decision criteria.

A second task was to assess the possibility to introduce admixed tree species under current stand conditions in view of desirable future growth stock objectives. Stands which had been opened by snow breakage could, thus, be considered for instant advance planting of shade tolerant species. As a first step in deciding on desirable future species mixtures (growth stock objectives), species mixtures which were considered reasonable from a silvicultural point of view had to be defined (Schütz 1994). For this task, the full range of regionally occurring site conditions was considered (Table 2). Considering the various growth stock objectives (GSO) from Table 2, it is obvious that with regard to the management objectives of the forest owner not all of the GSOs were equally preferred. Thus, as a further step in the analysis the

Table 1. Stand categories as defined for the analysis of the decision problem. – Stand treatment options (STO): 1.1, 1.2 = refill blanks; 2.1, 2.2, 2.3, 2.4 = advance planting; 3 = afforestation; 4 = final cutting; 5 = do nothing, 9 = need more information.

stand type	stand age	degree of stocking	crop trees/ha	possible STO
1	> 60	> 0.7		2.1, 5
2	> 60	> 0.6 ≤ 0.7		2.1, 2.2, 5
3	> 60	> 0.3 ≤ 0.6	≥ 100	2.1, 2.2, 2.3, 4, 5
4	> 60	> 0.3 ≤ 0.6	< 100	2.1, 2.2, 2.3, 4, 5
5	> 60	> 0.0 ≤ 0.3		2.4, 4, 9
6	< 60	> 0.4 ≤ 0.7		1.1, 1.2, 9
7	< 60	> 0.3 ≤ 0.4	≥ 150	1.1, 1.2, 4, 5
8	< 60	> 0.3 ≤ 0.4	< 150	1.1, 1.2, 4, 5
9	< 60	≤ 0.01		3
10	< 60	> 0.7		1.1, 9
11	< 60	> 0.01 ≤ 0.3		1.2, 4, 5

Table 2. The set of apriori defined growing stock objectives (GSO).

mixture type	species proportions
GSO1	<i>Picea abies</i> (8), <i>Acer pseudoplatanus</i> (2)
GSO2	<i>Picea abies</i> (10)
GSO3	<i>Picea abies</i> (7), <i>Larix decidua</i> (2), <i>Fagus sylvatica</i> (1)
GSO4	<i>Picea abies</i> (6), <i>Abies alba</i> (2), <i>Fagus sylvatica</i> (2)
GSO5	<i>Alnus glutinosa</i> (7), <i>Fraxinus excelsior</i> (2), <i>Acer pseudoplatanus</i> (1)
GSO6	<i>Quercus robur</i> (4), <i>Tilia cordata</i> (2), <i>Prunus avium</i> (4)
GSO7	<i>Quercus petraea</i> (7), <i>Pinus sylvestris</i> (2), <i>Tilia cordata</i> (1)
GSO8	<i>Quercus rubra</i> (8), <i>Larix decidua</i> (2)
GSO9	<i>Pseudotsuga menziesii</i> (8), <i>Tilia cordata</i> (1), <i>Acer pseudoplatanus</i> (1)

preferences of the owner for the set of suggested future growth stock objectives had to be determined. It is important to note that the process of determining preferences for the GSOs was carried out independently from specific site conditions. Thus, it has been implicitly assumed that the site requirements of each GSO are reasonably met. Therefore, to arrive at a final decision on a GSO for a particular site, information on the physiological suitability of involved tree species for the given site conditions had to be considered additionally.

A further step in the decision analysis was to evaluate the possibilities to realize the a-priori defined growth stock objectives under different silvicultural treatment regimes. Finally, in view of the general management objectives of the forest owner a possible trade-off between the best silvicultural treatment option (STO) for a given stand and the most preferred future growth stock objective (GSO) had to be considered. Both the possibility to realize a GSO

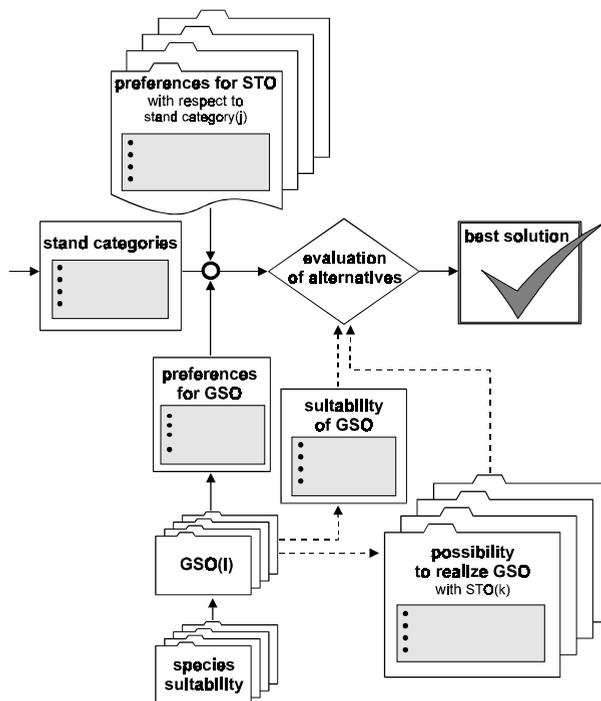


Figure 2. Structuring the decision problem.

with a particular STO and the suitability of the GSO for the site were used as decision constraints in the evaluation process (Figure 2).

3.3 Methodology for analysing the decision problem

To provide all the information needed for the analysis of the structured decision problem, from Figure 2 we may apply various techniques and models from the tool box or the model base of a DSS. For our example we selected

- a static climate-sensitive model to assess the suitability of tree species for a particular site
- the analytic hierarchy process (AHP), a multi-criteria decision-making technique, and
- a multiple-attribute utility function to calculate overall utility values for the decision alternatives

3.3.1 A model for evaluating the ecophysiological suitability of tree species

A static model was applied to analyse the ecophysiological suitability of tree species at stand level (Steiner and Lexer 1998). In an approach which essentially follows the life-zone concept of Holdridge (1947), the physiological suitability of a species for a particular site was calculated from the monocausal effects of selected site factors on species suitability, including physical and chemical soil parameters, a soil moisture index, the growing degree days above a threshold temperature of 5.5 °C and the winter minimum temperature (Table 3). The monocausal response functions which were meant to describe the effect of the individual site parameters on species suitability had been parameterized based on data and qualitative information from the literature (e.g. Ellenberg 1996; Dohrenbusch 1982). Recent results from an analysis by Lexer and Hönninger (1997), where tree growth data from more than 11.000 sample plots of the Austrian Forest Inventory had been related to bioclimatic variables were used to back-up the parameterization procedure. For the site factors "growing degree days",

Table 3. Site parameters included in the suitability model.

factor group	parameter	characterization
	Growing Degree Days (GDD)	Temperature sum above atreshold value of 5.5 °C; range of positive net primary production
T	Winterfrost	average air temperature of the coldest month Dec.–February; frost hardiness of tree species
	Soil Moisture Index (SMI)	relative water deficit in the growing season (> 5.5 °C), SMI is derived from site-pecific water balance calculations
W	gleyification	effects of gleyification are not represented by the soil moisture index (SMI)
	pH-value of the mineral soil	index for the buffer capacity of the mineral soil and for nutrient availability
N	C/N- ratio of the mineral soil	index for the cycling of nutrients and for the general nutritional status of the soil
	coarse fraction, soil texture and soil depth	characterizes the nutrient sorption potential of the root horizon

winter minimum temperature", "soil moisture index" and "pH of the mineral soil" continuous response functions had been parameterized. For the effect of "soil depth", "soil texture", "coarse fraction" and "C/N-ratio" the available information was considered to be insufficient for the parameterization of continuous response functions. Therefore, the effects of these site factors were represented in a matrix form.

Nonparameterized operators such as the minimum (Min), the algebraic product (AP) and the geometric mean (GM) were used to combine site factor effects on species suitability within a hierarchical frame. In contrast to the Min-operator, the GM-operator considered partial compensation, the AP-operator decreases the combined effect of site factors. The model structure is shown in Figure 3.

The presented model was applied to assess ecophysiological species suitability under current climatic conditions as well as species sensitivity to climatic extremes and to a climate change scenario of IPCC (Houghton et al. 1990) (Table 4).

The overall ecophysiological suitability of a species was calculated as the weighted average from the three scenarios, where the suitability rating under the current climatic conditions had been assigned the highest weight and the climate change scenario the smallest. The composite suitability value for a growth stock objective was calculated from the species-specific values.

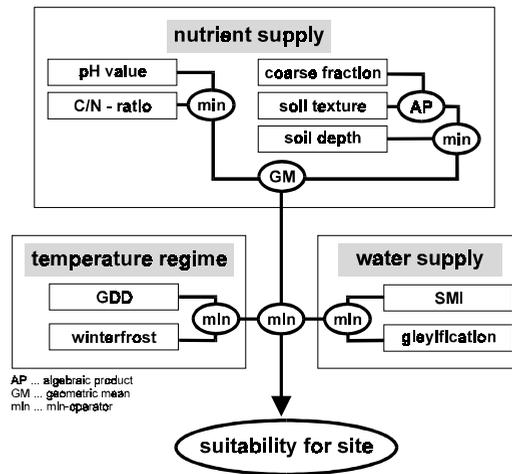


Figure 3. Schematic representation of the model structure.

Table 4. Climate parameters (seasonal averages for temperature (T) and precipitation (P)) used in the analysis of species suitability.

scenario	T _{summer} [°C]	P _{summer} [mm]	T _{winter} [°C]	P _{winter} [mm]
1960–90 (average)	14.9	545	1.2	294
1992 (drought year)	16.8	406	2.0	403
IPCC 2030 (average)	17.4	464	2.7	294

3.3.2 The Analytic Hierarchy Process

The analytic hierarchy process (AHP) is a mathematical method for the analysis of multiple-criteria decision problems. Since its introduction by Saaty (1977), the AHP has been applied in a variety of practical applications, mainly in economics, planning and conflict resolution. However, to date applications in forestry have been rare (e.g. Kangas 1993). Essentially the AHP is based on pairwise comparisons of elements in a decision hierarchy with regard to the parent element at the next higher hierarchical level. The pairwise comparisons are made on a scale of relative importance where the preferences between two elements are expressed on a ratio scale from equally important to absolute priority (Table 5).

These ratings are then arranged in a symmetric comparison matrix and the local priorities of the elements in the matrix are calculated from the normalized right eigenvector (Jobson 1992). Because the method is based on the direct comparison of the preference of elements without using measurement units it can be used for qualitative as well as quantitative attributes (Saaty 1996). One of the important features of AHP is that it provides a measure for the consistency of the ratings in the comparison matrices. Inconsistency is measured by the consistency ratio (CR) which is calculated with eq. 1. Matrices with values of CR > 0.10 should be checked for inconsistent comparison ratings (Saaty 1977).

$$CR = \frac{\lambda_{max} - N}{(N - 1) \cdot RI}$$

λ_{max} = dominant eigenvalue of the comparison matrix
 N = dimension of the matrix
 RI = random index, increases with N (Saaty 1977)

(1)

As an example the calculation of preference values for the set of growth stock objectives from Table 2 the criterion "risk of snow breakage" is presented. In eq. 2, the pairwise comparisons of the GSOs are given. For instance, GSO1 (first row) is moderately more preferred (= a rating of 3) with regard to the risk of snow breakage than GSO2 (second column).

	GSO1	GSO2	GSO3	GSO4	GSO5	GSO6	GSO7	GSO8	GSO9	
A =	1	3	1/2	1/4	1/4	1/5	1/4	1/5	1/4	GSO1
	1/3	1	1/4	1/4	1/6	1/6	1/5	1/6	1/5	GSO2
	1/2	4	1	1	1/4	1/4	1/3	1/4	1/3	GSO3
	4	4	1	1	1/3	1/5	1/4	1/5	1/4	GSO4
	4	6	4	3	1	1	3	1	2	GSO5
	5	6	4	5	1	1	3	1	3	GSO6
	4	5	3	4	1/3	1/3	1	1/2	3	GSO7
	5	6	4	5	1	1	2	1	3	GSO8
	4	5	3	4	1/2	1/3	1/3	1/3	1	GSO9

C.R. = 0.06

(2)

The normalized right eigenvector of this matrix represents the relative preferences for the GSOs (Figure 4).

Table 5. Numerical values and corresponding linguistic terms for the pairwise comparisons according to Saaty (1996).

rating	linguistic term
9	Extremely more preferred
7	Very strongly more preferred
5	Strongly more preferred
3	Moderately more preferred
1	Equally preferred
1/3	Moderately less preferred
1/5	Strongly less preferred
1/7	Very strongly less preferred
1/9	Extremely less preferred

2, 4, 6, 8 and $1/2, 1/4, 1/6, 1/8$ are intermediate values

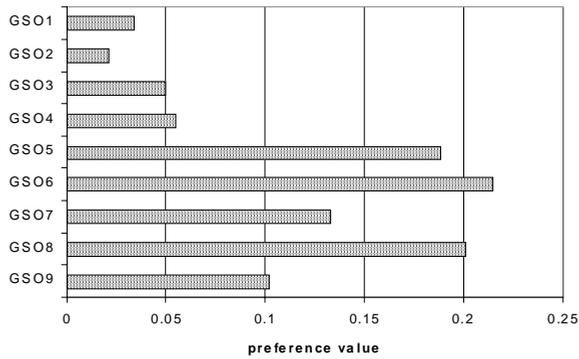


Figure 4. Preference values for a set of growing stock objectives (GSO) with regard to the criterion “risk of snow breakage”.

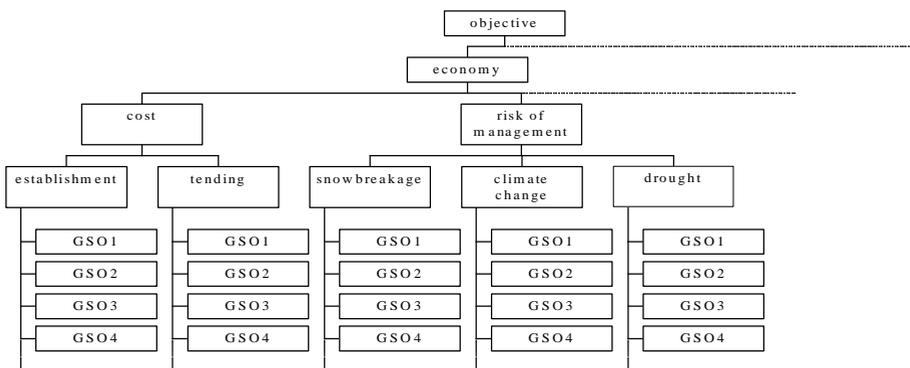


Figure 5. Example for the structure of the decision hierarchy for the determination of preference values for the growing stock objectives (GSO).

3.3.3 Determining the overall utility of silvicultural alternatives

To find the overall best solution for a stand in case more than one possible solution does exist, an approach that borrows from multiple-attribute utility theory was adopted. Overall utility of a silvicultural alternative for a damaged stand consists of partial utilities which are obtained from selecting a stand treatment option (STO) and a future growth stock objective (GSO). This approach has proven to be useful in trade-off situations (Kangas 1993). The general form of the utility function can be written as

$$U = a \cdot U_{GSO} + b \cdot U_{STO} \quad (3)$$

under the constraints that

$$a + b = 1$$

and

$$P_{SR} > C1 \quad (4a)$$

$$S_{GSO} > C2 \quad (4b)$$

where U is the overall utility of a solution. The parameters a and b denote the relative importance of the expected utility from choosing a particular GSO and STO respectively. PSR represented an expert judgement on the possibility to realize a particular growth stock objective with a given silvicultural treatment option where mainly the light conditions created by the stand treatment as well as the risk of the regenerated species to suffering from frost damage was considered. $SGSO$ is the ecophysiological suitability of a growth stock objective for given site conditions, and $C1$ and $C2$ are the corresponding minimum requirements set by the decision-maker to ensure the compatibility of a silvicultural treatment option and a particular GSO as well as the suitability of a GSO for the site. The partial utilities $USTO$ and $UGSO$ are calculated from additively aggregated preferences for a particular GSO and STO respectively with respect to the involved management objectives. To accomplish this task, the management objectives of the forest owner had to be decomposed into a decision hierarchy. As an example, the calculation of the partial utility expected from a GSO is demonstrated. The expected utility of a particular growth stock objective had been structured into economic (ECON) and ecological (ECOL) criteria (5)

$$U_{GSO} = a_{11} \cdot P_{ECON} + a_{21} \cdot P_{ECOL} \quad (5)$$

where

$$\sum_{k=1}^2 a_{kl} = 1 \quad (6)$$

The parameters a_{kl} characterize the relative importance of the partial objectives. The partial utilities from $PECON$ and $PECOL$ were further factorized into several decision criteria. For $PECON$, the second-order preference functions were calculated from the criteria risk of management (P_{111}), length of the rotation period (P_{112}), marketability of expected timber assortments (P_{113}) and costs associated with the implementation of a GSO (P_{114}) (7).

$$P_{ECON} = a_{111} \cdot P_{111} + a_{112} \cdot P_{112} + a_{113} \cdot P_{113} + a_{114} \cdot P_{114} \quad (7)$$

$PECOL$ consisted of preferences for a particular GSO with regard to sustained site productivity (P_{211}) and the maintenance of biodiversity (P_{212}). As an example, for further decomposition into more detailed decision criteria the third-order preference functions for the evaluation of $PECON$ are described (compare Figure 5). The preference values for P_{112} and P_{113} were calculated with eqs. (8) and (9)

$$P_{I/2} = a_{I/21} \cdot x_{GSO1} + \dots + a_{I/2z} \cdot x_{GSOz} \quad (8)$$

$$P_{I/3} = a_{I/31} \cdot x_{GSO1} + \dots + a_{I/3z} \cdot x_{GSOz} \quad (9)$$

where x_{GSOz} are dummy variables [0,1] and the function parameters $a_{I/2z}$ and $a_{I/3z}$ respectively are the scaled preferences of GSO_z from the pairwise comparisons of the GSO_z from Table 2 with regard to the parent decision criteria with $a_{\max} = 1$.

The criterion risk of management (P_{111}) is further decomposed into snow breakage (P_{111}), climatic change (P_{121}) and drought (P_{131}) respectively (10). The preferences with regard to the cost of implementation (P_{114}) were factorized into preferences with regard to establishment costs (P_{114}) and tending costs (P_{124}) (11) respectively.

$$P_{I/1} = a_{111} \cdot P_{111} + a_{121} \cdot P_{121} + a_{131} \cdot P_{131} \quad (10)$$

$$P_{I/4} = a_{114} \cdot P_{114} + a_{124} \cdot P_{124} \quad (11)$$

Equivalent to eqs. (8) and (9) the third-order preference values from eq. (10) and (11) were calculated with fourth-order preference functions from preference values of GSO_z with regard to the pertinent parent decision criteria. In evaluating possible silvicultural treatment options for currently existing Norway spruce stands, the first-order decision criteria risk of management, costs, required silvicultural know-how level and utilization of a stand's yield potential were considered. The judgements (P_{SR}) on the feasibility of realizing the defined GSOs with a particular stand treatment option (STO) were based on silvicultural expert knowledge on the light requirements as well as on the frost hardiness of involved tree species. Table 6 presents the light and frost conditions which were related to the defined stand categories. To provide consistent estimates of P_{SR} essentially the same multi-criteria approach as demonstrated for the calculation of partial utilities from GSO and STO respectively was employed.

3.4 Results

To demonstrate the application of the suitability model we compared the suitability of two species under different climatic conditions to assess their sensitivity to different climate inputs (Figure 6a–b).

It can be seen that under average climatic conditions *Picea abies* would be the preferred species from a mere physiological point of view. However, under the climatic conditions of a climate change scenario for Central Europe (Houghton et al., 1990), the suitability of *Picea abies* decreased substantially, whereas the suitability of *Quercus robur* essentially remained unchanged. The physiological sensitivity of *Picea abies* to drier and warmer climatic conditions would most probably result in increased damage by bark beetles.

To demonstrate the output provided by the utility function (eq. 3) we selected stand no. 11 from the data base. Due to its attributes, the stand was assigned to stand category 2 (compare Table 1). In our example, the forest owner had given high priority to the short- to midterm goal of maximizing the economic gains from current Norway spruce stands (relative weight of 0.8). The resulting overall utilities from the employed utility function (eq. 12) are presented in Table 7.

$$U = 0.2 \cdot U_{GSO} + 0.8 \cdot U_{STO} \quad (12)$$

$$C1 = 0.7$$

$$C2 = 0.7$$

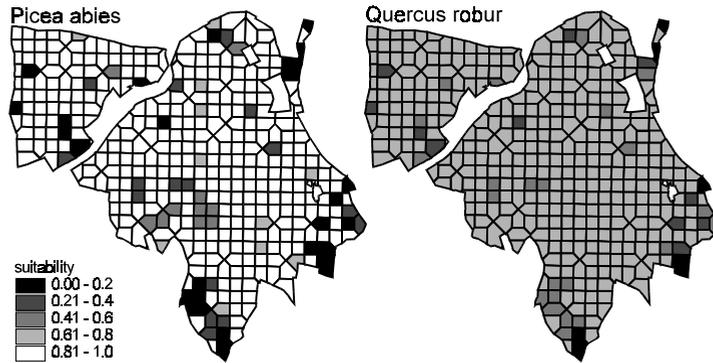


Figure 6a. Suitability of *Picea abies* and *Quercus robur* under current average climatic conditions.

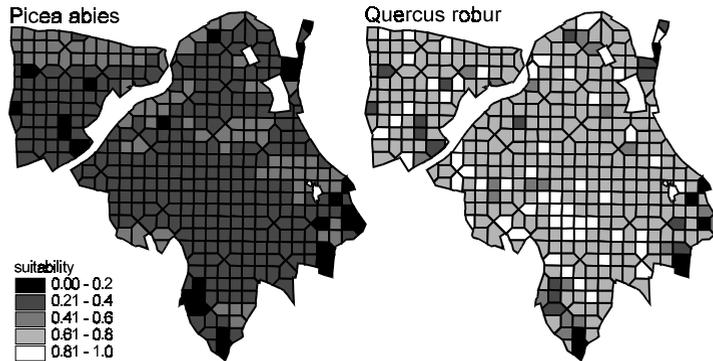


Figure 6b. Suitability of *Picea abies* and *Quercus robur* under the average climatic conditions of a climate change scenario for Central Europe (Houghton et al. 1990).

Table 6. Light and frost conditions related to the defined silvicultural treatment options for the study area. Source: Burschel and Huss (1997).

STO-ID	option	frost occurrence	relative light	
			from [%]	to [%]
1.1	refill blanks	Yes	21	40
1.2	refill blanks	Yes	41	70
2.1	advance planting	No	8	20
2.2	advance planting	No	21	40
2.3	advance planting	Yes	41	70
2.4	advance planting	Yes	71	100
3	afforestation	Yes	71	100
4	final cutting	Yes	71	100
5	do nothing	No	0	100

Table 7. Overall utility value, possibility of realization and site suitability for all possible solutions for stand no. 11. – STO = silvicultural treatment option, U_{STO} = partial utility from STO, GSO = growing stock objective, U_{GSO} = partial utility from GSO, U = overall utility expected from the combination of STO_w and GSO_z , P_{SR} = possibility to realize GSO with STO_w , S_{GSO} = ecophysiological suitability of GSO_z for the site.

Stand-ID	STO	U_{STO}	GSO	U_{GSO}	U	P_{SR}	S_{GSO}
11	5	0.591	5	0.775	0.628	1.000	0.703
11	2.1	0.409	9	0.847	0.496	0.633	0.733
11	2.1	0.409	10	0.833	0.494	0.765	0.824
11	2.1	0.409	1	0.708	0.469	0.969	0.728
11	2.1	0.409	4	0.611	0.449	0.612	0.758
11	2.2	0.409	2	0.563	0.440	0.800	0.729

As a minimum requirement for the selection of a future growth stock objective the possibility to realize the particular GSO with the selected stand treatment option (STO) relied on a fairly high rating of $P_{SR} = 0.7$ (C1). The decision constraint C2 implied that all future species mixtures were excluded whose ecophysiological suitability for the site did not exceed a rating of $S_{GSO} = 0.7$, which can be considered a fairly high threshold. The highest partial utility from applying one of the possible silvicultural treatment options was calculated for the "do nothing"-option ($U_{STO} = 0.591$), the option "advance regeneration" yielded a utility value of $U_{STO} = 0.409$.

In our decision making example, the solution with the highest overall utility was STO 5 ("do nothing") with $U = 0.628$. From this option, it automatically follows that species mixture type linked to this option is GSO2 (pure Norway spruce). From this it follows that the chance to realize this species composition is totally sure ($P_{SR} = 1.0$). However, from $S_{GSO} = 0.703$ it can be seen that *Picea abies* is only moderately suited for the site and rarely exceeds the minimum requirement C2.

4. Conclusions

The presented multicriteria decision making approach was intended to demonstrate the application of decision support methodology in solving complex decision problems in silvicultural planning. After decomposing the decision problem into tractable portions different tools were applied to analyse the problem. The assessment of species suitability at low-elevation sites is a high-priority task in developing stand conversion programmes. The presented model approach integrates and formalizes available knowledge on relationships between selected site factors and the ecophysiological requirements of tree species and allows for an operational assessment of species suitability (Steiner und Lexer 1998). In view of partly incomplete and "fuzzy" knowledge on the relations between site characteristics and species response, relatively simple mathematical operators were chosen to combine the monocausal effects of selected site factors. These operators provide rather conservative estimates of overall species suitability and are considered to be a reliable compromise between detailed parameterized multiple-factor solutions (e.g. Moosmayer and Schöpfer 1972) and a quite often non-reproducible ad-hoc guess on species suitability in the field. The suitability model will be improved by the integration of a rule-based fuzzy controller. Thus, it will be possible to better utilize the available "fuzzy" expert knowledge on site-tree

interactions. A further advantage will be the possibility to provide "fuzzy" input for the suitability model (e.g. the fuzzy set "moderately acidic" instead of a crisp value for pH). To solve the multiple-criteria problem of selecting the silvicultural treatment option and growth stock objective respectively which best meets the objectives of the forest owner, the analytic hierarchy process was combined with an additive multi-attribute preference function. AHP is a method which allows for consistent pairwise comparisons of both qualitative and quantitative criteria on a ratio scale. Moreover, it is one of the few ranking procedures which is based on sound mathematical theory (Saaty 1977). The multi-attribute preference model generates a cardinally scaled order of all alternatives with regard to their expected utility. In the case where an alternative is considered to be best with regard to all involved decision criteria, it will yield an overall utility value of 1. However, it has to be considered that even with an overall utility of 1 the solution may just be a best-compromise solution. Regarding this problem, constraints external to the preference model can serve as "back assurance" to avoid unsatisfying solutions. Finally, it has to be noted that DSS are not meant to provide a ready decision. It should be emphasized that the decision maker always has to take responsibility for any decision. There is no guarantee that a "good" decision will always achieve a "good" outcome. A good decision is one that is made based on a thorough understanding and analysis of the problem. A decision resulting in a bad outcome could still be considered a good decision as long as the decision-making process indicated the possibility of a bad outcome. Beyond the advantages of formal sensitivity analysis the presented methods and tools provide a good documentation of the decision making process. Thus, rationales and information used in arriving at a decision can be compared with the achieved outcome, which enables better decisions in the future. We therefore conclude that the application of DSS can provide valuable help for a formal and rational decision making process in silvicultural planning.

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Silvicultural Aspects of the Conversion of Spruce Forests of the Ore Mountains into Mixed Stands

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Abstract

Unstable spruce (*Picea abies*) monocultures in the Ore Mountains (Germany) have to be converted into stable mixed stands. Secondary succession processes should be integrated into conversion strategies due to ecological benefits. Direct sowing and advance planting of tree species not present in the secondary succession supplement secondary succession processes should be implemented. Examples and recommendations for direct sowing and advance planting of beech (*Fagus sylvatica*) are given and discussed.

Keywords: conversion, secondary succession, direct sowing, advance planting, beech

1. Introduction

The forests in the Ore Mountains (Erzgebirge) in eastern Germany are predominantly made up of spruce (*Picea abies*) monocultures. Unstable stand structures, resulting from thinning from below as a common management strategy in the past, as well as natural and anthropogenic disturbances involve a high degree of production risk for these spruce stands. Moreover, high deposition rates of acidic substances (Kubelka et al. 1993; Zimmermann et al. 1998) and the resulting imbalances of nutrient cycles (LAF 1998) as well as a tree species composition far from nature (Bitter et al. 1998) strengthens the instability of these artificial monocultures on the ecosystem level.

The objective of this study is to investigate silvicultural means for converting unstable spruce monocultures into mixed stands via benefiting from successional processes, via direct sowing of beech nuts and via advance planting of beech seedlings. The research work was conducted in the eastern Ore Mountains in mature spruce stands, growing on podsollic soil types with medium soil water availability. The spruce stands are located in different altitudes,

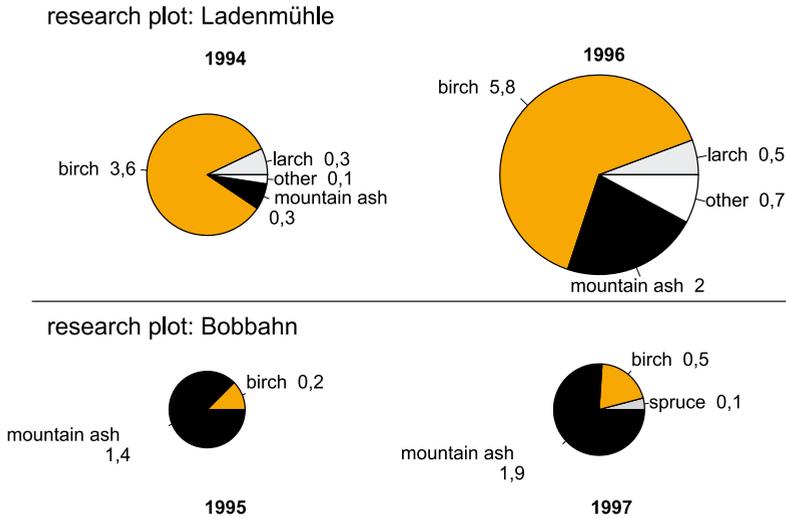


Figure 1. Species composition and density (1,000 per hectare) of trees in the shrub layer (0.5 m ≤ height <5.0 m) beneath two spruce stands.

ranging from the lower altitudes (research plot Ökologisches Meßfeld: 370 m a.s.l.) to the medium altitudes (research plots Ladenmühle and Bobbahn: 670 m a.s.l.). The mean annual precipitation in the lower and medium altitudes, respectively, amounts to 750–900 mm; the mean annual temperature is about 7.5 °C (lower altitudes) and 6.0 °C (medium altitudes). The natural forest vegetation is dominated by beech (*Fagus sylvatica*), admixed with oak or spruce in the lower altitudes and with spruce and silver fir (*Abies alba*) in the medium altitudes.

2. Integration of successional processes into forest conversion

Extremely high rates of emissions of SO₂ in recent decades led to the disintegration of spruce on stand level in the higher altitudes of the Ore mountains. In the medium altitudes, spruce was mainly affected at the single tree level by high rates of needle loss or by single tree mortality. In these opened-up spruce stands, secondary succession may lead to more diverse stand types with a high proportion of birch (*Betula pendula*) and mountain ash (*Sorbus aucuparia*) in the regeneration. Two examples are given in Figure 1 for spruce stands in the medium altitudes of the Ore Mountains. The density of trees in the shrub layer (0.5 m ≤ height <5.0 m) increases within two years from 4,300 trees/ha to 9,000 trees/ha (Ladenmühle) and from 1,600 trees/ha to 2,500 trees/ha (Bobbahn).

The vertical stand structure of these hitherto mono-layered spruce stands changes rapidly because of such secondary succession processes (Figure 2), while some of the birch and mountain ash at Ladenmühle reach a maximum height of more than 2.5 m.

Such successional processes enhance diversity – and, consequently, stability on ecosystem level – and, therefore, should be integrated into the conversion of spruce stands by tolerating and promoting birch and mountain ash as admixed tree species. This promotion involves positive impacts of successional tree species, like mountain ash, concerning the biological stabilization of nutrient supply (Nebe 1994; Emmer et al. 1998). The development of

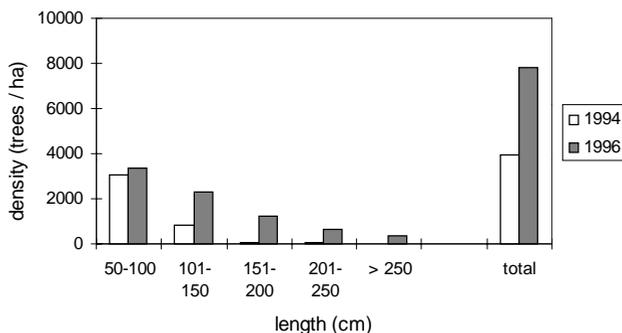


Figure 2. Frequency of birch and mountain ash in different length classes of the shrub layer (research plot Ladenmühle).

successional tree species can be hindered by game browsing (Küßner 1997) but, thereby, might avert browsing from advance planted tree species like beech. Successional processes offer the opportunity to reduce the number of advance planted trees by replacing intraspecific competition within the advance planted trees through interspecific competition – and, hence, provides economic benefits. The integration of successional processes into conversion strategies involves ecological and economical benefits, especially since some of the successional trees show perfect stem quality (Küßner 1997).

3. Forest conversion of spruce stands by direct sowing of beech nuts

Since important tree species of the natural forest vegetation, like beech or silver fir, are generally not present in the natural regeneration and within the secondary succession in pure spruce stands (Küßner 1997), these tree species have to be implemented through direct sowing or through advance planting beneath the mature spruce stands.

In the spring of 1995, beech nuts were sown beneath a spruce stand at Ladenmühle to investigate the impact of competition by trees in the shrub layer and the impact of liming on the performance of beech seedlings in comparison to an untreated control variant. Each of these three main variants (control, manual removal of woody competitors, liming) – replicated twice – contains 4 sub-plots with a size of 1 m² (total number of sub-plots: n=36); the humus layer of every second sub-plot within the main variants was removed. Within each sub-plot 60 beech nuts were manually sown and covered with humus layer (without soil preparation) or with mineral soil (after soil preparation).

The treatments had impacts on site conditions. Liming raised the base saturation of the mineral soil from 14 to 32%. The removal of woody competitors as well as the soil preparation (by removal of herbaceous competitors) modified the radiation availability. The percentage of available diffuse radiation, measured with a Plant Canopy Analyzer (LAI-2000, LiCor) at top of the leaders of 3-years-old beech seedlings is presented in Table 1. Soil preparation, in general, led to an increase in radiation availability; this effect diminished when soil preparation was combined with liming: the rapid re-establishment of ground vegetation and some newly established tree species (e.g. *Salix spec.*) decrease the amount of available radiation. It is obvious that the removal of woody competitors without soil preparation did not affect the average radiation availability but increased the minimum

Table 1. Percentage of transmitted diffuse radiation (DIFN, in %) measured at the top of 3-years-old beech leaders in 1997 (after Kűßner and Wickel (1998)).

	Control			Removal of woody competitors			Liming		
	mean	sd ¹	min.	mean	sd	min.	mean	sd	min.
Without soil preparation	16	± 5	3	16	± 4	11	11	± 4	5
With soil preparation	20	± 4	16	26	± 7	20	13	± 4	8

¹ sd: standard deviation; min: minimum; n = 6 measurements per variant.

percentage of available radiation; soil preparation, in addition to the removal of trees in the shrub layer, resulted in maximum radiation resource availability.

The density of 1-year-old beech seedlings in the plots where woody competitors were not removed was significantly influenced by soil preparation. Assuming that 2,500 sub-plots per hectare were sown, the density of beech seedlings reaches 48,000 in the sub-plots with removal of humus layer, whereas the density in the control sub-plots amounts to 5,750 beech seedlings per hectare (Figure 3). Although the density of beech seedlings in the sub-plots without soil preparation was significantly higher when woody competitors were removed, this effect is not causal explicable for two reasons. Since water availability is not a limiting factor in medium altitudes, beech seedlings may especially compete with trees in the shrub layer for radiation availability. If higher radiation availability is supposed to explain the higher seedling density in the sub-plots where woody competitors were removed, this effect should be the same in the sub-plots with soil preparation – which is not the case. Secondly, if the removal of woody competitors would affect beech seedling performance, survival rates of beech seedlings should be higher when competition is controlled – which is not the case, too, as will be discussed later. It can be concluded that the removal of woody competitors does not promote the performance of beech seedlings at this stage.

The density of 1-year-old beech seedlings in dependence on liming is presented in Figure 4. Liming in combination with soil preparation proved to be the most effective measure to promote beech seedling density: the beech seedlings amount to 73,000 per hectare which is 13 times more than the control (without liming, without soil preparation) and 1.5 times more than the density within the sub-plots with soil preparation and without liming.

The survival rates – besides the germination rate most important for the success of direct sowing of beech nuts – after two years of observation (in autumn of 1997) amounted to 77 and 79% in the sub-plots without soil preparation for both treatments for the control and removal of woody competitors, respectively. With soil preparation, the survival rates for these two treatments reached 91%. These data indicate that competition control did not promote the survival rate of beech seedlings. The survival rates within the liming treatment are lower amounting to 69 and 63% within the sub-plots without and with soil preparation, respectively.

The length growth is decisive for the outcompeting of ground vegetation by the beech seedlings. The length of 3-year-old beech seedlings is between 10 and 16 cm and shows a distinct differentiation in relation to available radiation. Beech seedlings apparently compensate for a reduction in radiation availability when the nutrient status is high. Beech seedlings within the liming treatment show a comparable length growth in relation to beech seedlings without liming, although the radiation availability is lower due to the competition by ground vegetation and trees in the shrub layer.

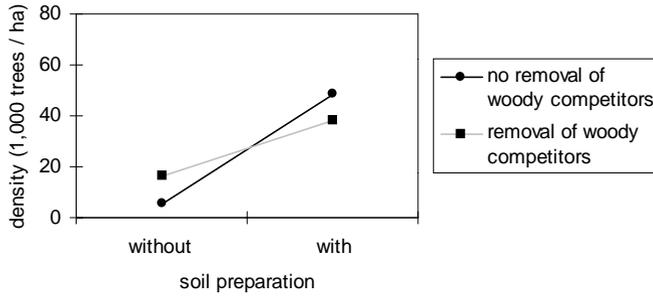


Figure 3. Density of 1-year-old beech seedlings as influenced by soil preparation and removal of woody competitors beneath a mature spruce stand (after Küßner and Wickel 1998).

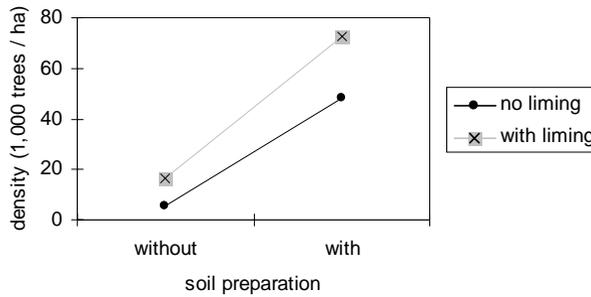


Figure 4. Density of 1-year-old beech seedlings as influenced by soil preparation and liming beneath a mature spruce stand (after Küßner and Wickel (1998)).

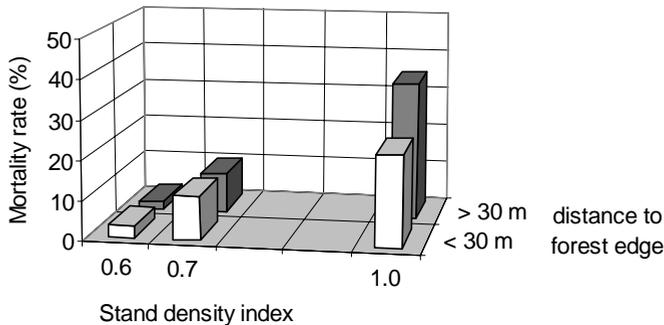


Figure 5. Mortality rates (in %) of advance planted beech seedlings within the first three years in dependence on stand density index (fully stocked stand: index = 1.0) and distance of seedlings to forest edge.

Table 2. Average biomass of 3-years-old beech seedlings (g dry weight) for different treatments (after Küßner and Wickel (1998)).

Biomass	Soil prep.	Control		Removal of woody competitors		Liming	
		mean (g)	± sd ¹	mean (g)	± sd	mean (g)	± sd
Leaves	Without	0.23	0.20	0.24	0.20	0.15	0.10
	With	0.26	0.16	0.25	0.19	0.24	0.16
Stem	Without	0.31	0.23	0.52	0.43	0.27	0.17
	With	0.47	0.34	0.38	0.26	0.47	0.34
Roots	Without	0.76	0.66	0.73	0.55	0.48	0.26
	With	0.93	0.52	0.97	0.59	0.80	0.45

¹ sd: standard deviation; n=364.

In Table 2, biomass data of 3-year-old beech seedlings are presented for the leaves, stem and roots. In general, the biomass of beech seedlings within the sub-plots with soil preparation are higher than those growing on the humus layer. The roots, in particular, profit from a removal of the humus layer – which, of course, has to be seen in context with an increase in radiation availability, too (cf. Table 1). Again, it seems that beech seedlings compensate for a reduced radiation availability by a higher nutrient availability. Beech seedlings in the liming treatment with soil preparation have a lower radiation availability (13%) than those in the control (20%) and removal of woody competitors treatment (26%) but show a comparable leave and stem biomass.

Direct sowing of beech nuts as a measure for converting spruce stands appears to be an appropriate tool. The density of beech seedlings is most effectively promoted by soil preparation in combination with liming. These results are confirmed by Gehrman (1984) and by Spellmann and Meiwes (1995). In addition, soil preparation itself increases seedling density considerably compared to untreated control plots, as was shown before by investigations by Huss and Stephani (1978) or by Dohrenbusch (1990). The compensation of reduced radiation availability by a high nutrient status was investigated by Burschel and Schmaltz (1965) and by Larsen and Buch (1995). They report in accordance with one another that liming – on sites with low nutrient status – positively affects beech seedlings' performance when radiation availability is low.

4. Forest conversion of spruce stands by advance planting of beech

2-year-old beech seedlings were manually planted in spring 1995 beneath a mature spruce stand of different stand densities (research plot Ökologisches Meßfeld). The stand density index ranged from 1.0 (fully stocked stand) to 0.6. The highest stand density level has a severe impact on mortality rates as shown in Figure 5; only the beech seedlings close to the forest edge, benefiting from lateral radiation, show lower mortality rates than seedlings far away from the forest edge.

Three years after planting, the beech seedlings have average root collar diameters of 10 to 15 mm and average lengths of 77 to 126 cm – distinctly differing in dependence on stand density. Some of the beech seedlings were harvested in mid-summer of 1997. The leaf, stem and root biomass of the seedlings were related in multiple regression analysis to growth

Table 3. Regression analysis for explaining biomass (in g) of advance planted beech seedlings, harvested in 1997, in relation to growth parameters and amount of available diffuse radiation (DIFN, in %).

Biomass	Regression	adj. r ²	n
Leaves	$b_l = -10.03 + 1.35 D96 - 0.02 DIFN D96 + 0.006 DIFN L96$	0.71	109
Stem	$b_s = -15.26 + 3.05 D96 - 1.0 DIFN + 0.02 DIFN L96$	0.79	105
Roots	$b_r = -17.89 + 2.76 D96 + 0.007 DIFN L96$	0.73	109

b_l , b_s , b_r : biomass of leaves, stem, roots (in g); D96: diameter in 1996 (in mm); L96: length in 1996 (in cm); Sign $F < 0.001$ for all regression models; note: although regression coefficients of variable DIFN may be negative, the seedlings' growth is positively correlated to DIFN due to interaction between DIFN and growth parameters.

parameters (diameter, length) of the previous year and to the amount of diffuse radiation (DIFN, in %), measured by fisheye-photos at the top of the leaders in 1997. The results are presented in Table 3. The attained growth in the previous year and the available diffuse radiation in the current year significantly influence the biomass of beech seedlings; for a given diameter and length beech seedlings correlate linearly and positively with the amount of diffuse radiation – at least within the frame of observed diffuse radiation on this research plot which ranges from 2 to 45%.

Most of the investigations on the performance of advance planted beech seedlings relate radiation availability to growth parameters like diameter or length, indicating that growth rate is affected by reduction in radiation availability (e.g. Schmitt et al. 1995; Wagner and Müller-Using 1997). But, generally, it is stated that beech seedlings even show sufficient growth rates when the mature spruce stand is only slightly opened up within the first years of the seedlings' performance. This approach diminishes competition with naturally regenerated spruce (Wagner and Müller-Using 1997; Wickel et al. 1998) and reduces risks of biotic interference (e.g. mice damage, competition by ground vegetation). On the other hand, not only growth or biomass performance is influenced by different stocking densities and the resulting modification of radiation resource availability: the morphology (e.g. stem form) can be negatively influenced by high stocking densities. Under these conditions beech seedlings tend to grow horizontally (Sagheb-Talebi 1996; Gralla et al. 1997; Wickel et al. 1998) in order to increase the amount of leave surface exposed to direct radiation. Therefore, the morphological development of beech seedlings should be observed in order to avoid negative long-term effects of high stand densities on the quality of advance planted beech and – if necessary – the stand density should be reduced. Low stand density levels, on the other hand, may lead to economic losses concerning the growth of the mature stand (Wagner and Müller-Using 1997).

5. Conclusions

Conversion of monocultures into mixed stands can be accomplished by passive or active management means (Emmer et al. 1998) involving different silvicultural intensities such as acceptance of secondary succession, direct sowing or advance planting.

The integration of secondary succession processes in opened-up spruce stands in the eastern Ore Mountains into conversion of these stands provides ecological benefits. Mountain ash and birch should be accepted and promoted, assuming good stem quality. Secondary succession of mountain ash and birch can be supplemented by direct sowing or by advance planting of beech not present in the secondary succession.

Direct sowing of beech nuts requires soil preparation (removal of humus layer), and, if necessary, combined with liming, to achieve high seedling densities. The biomass performance of directly sown beech seedlings within the first three years is sufficient even when radiation availability is low; liming seems to compensate for reduced radiation resource availability.

The density of the mature spruce stand has to be optimized to balance productivity of the mature stand and the performance of advance planted beech seedlings. High stand density levels increase mortality rates for beech and may have negative long-term effects on morphological parameters – but are most productive with regard to the mature stand. On the other hand, performance of advance planted beech is promoted when the mature stand's density is reduced. New tools are needed for assessing such silvicultural optimization processes.

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Evaluation of Morphometric Properties of Several Spruce (*Picea abies* /L./ Karsten) Provenances in Monocultures in Serbia

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Abstract

Comparative analyses of morphometric characters of 8 spruce provenances (Golija, Zlatar, Cemerno, Radocelo, Kopaonik, Menina, Mašun and Jelovica) were carried out in three monocultures established at different sites, with the purpose of a closer study of the character of genetic, physiological and morphological variability.

Morphometric analyses of variabilities in height, height increment, diameter, diameter increment, number of whorls, number of branches, and crown width were carried out on 4.5 and 6-year-old seedlings. Statistical parameters were applied in the comparative assessment of adaptation and development of the selected provenances in these monocultures.

This paper is a contribution to the study of the spruce genepool in its natural range in Serbia and Slovenia. Free genetic variability is high in all analysed provenances, both within and between monocultures. This research provides preliminary information on the productivity of individual spruce provenances at a juvenile stage and under different ecological conditions and a closer study of inter- and intra-provenance variability. All previous and future research is significant for a more reliable choice of suitable provenances or groups of provenances for particular sites. The results refer to plants at a juvenile stage, so these results should be verified by further research.

Key words: monocultures, provenances, spruce, genetic potential

1. Introduction

For the Yugoslavian forestry, spruce (*Picea abies* /L./ Karst.) is one of the most important species of forest trees, not only because of its individual and population adaptability, but also because of timber volume productivity. Spruce is a vigorous and genetically very variable

species. It is widespread over a large area outside its natural range, mainly in Europe. After planting, seedlings survive very well, at the beginning they grow more slowly, but they soon attain the maximal height growth. It is a species with an expressed “genetic polymorphism”, as its populations constantly contain several different forms, which are genetically conditioned (Sperlich 1973; Guzina 1976). Spruce polymorphism is the consequence of a remarkable ecological plasticity, which enables adaptation to different conditions during development (Fanta 1974). There are almost no organs or individual properties that do not possess an exceptional variability. Spruce variability has been since studied from almost all aspects during the last two centuries (botanic, dendrological, plant-geographical, forestry, genetic, etc.) (Schmidt-Vogth 1978)

Research on genetic potential, including research on spruce provenances, is significant both for science and for the practical application of results in silviculture and in plantation establishment. Bearing in mind its multiple utilization from the technological aspect, spruce deserves prime importance.

This research aims at studying the genetic variability of spruce in a part of its natural and artificial range in Serbia and in Slovenia. Another aim of this research is to examine the productive capacity of particular provenances at the juvenile stage, for a given site (different altitudes, edaphic conditions, exposure, site type, etc.), and to obtain information on the variability of inter- and intra-provenances.

2. Material and Method

Eight provenances were selected for the establishment of a spruce provenance test at three localities near Ivanjica (Isajev, Tucović 1992). Five provenances were taken from Serbia: Kopaonik, Radočelo, Čemerno, Golija and Zlatar, and three provenances from the Republic of Slovenia: Menina, Mašun and Jelovica. General characteristics of the selected provenances are presented in Table 1. These provenances were tested in monocultures established at three localities. Their main characteristics are presented in Table 2.

Table 1. General characteristics of analyzed spruce provenances.

Provenance	community	altitude, m	vegetation type	parent rock/soil
Kopaonik	Raška	1520-1620	<i>Picetum excelse serbicum</i>	Granite/ sandy
Čemerno	Raška	1000	<i>Picetum excelse serbicum</i>	Limestone/ brown
Radočelo	Raška		<i>Picetum excelse serbicum</i>	Adensite/ ranker
Golija	Ivanjica	1400-1500	<i>Picetum excelse montanum</i>	Granite/ sandy
Zlatar	Nova Varoš	1200-1300	<i>Picetum excelse serbicum</i>	Limestone/ brown
Menina	Gornji grad	1200	<i>Picetum subalpinum</i>	Limestone
Jelovica	Škofja Loka	1150-1200	<i>Picetum subalpinum</i>	Slates
Mašun	Ilirska Bistrica	890-1320	<i>Picetum subalpinum</i>	Limestone and dolomite

Table 2. Site characteristics of provenance tests.

Locality	51.Compartment GJ Mučanj “Rača”	38.Compartment, GJ Kovilje-Rabrovica “Rabrovica”	46.Compartment, Block C GJ Golija, “Pavičev laz”
Altitude	570-610	1105-1125	1560-1570
Exposure area	north 2.02 ha	southeast 63.88 ares	northeast 73.64 ares
Edaphic condition	deep acid soil (dystric cambisol) on schists (Škorić et al., 1973)	deep acid soil (dystric cambisol) on schists (Škorić et al., 1985)	-brown podzolic soil on phyllites
Associated vegetation	<u>Tree layer:</u> <i>Fagus moesiaca</i> <u>Shrub layer:</u> <i>Fagus moesiaca</i> , <i>Carpinus betulus</i> , <i>Corylus avellana</i> <u>Ground flora layer:</u> <i>Pteridium aquilium</i> , <i>Rubus hirtus</i> , <i>Cardamine bulbifera</i>	<u>Tree layer:</u> <i>Fagus moesiaca</i> <u>Shrub layer:</u> <i>Fagus moesiaca</i> , <i>Carpinus</i> <i>betulus</i> , <i>Prunus avium</i> , <i>Salix caprea</i> <i>Populus tremula</i> , <i>Picea abies</i> <u>Ground flora layer:</u> <i>Rubus hirtus</i> , <i>Fagus moesiaca</i> , <i>Asperula odorata</i> , <i>Festuca drymeia</i> , <i>Luzula silvatica</i>	<u>Tree layer:</u> <i>Fagus moesiaca</i> <i>Picea abies</i> , <i>Sorbus aucuparia</i> <u>Shrub layer:</u> <i>Acer heldreichii</i> , <i>Daphne mezereum</i> , <u>Ground flora layer:</u> <i>Glechoma</i> <i>hirsuta</i> , <i>Dryopteris filixmas</i> , <i>Oxalis acetosella</i> , <i>Daphne</i> <i>mezereum</i> , <i>Athyrium filix femina</i>

Morphometric analysis of seedlings began in May 1993, immediately after transplanting from the nursery to the field, when the plants were four years old, and it was continued with five- and six-year-old seedlings (Šijacic-Nikolic 1995). The following quantitative properties were measured in the field: seedling height, diameter of root collar, number of whorls, number of branches and crown width, and height and diameter increments of 5-year- and 6-year-old seedlings.

The number of replicates of the particular provenances at the sites varied from three to five. Twenty plants were measured per one replicate. Aiming at the simplest possible data presentation, we present the mean value, the coefficient of variation as the intra-provenance variability and the analysis of variance as an indicator of the significance of differences between the analysed provenances and localities.

The variability of the measured macroscopic characteristics was analyzed by standard statistical methods. Mean values of statistic parameters were used in the comparative assessment of adaptation and development of all provenances in the same locality and for the evaluation of the same provenance at different localities. Table 3 gives a correlative review of the assessment of provenances according to the variability of mean values of the analyzed parameters at three localities, seedling age 4, 5 and 6 years.

3. Results and Discussion

The results of morphometric analyses of 4-, 5-, and 6-year-old spruce seedlings showed a remarkable inter-provenance variability of all the analyzed properties, both within and among monocultures.

In the first year after transplanting, according to mean values of the analyzed parameters at the three sites, the Golija provenance had the best results almost for all analyzed properties, which is most probably the consequence of uniform site conditions in the pilot plot of the nursery. With age, the effect of the site became fully expressed so that five-year-old seedlings show a greater differentiation between provenances and, along with the Golija provenance, the plants of the Zlatar and Radočelo provenances have high values for the analyzed parameters for several properties. At the age of six, the differences between provenances changed in all three sites, so that the highest mean values of analyzed parameters, in addition to Golija provenance, are also achieved by other provenances (Čemerno, Jelovica, Radočelo). Six-year-old plants, in which the effects of transplantation stress have almost disappeared and in which there are no consequences from uniform site conditions in the pilot plot of the nursery, illustrate to a higher extent the interaction of provenance gene pool and micro-ecological characteristics of the locality. Based on this fact, it can be assumed that according to the age of the plants in the monocultures the provenances will be more clearly differentiated depending on the analyzed localities, so these results will be more reliable for the establishment of future spruce plantations.

From the above, it can be seen that the Golija provenance shows phenotypic stability, as illustrated by the statistic parameters in Table 3, at all three monocultures established at different localities, so it can be considered as having wide norms of reaction. The dominance of the Golija provenance, as well as of other Serbian provenances Zlatar, Čemerno, Radočelo, can be explained by their better adaptation and by the fact that they are the nearest to phylogenetic and ecological conditions of study sites. Based on previous analyses with spruce seeds, and to estimate the value of provenances in the area of spruce's natural range in Central and South Europe (Kleischmit 1970; Gračan 1984), it was concluded that spruce provenances from Slovenia, according to their total morphological and physiological

Table 3. Correlative survey of provenance assessment according to variability of analyzed parameter mean values, at three localities, seedling ages 4, 5 and 6.

FOURTH YEAR	V (8±Kv)	P (8±Kv)	BP (8±Kv)	BG (8±Kv)	ŠK (8±Kv)
G.J. MUČANJ					
1. MENINA	38.36±23.80	0.82±18.29	1.75±25.14	10.20±33.33	27.81±22.15
2. ČEMERNO	39.64±29.72	0.96±21.87	1.55±32.90	9.15±31.37	27.81±30.20
3. ZLATAR	41.00±21.15	1.06±16.98	1.90±15.79	11.85±26.75	27.81±23.37
4. GOLJIA	43.75±17.44	1.08±15.74	1.95±11.28	11.95±30.79	30.23±20.05
5. RADOČELO	31.23±22.06	0.89±21.35	1.95±30.77	10.55±28.91	23.43±27.83
6. MAŠUN	32.84±18.70	0.99±19.19	2.00±10.00	9.00±23.11	26.40±18.22
7. JELOVICA	23.76±24.24	0.77±24.67	1.40±35.71	6.40±38.12	18.39±31.97
8. KOPAONIK	20.86±42.76	0.65±30.77	1.15±31.30	5.95±44.20	15.80±32.59
G.J. GOLJIA					
1. MENINA	29.69±24.86	0.79±22.78	1.92±14.58	19.58±26.97	19.58±26.97
2. ČEMERNO	23.94±23.35	0.74±18.92	1.83±20.76	16.83±22.10	16.83±22.10
3. ZLATAR	40.08±20.83	1.04±13.46	2.58±25.19	25.74±20.08	25.74±20.08
4. GOLJIA	43.49±21.91	0.99±14.14	2.67±23.97	27.03±26.04	27.03±26.04
5. RADOČELO	29.08±30.09	0.88±14.77	2.63±18.63	22.03±26.69	22.03±26.69
6. MAŠUN	30.73±24.99	0.82±17.07	2.04±9.80	19.92±37.95	19.92±37.95
7. JELOVICA	27.54±34.57	0.79±20.25	1.79±22.90	18.77±32.28	18.77±32.28
8. KOPAONIK	18.05±36.62	0.62±25.81	2.13±15.96	14.60±34.79	14.60±34.79
G.J. KOVILJE-RABROVICA					
1. MENINA	32.75±24.52	0.88±20.45	2.16±37.50	26.15±26.73	26.15±26.73
2. ČEMERNO	41.34±27.28	0.97±17.52	2.33±24.03	29.70±26.80	29.70±26.80
3. ZLATAR	36.83±18.62	0.94±17.02	2.75±24.72	25.67±19.62	25.67±19.62
4. GOLJIA	40.18±27.43	1.03±15.53	2.92±24.66	29.86±26.56	29.86±26.56
5. RADOČELO	27.27±22.51	0.81±27.16	2.17±22.12	21.81±29.76	21.81±29.76
6. MAŠUN	33.11±25.40	0.91±15.38	2.38±32.35	25.86±29.81	25.86±29.81
7. JELOVICA	27.68±38.33	0.73±31.51	2.17±42.40	21.57±44.74	21.57±44.74
8. KOPAONIK	24.93±30.08	0.80±20.00	2.21±40.27	19.24±26.56	19.24±26.56
F value for provenance	6.46**	1.02 ^{ns}	17.47***	5.28***	6.03***
F value for locality	0.32 ^{ns}	1.01 ^{ns}	6.33***	3.21*	5.60 ^{ns}

Table 3 continued. Correlative survey of provenance assessment according to variability of analyzed parameter mean values, at three localities, seedling ages 4, 5 and 6.

FIFTH YEAR	V (8±Kv)	VP (8±Kv)	P (8±Kv)	DP (8±Kv)	BP (8±Kv)	BG (8±Kv)	ŠK (8±Kv)
G.J. MUÈANJ							
1.	49.34± 21.65	10.01 ± 46.25	1.00 ± 19.00	0.17 ± 82.35	1.79 ± 23.46	11.63 ± 32.07	29.85 ± 24.02
2.	45.15 ± 23.32	7.83 ± 21.20	1.09 ± 13.76	0.19 ± 105.26	1.55 ± 32.90	12.00 ± 24.00	34.91 ± 26.73
3.	47.98 ± 19.51	8.37 ± 29.75	1.13 ± 14.16	0.14 ± 114.28	2.90 ± 10.68	13.90 ± 18.50	33.84 ± 19.23
4.	52.48 ± 16.88	8.86 ± 37.76	1.30 ± 15.38	0.22 ± 72.27	2.95 ± 7.79	14.79 ± 29.61	42.37 ± 18.34
5.	38.53 ± 19.75	7.34 ± 27.65	0.95± 14.73	0.13 ± 100.00	2.94 ± 21.77	13.05 ± 22.22	28.49 ± 30.68
6.	41.35 ± 14.39	8.89 ± 42.53	1.03 ± 23.30	0.10 ± 90.00	3.00 ± 20.66	12.86 ± 25.17	33.82 ± 17.65
7.	39.50 ± 23.26	8.58 ± 27.73	1.15 ± 20.00	0.18 ± 90.00	2.58 ± 30.62	11.52 ± 33.42	27.56 ± 26.52
8.	28.64 ± 36.62	6.92 ± 25.72	0.73 ± 34.25	0.10 ± 120.00	2.18 ± 17.89	9.35 ± 29.95	16.79 ± 32.46
G.J. GOLJA							
1.	38.46 ± 23.60	8.95 ± 44.13	0.89 ± 24.72	0.09 ± 88.88	2.91 ± 9.96	9.78 ± 24.64	26.27 ± 29.08
2.	30.25 ± 20.40	6.13 ± 25.83	0.84 ± 17.64	0.13 ± 107.69	2.83 ± 13.42	9.92 ± 41.43	21.51 ± 23.24
3.	46.70 ± 16.81	6.62 ± 35.95	1.18 ± 16.10	0.26 ± 114.61	3.58 ± 18.15	13.62 ± 24.82	35.52 ± 16.14
4.	50.44 ± 21.65	7.16 ± 36.45	1.09 ± 16.51	0.10 ± 130.00	3.62 ± 19.61	13.67 ± 25.02	37.24 ± 21.67
5.	34.53 ± 25.62	5.40 ± 30.00	0.95 ± 22.11	0.09 ± 66.67	3.61 ± 13.85	13.78 ± 17.78	28.97 ± 21.75
6.	36.79 ± 25.77	6.03 ± 63.00	0.92 ± 18.47	0.11 ± 72.72	3.04 ± 6.90	9.96 ± 25.00	26.01 ± 32.79
7.	33.87 ± 35.02	7.57 ± 40.42	0.87 ± 21.84	0.07 ± 114.28	2.83 ± 13.78	9.48 ± 25.21	24.83 ± 27.90
8.	25.10 ± 33.26	7.06 ± 45.89	0.72 ± 29.17	0.07 ± 71.42	3.12 ± 10.89	10.87 ± 29.16	20.00 ± 38.80
G.J. KOVILJE-RABROVICA							
1.	47.65 ± 25.29	6.70 ± 30.74	1.11 ± 19.85	0.13 ± 84.62	3.34 ± 17.36	12.73 ± 24.98	38.02 ± 24.57
2.	42.51 ± 21.83	10.16 ± 36.52	1.01 ± 16.83	0.15 ± 60.00	3.17 ± 26.18	11.47 ± 39.67	32.48 ± 26.45
3.	43.24 ± 15.22	6.59 ± 35.81	1.06 ± 15.09	0.12 ± 66.67	3.64 ± 18.13	14.41 ± 25.40	33.06 ± 17.30
4.	45.76 ± 23.36	6.12 ± 44.12	1.15 ± 13.04	0.14 ± 64.29	3.72 ± 26.34	15.75 ± 23.68	40.81 ± 17.46
5.	33.89 ± 18.41	6.57 ± 27.25	0.95 ± 21.00	0.14 ± 85.71	3.23 ± 13.31	11.82 ± 38.07	27.75 ± 26.92
6.	39.87 ± 12.94	7.13 ± 34.50	1.01 ± 12.87	0.08 ± 75.00	3.33 ± 21.92	11.48 ± 10.19	12.48 ± 26.28
7.	35.59 ± 30.09	10.29 ± 38.97	0.94 ± 21.27	0.19 ± 63.15	3.22 ± 27.95	11.39 ± 10.79	28.04 ± 37.27
8.	33.18 ± 23.29	8.95 ± 25.81	0.93 ± 20.43	0.17 ± 88.23	3.00 ± 14.67	12.09± 24.56	25.49 ± 23.85
F.	16.55***	10.33***	0.66 ^{ns}	1.06 ^{ns}	22.78***	17.28***	19.56***
F.	2.26 ^{ns}	6.46***	0.49 ^{ns}	11.57***	15.44***	4.90**	82.26***

Table 3 continued. Correlative survey of provenance assessment according to variability of analyzed parameter mean values, at three localities, seedling ages 4, 5 and 6.

SIXTH YEAR	V (8±Kv)	VP (8±Kv)	P (8±Kv)	DP (8±Kv)	BP (8±Kv)	BG (8±Kv)	ŠK (8±Kv)
G.J. MUÈANJ							
1.	61.18 ± 19.06	12.33 ± 45.42	1.53 ± 28.84	0.52 ± 48.08	2.83 ± 13.42	16.22 ± 24.41	37.83 ± 20.24
2.	60.53 ± 19.79	15.38 ± 60.99	1.69 ± 18.93	0.60 ± 38.33	2.55 ± 20.00	16.70 ± 18.80	43.90 ± 17.44
3.	58.62 ± 21.19	10.68 ± 58.52	1.61 ± 19.38	0.49 ± 53.06	3.90 ± 7.95	17.95 ± 13.70	41.51 ± 19.07
4.	65.02 ± 21.37	12.55 ± 66.45	1.79 ± 13.40	0.49 ± 40.81	3.94 ± 5.84	19.73 ± 23.16	55.00 ± 15.54
5.	46.61 ± 21.11	8.08 ± 70.92	1.17 ± 15.38	0.22 ± 54.54	3.94 ± 15.99	17.44 ± 18.46	33.11 ± 24.70
6.	49.27 ± 21.47	7.07 ± 80.20	1.31 ± 16.03	0.29 ± 62.07	4.00 ± 9.50	15.87 ± 26.40	38.80 ± 13.81
7.	55.08 ± 25.07	15.58 ± 51.79	1.90 ± 12.10	0.74 ± 45.94	3.76 ± 11.43	16.12 ± 25.37	39.11 ± 25.46
8.	37.91 ± 30.08	8.61 ± 42.39	0.75 ± 21.33	0.19 ± 52.63	3.10 ± 10.44	12.41 ± 24.79	20.29 ± 23.16
G.J. GOLJIA							
1.	45.84 ± 21.09	8.09 ± 55.62	1.22 ± 26.22	0.35 ± 60.00	3.83 ± 10.18	14.65 ± 17.95	36.00 ± 29.44
2.	36.67 ± 17.97	6.41 ± 71.14	1.11 ± 18.92	0.31 ± 64.51	3.87 ± 10.18	14.95 ± 29.43	27.17 ± 21.34
3.	50.29 ± 14.61	3.58 ± 63.12	1.39 ± 17.26	0.22 ± 81.81	4.62 ± 14.06	18.08 ± 18.41	39.88 ± 15.24
4.	54.81 ± 20.09	3.96 ± 56.82	1.26 ± 15.87	0.22 ± 86.36	4.73 ± 15.85	17.07 ± 25.95	39.92 ± 20.24
5.	38.97 ± 22.09	4.41 ± 83.67	1.21 ± 15.70	0.23 ± 56.52	4.63 ± 10.58	18.45 ± 14.30	34.50 ± 17.48
6.	41.67 ± 23.13	5.17 ± 54.93	1.17 ± 18.80	0.28 ± 71.43	4.04 ± 5.45	14.48 ± 23.20	30.32 ± 27.08
7.	40.43 ± 29.63	6.95 ± 67.19	1.04 ± 23.08	0.19 ± 63.16	3.83 ± 10.18	12.96 ± 34.46	27.56 ± 25.18
8.	35.45 ± 29.59	10.57 ± 43.52	1.02 ± 33.33	0.36 ± 52.78	4.14 ± 8.69	13.81 ± 27.08	27.62 ± 31.82
G.J. KOVILJE-RABROVICA							
1.	57.47 ± 17.54	14.96 ± 49.13	1.48 ± 21.62	0.50 ± 56.00	4.17 ± 19.90	17.26 ± 39.63	40.52 ± 23.99
2.	59.00 ± 23.86	11.39 ± 47.94	1.67 ± 26.35	0.57 ± 52.63	4.30 ± 13.02	17.34 ± 21.86	45.61 ± 25.08
3.	51.51 ± 14.81	8.27 ± 5.98	1.56 ± 15.38	0.50 ± 42.00	4.59 ± 14.60	18.14 ± 23.04	40.13 ± 18.17
4.	51.31 ± 23.31	5.58 ± 75.99	1.64 ± 21.34	0.50 ± 56.00	4.88 ± 13.94	19.42 ± 21.78	45.92 ± 20.51
5.	42.12 ± 20.08	8.22 ± 60.83	1.55 ± 23.33	0.60 ± 51.67	4.23 ± 10.16	16.64 ± 28.36	35.59 ± 19.78
6.	46.75 ± 15.34	7.15 ± 63.15	1.42 ± 21.13	0.40 ± 65.00	4.35 ± 17.24	16.70 ± 21.86	37.10 ± 18.22
7.	46.22 ± 34.33	9.09 ± 73.93	1.23 ± 38.21	0.37 ± 75.68	4.18 ± 21.77	13.59 ± 26.78	33.59 ± 34.65
8.	42.54 ± 18.29	10.68 ± 55.43	1.24 ± 23.39	0.37 ± 51.35	4.05 ± 9.88	16.05 ± 20.00	30.57 ± 19.63
F.	20.53***	8.15***	10.90***	1.01 ^{ns}	16.98***	4.07***	19.56***
F.	34.67***	4.36***	43.41***	0.59 ^{ns}	12.54***	1.80 ^{ns}	82.26***

Legend: V- height • BG-number of branches • P- diameter • ŠK-crown width • VP-height increment of the analysed property • DP-diameter increment • BP-number of whorls analysed property

characteristics, are closer to Central European populations. Provenances in Southeast Europe, at the south fringe of the range, are characterized by a special gene pool manifested by a greater production potential and by earlier phenophases. The results of the provenance Kopaonik can be explained by the specific provenance adaptability, as well as by its position, i.e. the fact that it is situated southernmost of all 8 analyzed provenances, at the fringe of spruce's natural range, which is manifested by lower values of the analyzed parameters.

The results should be considered with reservation, because they refer to plants in their juvenile stage of development. Therefore, more complete answers to open questions should be obtained in the subsequent researches. In addition, the results were influenced by the effect of transplantation stress, which probably concealed the manifestation of the provenance gene pool potential. This effect will be lowered with age. The results of the comparison of the generic potential of provenances from Slovenia and Serbia will be useful in the works of multiple utilization of this type of seed resources and in the establishment of prospective cultural communities. The analyses that will be carried out at the age of ten and older will complete the obtained results. Consequently, further research has been planned.

4. Conclusion

The research on properties of 8 selected spruce (*Picea abies* /L./Karst.) provenances in the juvenile stage, in monocultures at three localities near Ivanjica, deals with morphometric properties of 4-, 5-, and 6-year-old seedlings. The research includes 5 Serbian provenances (Golija, Radocelo, Cemerno, Kopaonik and Zlatar) and 3 Slovenian (Menina, Mašun and Jelovica).

The aim of this research was to study the differential properties and variability of spruces from 8 provenances in the monocultures established within the spruce natural range, in the southeast of Europe. In addition, another aim of the research was to estimate the individual productivity of provenances in the monocultures established in the more or less identical and different site conditions. This research resulted in the first set of information on the characteristics of inter and intra provenances variability for experimental plots in Serbia.

Free genetic variability of spruce is very high in all eight analyzed provenances. The effect of natural selection is most clearly expressed in monocultures established at three altitudes where the analyzed properties of Serbian provenances show greater adaptation to very different ecological conditions. On the site of montane beech, where it does not grow naturally, spruce shows successful growth and adaptation, which points out that along with its natural optimum in the spruce belt zone (*Picetum abietis serbicum*), its technogenic optimum can also be on the sites of other species. The results obtained for all three altitudinal belts contribute to the explanation of why spruce in Serbia, in comparison to other states of the Balkan Peninsula, makes a special climatogenetic belt.

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The State of Spruce Natural Stands in the Kopaonik National Park

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Abstract

Natural stands of spruce cover extensive areas of Serbia. They are especially well conserved in the Kopaonik and Tara National Parks and also over other mountainous massifs: Golija, Stara Planina and Zlatar. Along with natural stands, spruce has been widespread by afforestation at different sites. They differ very much by means of conservation, quality, health, age and tending. In large areas, in natural and artificial stands, spruce is endangered by *Fomes annosus*. The productivity (ecological potential) is great, while at mountain and alpine sites of the Kopaonik National Park, it is almost unbelievable, reaching a volume of above 800 m³/ha and volume increment of about 30 m³/ha. On the majority of sites, there are stands that can be considered as significant for the protection of the biodiversity of forest communities in Europe. In the Kopaonik National Park, there are specimens reaching 150 cm in diameter, more than 50 m high, representing monuments of nature of planetary significance. For the evolution of acid brown soils on granodiorites of Kopaonik and for the reduction of acidity and the increase of biogeny, the spread of mountain ash (*Sorbus aucuparia*) is very important.

The problems of planning measures for forest enhancement are numerous and some of them are difficult to solve. They depend on forest origin, stocking, physical and chemical properties of the soil, health, weeds, and the adverse consequences of man's impact.

1. Introduction

Natural stands of spruce in Serbia cover the area of about 20,000 ha. Another 26,500 ha of pure artificial forests of spruce have been established by afforestation. Mixed stands with beech, beech and fir, and fir occupy another 33,300 ha. In smaller areas, spruce was even introduced to pedunculate oak sites. The habitats of spruce are diverse, both for natural and

artificial sites. In natural stands, it ranges up to the altitude of about 2,000 meters, thus on Kopaonik it forms the “Kopaonik taigas”. In Serbia, on the mountains Kopaonik, Stara Planina, Tara and Golija, there are vast areas of exceptionally well-conserved spruce forests, with timber supply above 1,200 m³/ha, representing monuments of nature, significant for the protection of biodiversity of forest ecosystems of planetary rank.

By the Law on National Parks in Serbia, seventeen spruce stands have been designated as natural reserves. The remaining area of spruce forests is situated in the zone of a more tolerant regime of protection. All stands above 500 m³/ha, or about 30% of the study stands, can be regarded as special natural values of European forest ecosystems.

2. Problems

The problems of treatment for spruce monocultures are numerous. They result from various factors which have occurred during the last two hundred years. The state of natural stands differs considerably, depending on site conditions, properties of stand structure, conservation, tending, destructive consequences of *Fomes annosus*, changed composition of tree species, damage from overfelling and fires. Especially destructive adverse effects were caused by man, who affected the stable ecosystems of spruce created by post-glacial successions of vegetation on the Balkan Peninsula. In addition to the destruction of spruce forests on large areas, the system of forest reproduction changed (shelterwood, or selection forests, or their transition forms). They were not carried out persistently, which, together with insufficient tending, reduced the general vitality of these forests – the appalling consequences will be reflected in the future. However, the encouraging point is that, at the majority of sites and in all places, there are spontaneous natural processes of spruce spreading, and at the majority of sites it has an “explosive” course. Spruce spreads even above the present secondary anthropogenic upper limit, and it also reproduces massively in the belt of montane beech forest (*Fagetum moesiacaе montanum*). The procedure in natural spruce monocultures is delicate because of very different structural conditions, the hazard from *Fomes annosus* and often unclear courses of ecosystem evolution. In pure spruce stands, the spread of mountain ash (*Sorbus aucuparia*) is often abundant. It is a valuable bio-ameliorator of acid soils in spruce forests, which is also the case with the populations of beech and fir.

Previous research, although insufficient compared to the significance of the species, and some excellent examples of professional work at some sites in Serbia, makes it possible for the treatment of spruce forests in Serbia in the future to be based on scientific foundations and procedures verified in practice.

3. Object and method

Altogether 297 spruce stands were researched in the montane zone (155 – *Picetum excelsae montanum serbicum*) and in sub-alpine zone (142 – *Picetum excelsae subalpinum*) between the altitudes of about 1,000 and 1,960 m. Parent rock is predominantly composed of granodiorites, and the soil is the evolutionary series of humus-siliceous soil or acid brown soil. This study is based on the data collected in the construction of forest management plans, and the size of the sample was determined based on structural homogeneity.

All stands under the natural reserve regime were measured by total inventory, while the stands with a more liberal regime of protection were measured by taking samples from 7–

43% of the stand area. Volume increment was estimated by Meyer's method of diameter increment, with 65–120 data for each stand.

The survey and the analysis of data was based on the procedure applied in the working out of the Plan of protection and enhancement of forest ecosystems of Kopaonik National Park, which is called the "Kopaonik Method" (soon in print). This is an ecosystem approach, a special method of survey and analysis, as well as of planning of objectives and measures to be applied to the zones with more liberal regimes of protection. The state is presented and analyzed per forest communities, which are, except for *Picetum excelsae serbicum*, ecologically exceptionally homogeneous. They are: *Fagetum moesiaca montanum*, *Piceo-Fagetum*, *Piceo-Abieti*, *Piceo-Fago-Abieti*, *Abieto-Fagetum*, *Picetum excelsae serbicum*, *Picetum subalpinum*, *Ostrio-Aceri-Fagetum*, and some communities with very low representation. The analysis includes: tree numbers, basal areas, volume, volume increment, volume increment percentage. The arithmetical mean is calculated for all stands – Xs1, arithmetical mean for 50% of the best conserved stands – Xs2, and arithmetical mean for 20% best conserved stands – Xs3 (Tables 1, 3, 5 and 7). We also analyzed the variation width of each property (Tables 2, 4, 6 and 8). Tables 1–8 present the average values for 297 study stands.

As for the zones with a more liberal regime of protection, the Kopaonik Method plans special measures of enhancement in order to reach the functional state, i.e. selection of tree species, optimal volume, sizes of felling maturity, etc.

4. Results

The aim of the study was to inform the forestry public about the state of spruce forests in the Kopaonik National Park, with large areas of very well conserved forests.

The average values in Table 1 are characteristic of the "Kopaonik Method" of forest management planning in National Parks. They emphasize the variability of individual stand elements. The decrease of tree number per ha with the higher altitudes is a consequence of the distinguished change of biological properties of the species, elevated requirement for light. The average number of trees in the stand per hectare above the median shows the agreement with the number of spruce trees in the fourth site class at the age of 120, according to yield and increment tables after Schwapach (631). The number of spruce trees per hectare is very high and it is the consequence of a very high percentage of thin trees. The number of spruce trees per hectare in the stands of montane spruce is approximately 10% higher than in the stands of sub-alpine spruce.

Variation width of the number of trees per ha was applied for the first time in the study of forest ecosystems of the Kopaonik National Park (Tomanic 1996) and it indicates the stage of development, the degree of conservation, the conditions of forest structure and the method of management for the future. The tasks of timber stand improvement differ essentially, for instance, in the stands with the number of trees per ha below 200 and above 800. A great number of stands with more than 800 trees per ha are the consequence of regeneration and insufficient tending of these stands. The distribution of the number of trees per ha confirms the suitability of the applied mean values in the assessment of stand conditions in general and individually.

In general, average values are very high and they result from very good conservation of these forests as a whole, although the percentage of overfelled stands is also significant. In general, the altitude of the volume in *Picetum excelsae subalpinum* is about 15% lower than that in *Picetum excelsae montanum serbicum*. Average values for the part of the stand above

Table 1. The number of trees per hectare.

	<i>Picetum excelsae serbicum</i>	<i>Picetum subalpinum</i>
Xs1	518	479
Xs2	669	600
Xs3	845	779

The symbols are: Xs1 arithmetical mean, Xs2 mean value above the medial value, Xs3 average value for 20% best conserved stands.

Table 2. Variation of the number of trees per ha (trees per ha).

	1–200	201–400	401–600	601–800	801–1,000	1,001–1,200	
<i>P.e.s.</i>	1.3	31.4	39.1	18.6	5.1	4.5	100%
<i>P.s.</i>	7.8	36.2	31.2	13.5	7.8	3.5	100%

Table 3. Volume per hectare (m³).

	<i>Picetum excelsae serbicum</i>	<i>Picetum subalpinum</i>
Xs1	428	349
Xs2	545	466
Xs3	643	575

Table 4. Variation of timber volume per ha (m³ per ha).

	1–200	201–400	401–600	601–800	801–1,000	
<i>P.e.s.</i>	5.4	38.3	44.7	10.2	1.4	100%
<i>P.s.</i>	17.6	49.4	26.7	4.9	1.4	100%

Table 5. Volume increment per hectare (m³).

	<i>Picetum excelsae serbicum</i>	<i>Picetum subalpinum</i>
Xs1	12.7	8.6
Xs2	16.0	11.7
Xs3	20.6	15.4

Table 6. Variation of volume increment per ha.

	1–5	6–10	11–15	16–20	21–25	26–30	31 and more	m ³ /ha
Pe.s.	3.9	31.6	42.0	12.9	7.7	1.3	1.6	100%
P.s.	10.9	50.8	21.4	6.3	1.4	1.7	–	100%

Table 7. Percentage of current volume increment per hectare (%).

	<i>Picetum excelsae serbicum</i>	<i>Picetum subalpinum</i>
Xs1	2.97	2.46
Xs2	2.94	2.51
Xs3	3.20	2.68

Table 8. Variation of the percentage of the current volume increment (m³/ha).

	less than 1.0	1.0–2.0	2.0–3.0	3.0–4.0	4.0–5.0	5.0–6.0	6.0 and more	
Pe.s.	–	12.7	49.7	19.1	16.6	1.9	–	100%
P.s.	0.79	21.8	52.1	14.8	9.2	1.4	–	100%

the median represent the orientation value for the evaluation of the optimum volume in these forests.

The distribution of volume per ha indicates a great deterioration of site conditions with higher altitudes. All the stands with volumes above 600 m³/ha can be considered as special natural values in forest ecosystems of Europe.

Volume increment in these montane and sub-alpine altitudinal zones is a surprise for the forestry public in Serbia, accustomed to the values in yield and increment tables after Schwapach, any values above 30 m³/ha are outstanding. In general, volume increment in *Picetum subalpinum* is lower for about 28% than that in *Picetum excelsae serbicum montanum*.

The distribution of volume increment per ha indicates a great deterioration of site conditions in *Picetum subalpinum*, as well as the outstanding differences in stand The percentage of current volume increment in study stands shows the relationships that change the accepted ideas of productivity in these forests. These values indicate a very significant yield, which according to previous research results can be classified as the optimum amounts – that is, all the percentages above 2.5%. The percentages of current volume increment in *Picetum subalpinum* are about 26% lower than those in *Picetum excelsae serbicum*.

The distribution of values per individual stand shows a less distinguished lowering of productivity with higher altitudes. However, it should be noted that a notably greater number of stands with the percentage of current volume increment between 1.0 and 2.0% occurs in *Picea subalpina*, as well as the lower number of cases between 3.0 and 4.0%. The relations of the percentage of current volume increment are “covered” by the effects of the stage of development and by the structure, which deserves special research.

5. Conclusions

The results of this study enable the planning of special measures of enhancement and conversion to a functional state of spruce forests in the zones with a more liberal regime of protection.

The research of 297 spruce stands on Kopaonik shows that the conservation of these forests, in general, is very good and, on extensive areas, the state is satisfactory. On Kopaonik, there are stands which, by their conservation, vitality and productivity, can be considered special natural values significant for the protection of the gene pool in Europe. Their volume exceeds 1,000 m³/ha. On extensive areas, however, there are overfelled stands as well as stands which have been attacked by *Fomes annosus*. In pure spruce stands, the biologically very significant spreading of *Sorbus aucuparia* and *Fagus moesiaca* is in progress.

Future timber stand improvement in the forests outside the nature reserve should be based on tending, regeneration of the remaining forests and establishment of all-aged and group-selection stands. In this process, the inventory of broadleaf species should be preserved, with the aim of bio-melioration of acid soils in spruce forests.

As an approximate value, the temporary optimum of 600 m³/ha for *Picea excelsa serbicum* and 500 m³/ha for *Picea subalpina* should be determined. Special care should be taken with trees with a diameter at breast height of above 60–90 cm and height above 40 m. Special attention should be drawn to the trees 40–60 cm. The trees above 120 cm dbh, and about 50 m high represent monuments of nature. They must be conserved without exception.

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Influence of Nutrient Amendment on Photosynthetic Parameters in *Fagus sylvatica* L. Plants under a Norway Spruce Canopy

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The photosynthetic response of beech (*Fagus sylvatica* L.) to different fertilizer treatments was measured along a light gradient from a closed canopy to the open. Plants along one transect were fertilized with a Ca/Mg-fertilizer and compared with control counterparts in an adjoining transect. After photosynthesis measurements, the leaves were collected and specific leaf weight, leaf number, and total of N, Ca, Mg, and K contents were examined. Canopy gap fraction and photon flux density (PPFD) were measured to assess the light environment of the plants.

Plants of both treatments showed the typical adaptation to shading, as specific leaf weight [SLM, mg cm⁻²] increased with increasing gap fraction while leaf nitrogen per mass decreased. The other biometric parameters did not show any differences between fertilizer and control treatment. The nutrient treatment positively influenced the maximal photosynthetic capacity per unit leaf area and the light compensation point. Dark respiration and light compensation points were decreased under higher magnesium contents.

Keywords: Fagus sylvatica, fertilization, light compensation point, magnesium, nutrient, photosynthesis, photosynthetic capacity

1. Introduction

In many forests with closed canopies, only a small fraction (0.5–5%) of solar radiation reaches the understory (Chazdon and Pearcy 1991). Shade tolerant or shelter requiring plants in the understory are able to utilise low irradiance. They adapt their phenotype and photosynthetic system to the varying light conditions (Chazdon and Pearcy 1986). The minimum relative radiation of beech was estimated to be 1.6% (Walter 1960 from Mayer

1992). Burschel et al. (1985) and Schmitt et al. (1995) recommended advanced planting with 30–60% light in the understory. Plant growth is not only limited by light but also by nutrients. Leaf nutrients are generally known to affect the photosynthetic performance of plants. Not only nitrogen is associated with gas exchange but also magnesium. Dimassi-Theriou and Bosabalidis (1997) demonstrated increasing maximal photosynthetic capacity of leaf when magnesium concentration is enhanced. The objective of this study was to determine the influence of nutrient supply on the photosynthetic performance of beech seedlings growing in different light conditions. The following questions have been addressed:

- Which differences in photosynthetic performance do *Fagus* trees show under different light and nutrient conditions?
- Is there any growth or photosynthesis adaption to prevailing light conditions?
- Can a high nutrient supply compensate for low light conditions in the understory?

2. Methods

2.1 Study site

The study area is located in north western Austria near the German border. The investigation took place in a forest stand of the Castell Castell'sche Forest Enterprise. In 1996, *Fagus sylvatica* L. were planted along two transects, including a closed canopy of mixed spruce/pine forest and a clear cutting. In April 1996, one transect was fertilized with 3000 kg ha⁻¹ of a calcium/magnesium fertilizer, consisting of MgO, MgCO₃, and CaCO₃ (13.5% Mg, 11.5% Ca).

2.2 Data collection

In July 1997, photosynthetic responses (light response curve) to increasing photon flux density were measured on 18 plants from each transect. Measurements were taken with a LI-6400 CO₂/H₂O porometer (Licor Inc. Nebraska) on the third leaf from the top of each plant. For stabilized conditions, the Vapor Pressure Leaf Deficiency was adjusted to 0.5–1.2 kPa and the temperature to 20 °C. Gap fraction above each plant was recorded with a LAI-2000 Plant Canopy Analyser (Licor Inc. Nebraska). The total leaf number was counted, and measured leaves together with every tenth leaf were harvested. Thereafter, dry mass, leaf area, and the leaf-nutrient contents of N (of the Kjeldahl definition), Ca, Mg, and K (HNO₃-definition) were examined.

3. Results and Discussion

Gap fraction along a transect ranged from 10% in the understory to about 70% in the open (Figure 1). The leaf mass per area increased with increasing gap fraction (Figure 2). Plant adaption to increasing light was also described by Abrams and Mostoller (1995), who found that due to elevated light the leaf thickness, i.e. thicker mesophyll and leaf area increase toward the open. The other biometric parameters showed no significant differences between the fertilization treatments.

The estimated nutrients (N, Mg, K, Ca) did not differ between the treatments except for calcium per leaf mass and area, being significantly higher in control plants ($p < 0.05$) than in fertilized plants. Magnesium as an antagonist to calcium impaired the calcium uptake of the fertilized plants. Exclusively influenced by gap fraction, both treatments adapted the leaf nitrogen content to the light conditions. Thus, *Fagus* in the open contained less leaf nitrogen

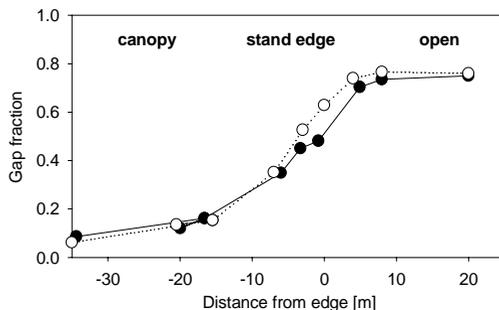


Figure 1. Gap fraction in relation to the distances along a transect. ● *Fagus* fertilized, ○ *Fagus* control

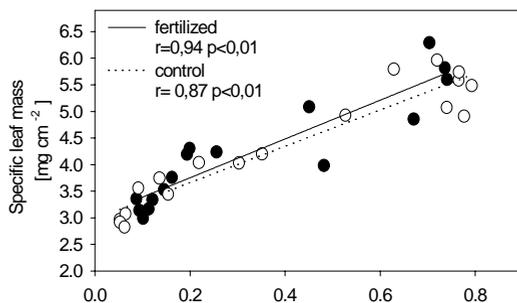


Figure 2. Specific leaf mass in relation to gap fraction. ● *Fagus* fertilized, ○ *Fagus* control

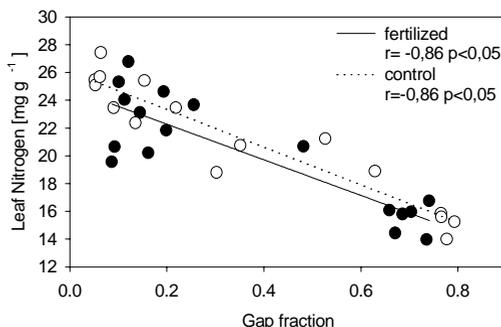


Figure 3. Leaf nitrogen per mass in relation to gap fraction. ● *Fagus* fertilized, ○ *Fagus* control

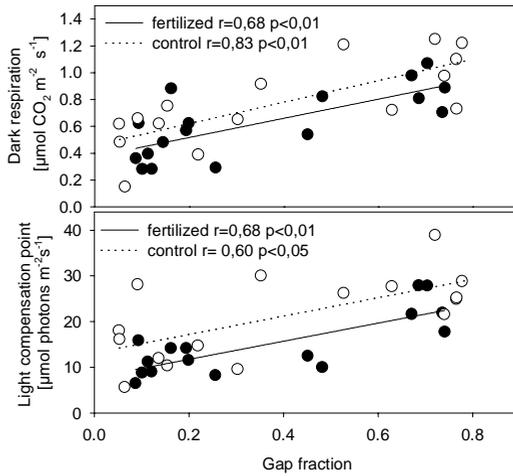


Figure 4. Dark respiration and light compensation point in relation to gap fraction. ● *Fagus* fertilized, ○ *Fagus* control

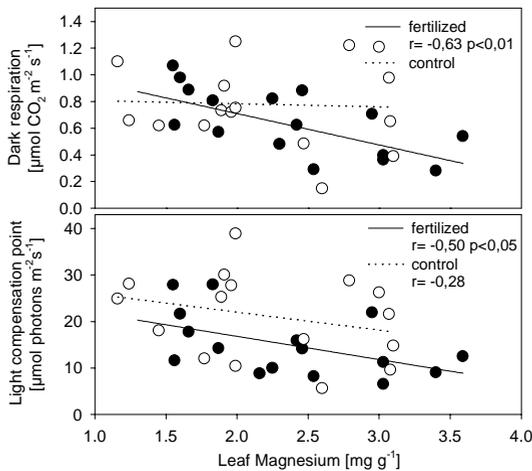


Figure 5. Dark respiration, light compensation point in relation to magnesium content. ● *Fagus* fertilized, ○ *Fagus* control

per mass (Figure 3) than *Fagus* in the closed canopy. However, the fertilization did not affect the nitrogen contents in leaves.

Covariance analyses including gap fraction and magnesium content as covariates showed a significantly higher maximal photosynthetic capacity per unit leaf area ($p<0.05$; mean fertilized: 8.65 ± 0.7 SE; mean control: 6.67 ± 0.53 SE) and a lower light compensation point ($p<0.05$) for the fertilized plants than for control plants. However, beech growing in shade adjusted its photosynthetic system to low solar radiation: light compensation point and dark respiration were reduced with a decreasing gap fraction as an adaption to low irradiance (Figure 4). This was true for fertilized and control plants.

Küppers et al. (1985) demonstrated an elevated photosynthetic response for pines fertilized with Mg/K. Our results confirmed this, showing that dark respiration and light compensation points were reduced with increasing magnesium content of the leaf (Figure 5). The Plants with improved magnesium supply are able to use low solar radiation more efficiently (Dimassi-Theriou and Bosabilidis 1997) than plants with a higher magnesium supply.

We concluded that Mg/Ca fertilization and adaption to different light conditions seemed to influence the maximal photosynthetic capacities and light compensation points positively. However, more data are needed to evaluate the effective influence of fertilization, and to provide reliable recommendation for silviculture.

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Changes in Sap Flow Rate in Tree Trunks and Roots After Mechanical Damage

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Abstract

For practical reasons it is important to define the acceptable load imposed by the use of heavy machinery on complex root systems of forest trees during logging and hauling operations. As a first step, such features were studied on the basis of the estimated absorption activity of roots as reflected by sap flow measured at tree trunks or coarse roots close to trunk basis. Sap flow in roots responded immediately to an abrupt damage of the conducting system corresponding in extent to the importance of a particular part of the root system. It is possible to study the behaviour of coarse roots when measuring sap flow in trunks above them, if the corresponding conducting pathway is exactly determined or sufficiently wide; this is difficult if only a single root is treated. Experiments indicated that a compensation mechanism operates in trees, allowing for a temporary increase in the absorption of additional water (as reflected by sap flow) by using only one part of the root system in such cases where another part of the root system is damaged or loses its water source.

Keywords: radial pattern of sap flow, root excavation, root severing, spruce, pine

1. Introduction

Application of heavy machinery during logging and hauling operations in forest stands often leads to mechanical damage of surface roots in trees along the skidding lines, which lowers the functional stability of such trees and decreases stand production. For practical reasons, it is important to define the acceptable load imposed on roots. To study root systems in large trees in the field is a rather difficult and time consuming task, which was based usually on manual excavating methods (Vyskot 1976, Jenik 1978, Carlson et al. 1988). Only recently have other methods such as ground penetrating radar been also applied for such purposes (Cermak et al. 1997; Hruska et al. 1998). All these methods describe root structure (especially of coarse roots)

in varying details. In contrast, the present study was focused on the description of the functions of complex root systems (including the behaviour of fine roots), particularly on the transport of water (the sap flow) reflecting root absorption of water from the soil.

Sap flow as the physiological process reflecting the activity of root systems was found to be a good indicator of the functional state of roots in different environmental conditions (Lott et al. 1996; Howard et al. 1996) or roots subjected to different treatments (Nadezhdina and Cermak 1998). The later study, especially, has shown that measuring the sap flow pattern along stem radii may help to understand the relations between the layers of conducting sapwood in trunks, buttresses or large coarse roots and the path of water supplied by the roots, thus evaluating root activity in different locations in the soil. In the present study, we focused on methodical issues applicable to further studies, i.e. where the flow should be measured in trees and what are the typical features of flow under such conditions. In order to elucidate fundamental questions of this problem, an extreme extent of root damage represented (1) by their excavation from soil (i.e. damage to fine roots and stoppage of water absorption by all open roots) and (2) by cutting the coarse roots was studied experimentally in large pine and spruce trees respectively.

2. Material and methods

2.1 Sample trees and experimental sites

Norway spruce (*Picea abies* (L.) Karst., diameter at breast height, DBH=41.4 cm), supported by about six main surface coarse roots was studied in the forest district of Bilovice near Brno. This forest belongs to the *fagi-querqueta* forest-type group on loamy soils on Devonian limestone with favorable humification, high coverage by herb synusia, mainly consisting of *Carex pilosa*, *Melica uniflora*, *Asperula odorata* with occasional dominance of *Impatiens parviflora* and *Salvia glutinosa* (Vasicek 1984). The corresponding cover of thermophilous species characterises the beech/oak zone. The altitude of the site is 340 m, NE-facing slope. The mean annual temperature was 7.2 °C, precipitation 560 mm (340 mm over the growth season), soil sometimes dries out in late summer. The soil type is *terra calcis* on clay with limestone as a parent rock, it is mineral rich, pH (H₂O) up to 30 cm 5.2, subsoil 8.0, presence of physical clay more than 20%, needle litterfall has favourable humification.

Scotch pine (*Pinus sylvestris* L., DBH=28.6 cm) was sampled in Brasschaat (see Cermak et al. 1998). The original climax vegetation (natural forest) was a *Querceto-Betuletum* (Tack et al. 1993). The experimental plot was a pine plantation, 1.5% slope oriented N.N.E, altitude 16 m. Soil characteristics are moderately wet sandy soil with a distinct humus and/or iron B-horizon, umbric regosol or haplic podzol in the F.A.O. classification (Baeyens et al. 1991). The groundwater depth normally ranges between 1.2 to 1.5 m and might be lower due to non-edaphic circumstances. The climate is moist sub-humid, rainy and mesothermal. Mean (over 28 years) annual and growth season temperatures for the region were 9.8 °C and 13.7 °C, precipitation was 767 mm and 433 mm respectively.

2.2 Measurement of sap flow and xylem water content

Sap flow rate within the tree trunk and main coarse roots was measured by the heat field deformation method (Nadezhdina and Cermak 1998), applying dataloggers made by Environmental Measuring Systems & UNILOG, Brno, Czech Republic. The sensor for sap

flow measurement consisted of a linear heater (insulated resistance wire inserted in a hypodermic needle) and two pairs of similar needles with six thermocouples within each of them arranged at certain distances with the step of 5 to 15 mm in different sensors. Stainless steel hypodermic needles with a 1.2 mm-outer-diameter were used in both cases. Pairs of needles with thermocouples were installed around the heater in symmetrical (up and down) and asymmetrical (on its side) positions.

The sensors were installed along the trunk or root radii reaching from cambium to pith, which allowed us to characterise the radial pattern of the sap flow. Thermocouples marked as 'shallow' measured the sap flow in the outer sapwood (closer to cambium), while those marked as 'deep' measured the sap flow in the inner sapwood, closer to heartwood or pith. More points of sap flow along the radii were obtained when the needles were radially shifted during the measurements over periods of stable weather. Depth of the conducting xylem (the sapwood) and the corresponding area was estimated from the radial patterns of sap flow, taking into account the point where the sap flow approached zero. The sap flow rate was measured per unit radial section (i.e. one centimetre wide part of xylem from the heater in a tangential direction), $Q_{w,sg}$ in [$\text{kg cm}^{-1}\text{h}^{-1}$] by each pair of thermocouples, situated at a certain xylem depth; it has the same general pattern as the flow density along the radius.

The volumetric fraction of water (water volume, V_w expressed in percentage of fresh volume of samples, V) and specific dry mass (M_d) estimated after drying for 48 hrs at 80 °C, divided by sample volume (M_d/V) were estimated on wood cores sampled by a Pressler borer (Suunto, Finland) from the roots and two opposite sides of stems at breast height (1.3 m). Cores were placed in aluminium foil immediately after sampling and analysed gravimetrically within hours after cutting them into small pieces. The volumetric fraction of water was applied to estimate the depth of sapwood (and corresponding areas), here taken as xylem tissues, which differ in their hydration from the heartwood.

Arrangement of sensors and experimental treatment of roots

In pine, the radial sensor was installed in the tree trunk at breast height and was subsequently moved to measure the flow at different depths below the cambium in the order: West->South->East->North, so that the position of each sensor represented one quadrant. Soil was gradually removed from the south quadrant (down to the depth of 30 to 40 cm) during the sap flow measurements, so that surface roots first suffered drought.

In spruce, one radial sensor (S3) was installed in the tree trunk at breast height and two sensors on coarse roots below: one (S2) on the first-order root 16 cm wide (at about 30 cm from the trunk exactly below the sensor S3) and the other (S1) on its second-order branch (vertical ellipse in cross section, 7 x 12.5 cm, about 75 cm from the trunk) which ramificated after the next 30 cm into the three following branches (third-order roots). After stabilisation of sap flow records under fine late-April weather, the third-order root branches were cut subsequently (cuts 1, 2, 3), following this the second order root was cut above the sensor S1 (cut 4). Finally the main root was partially severed from the trunk below the sensor S2 (cut 5 performed down to the depth of 10 cm reached by the sensor).

3. Results and discussion

3.1 Physical characteristics of conducting systems

In pine, the fraction of solid matter in the sapwood (about 32%_{vol}) differs only slightly between the North-East and South-West sides of the trunk. The fraction of water (reaching

about 28%_{vol} in the outermost layers) decreased more rapidly from the South-West in direction of the heartwood (11%_{vol}), occurring at the depth of 10 cm, while it remained almost constant from the North-East down to the depth of 12 cm (Figure 1). This characterizes relatively wide, porous but dry sapwood with a large fraction of air-filled and thus non-conducting tracheids (representing on average about 40%_{vol}).

In spruce, the fraction of solid matter in the sapwood (mean approximately 25%_{vol}) was only about 1/5 higher in the trunk compared to that in coarse roots, but fractions of water differ substantially (Figure 2). The highest water content in the trunk sapwood (53%_{vol}) occurred close to the cambium and decreased gradually down to a depth of about 6 cm, to the value characterizing non-conducting heartwood (10 to 12%_{vol}). Air-filled tracheids represent, on average, only 22%_{vol}, which indicates higher possible sap flow there. Maximum sapwood water content in coarse roots was at a depth of 3 cm (48%_{vol}) and decreased down to about 20%_{vol} at a depth of 7 cm and below. Values in inner layers of roots remained rather high (~22%), indicating that some flow can take place there.

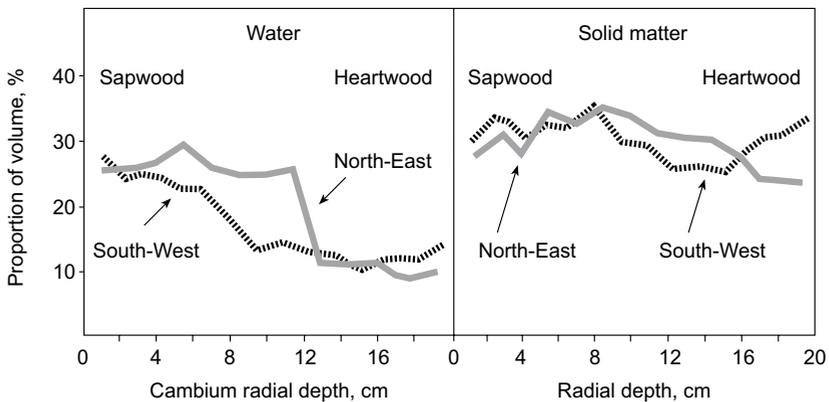


Figure 1. Radial pattern of volume fractions of solid matter and water in the xylem of pine trunk measured from different cardinal points.

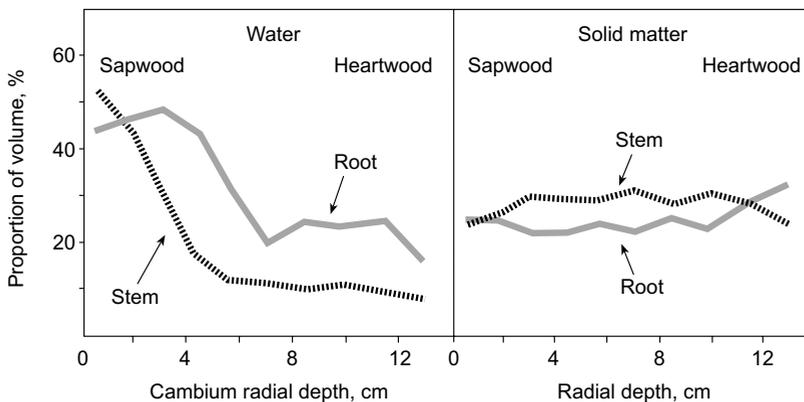


Figure 2. Radial pattern of volume fractions of solid matter and water in the xylem of spruce trunk and coarse root.

The estimated fractions of xylem water, solid matter and air provide background information about the conducting system (possible depth of sapwood, utilization of pores, etc.) which corresponds to previous findings in the same species (Kravka et al. 1998). However, this information is useful for the evaluation of possible damage to roots only in connection with other characteristics of trees, such as the sap flow.

3.2 Radial pattern of sap flow in trunks and coarse roots

The radial pattern of sap flow in the spruce trunk reached a maximum in the outermost sapwood layers and was similar to the pattern of sapwood water content (Figure 3, sensor S3). The radial pattern of flow within the intact first-order root had one peak at a shallow

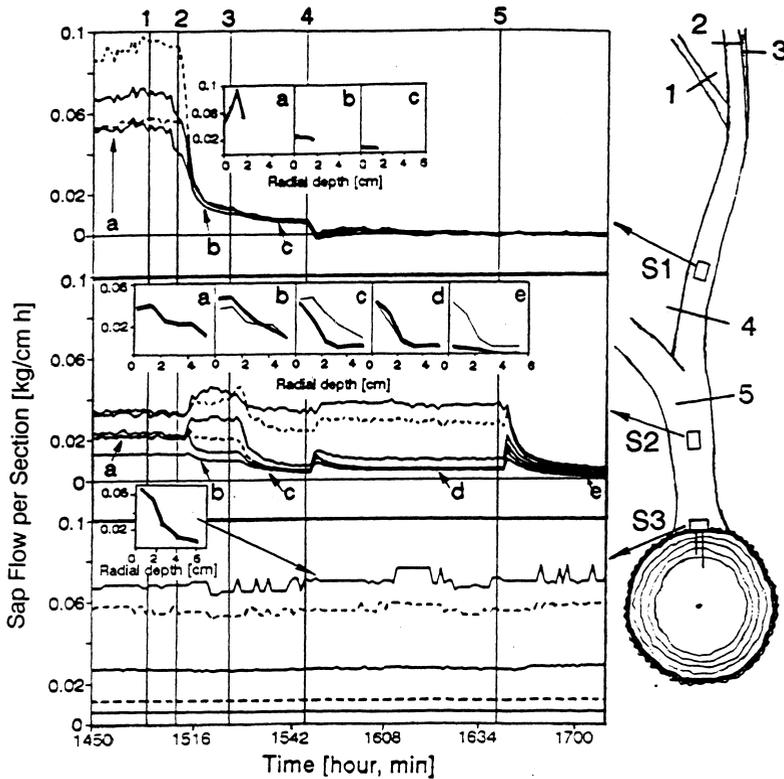


Figure 3. Responses of sap flow rate to severing of some roots in a large spruce tree. Sap flow is shown in different radial depths in the sapwood below cambium (shallow means close to cambium) within the trunk and roots of different order. Position of sensors in roots and tree-trunk (S1, S2, S3) and subsequently made cuts (1 to 5) are shown at the scheme on the right. S1: Root of second order, S2: root of first order, S3: tree trunk (at breast height). Responses of sap flow dynamics to individual cuts in different parts of the conducting system detected by these sensors are shown in diagrams on the left. Radial patterns of sap flow (a, b, c, d, e) corresponding to different phases of treatment (marked by arrows) are shown on a series of small diagrams for each figure (the ordinate is the same as for sap flow dynamics). Thin lines on radial patterns (b, c, d, e) in the first order root (S2) always represent the previous state compared to the actual one (thick lines). Only one figure is presented for the radial pattern of the trunk, because no changes in this pattern were observed irrespective of root treatments.

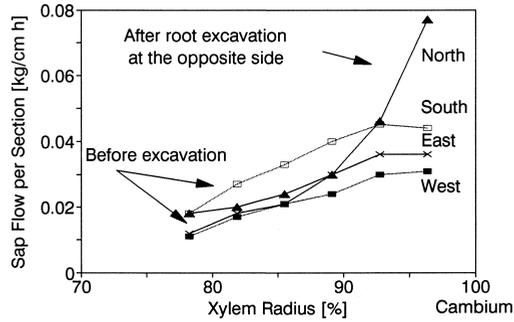


Figure 4. Radial pattern of sap flow rate from different cardinal points in the trunk of pine tree before and during excavation of its surface roots from the South side. Flow from the South, East and West sides was measured before excavation and flow from the North side during excavation, when flow from the South side was gradually decreasing to zero (not shown).

depth (at 1 cm) and another (lower peak) at a deeper layer (at about 4 cm) – no data were available below 6 cm, from where the sap flow started approaching zero (Figure 3, sensor S2).

The radial pattern of sap flow in the trunk of the pine tree had a slightly asymmetric form (Figure 4). It reached a maximum at a depth of about 13 mm (92% of xylem radius) decreasing rather steeply towards the cambium and more slowly towards the heartwood. Measuring at different sides of the pine trunk showed only small differences in this pattern.

Based on staining experiments, the radial pattern of sap flow was found to be asymmetrical in old spruces with flow prevailing in the outermost sapwood layers (Sipcanov and Baurenska 1965; Swanson 1967a). We could confirm this pattern which differs from the rather symmetrical pattern in young spruces (Cermak et al. 1992). Sap flow restricted mostly to outer sapwood layers may be expected in sites with frequent severe droughts, where water is gradually extracted from storage deeper in the sapwood which impairs the functioning of near-by tracheids (Cermak and Nadezhdina 1998).

A similar radial pattern of sap flow around the pine stem can be attributed to variation in sapwood conductance associated with slightly unequal distribution of roots and foliage (Cermak and Kucera 1990). A similar radial pattern with maximum flow at the depth of 15–20 mm below the cambium (based on heat-pulse measurements) was described in lodgepole pine by Swanson (1974). Measurements of radial patterns of sap flow in trunks of two species confirm Swanson's (1967b) findings that the conducting layer of sapwood is thinner in spruce when compared to pine. Appearance of maximum sap flow in the sapwood of coniferous species at a certain depth below the cambium is attributed to the interference of two processes occurring after cell differentiation: gradual increase of pit conductivity due to the erosion of pit membranes and simultaneous plugging of pits leading to a decrease in their conductivity (Mark and Crews 1973).

3.3 Responses of sap flow to severing the coarse roots

The radial pattern of sap flow in the intact second-order root (measured by sensor S1) showed a maximum at a shallow depth (1 cm – see Figure 3, upper part: a to c). The sap flow did not respond to cutting the small third-order surface root (diameter 2.5 cm – cut 1), but responded

immediately and substantially to severing the second larger third-order surface root (diameter 5 cm – cut 2) and to the same extent to cutting the third, vertically oriented root (diameter 2.2 cm – cut 3), which eliminated sources of soil water completely. However, sap flow fell to zero only when the whole root was finally severed from the trunk (cut 4, above the sensor) and the pulling force of the sink was thus eliminated. No increase in sap flow was observed following this treatment.

The radial pattern of sap flow in the first-order root (measured by sensor S2) was more variable (see Figure 3, medium part: a to e). The sap flow showed no response after the small third-order root was severed (cut 1). The flow slightly decreased in deeper layers and increased in shallow layers after cutting the larger third-order root (cut 2). It decreased significantly in all (especially medium) layers after cutting the third root (cut 3), by which all absorbing roots were severed. In contrast, sap flow temporarily increased when the whole second-order root was severed (cut 4) and then decreased to a stable low level for one hour. Sap flow increased again temporarily after the final cut 5 just below the sensor S2 and this was followed by a final decrease of flow, which approached zero within the next 30 minutes.

3.4 Sectorial pattern of sap flow

In our previous experiments with beech (see Cermak et al. 1993), sap flow measured at the height of 4 m responded dramatically within six minutes in stems, if half of the root zone was irrigated (stem sectors where the flow was measured were always in positions corresponding to the center of the root zone). It is clear, that water certainly reached the measured sector of sapwood in beech, where water was supplied to many roots. However, no response of sap flow to root severing in spruce was apparent in present experiments, when only a single and rather small coarse root was treated, particularly at the measuring point S3 located at the trunk base about 1.5 m above ground (see Figure 3, lower part). The continuing sectorial pattern of conducting pathway coming from this root to the stem was probably rather narrow, possibly slightly spiral (Rudinsky and Vite 1959; Zimmermann 1983; Cabibel 1994) and evidently passed outside the sector of sapwood, where the flow was measured. This contrasts with the situation we found earlier e.g. in apple trees (Nadezhdina 1986; unpublished), where the path of water spreads upwards, creating wider sectors within trees (thus, the flow from a particular root cannot be missed by a sensor). In general, there may be a large variation of sap flow around trunks, corresponding to root distribution patterns and availability of soil water for them (Cermak and Kucera 1990; Takizawa et al. 1996). Practically spoken, sensors should be placed close to particular roots or on root buttresses if their specific behavior is to be studied, or larger portions of roots should be treated in order to prevent similar uncertainties in coniferous species.

3.5 Compensation mechanisms for sap flow in trees

Sap flow (expressed per unit sector of xylem) in three of the four sides of the pine trunk measured before opening of roots by excavation showed a maximum of about 0.04 [kg/cm h] and mostly a convex radial pattern around this maximum at midday. Absorption of water naturally stopped on the South side after all surface roots were opened there and exposed to free air instead of direct contact with soil water. However, the sap flow rate on the opposite (undisturbed) North side increased substantially in the outermost layers of sapwood at the same time and obtained a concave pattern (see Figure 4). A variably responding flow in the first order root in spruce after severing small coarse roots (see Figure 3, sensor S2) might indicate a similar compensation, but

the situation was more complicated there due to the presence of one big deep root still attached to the main root from the other side of the severed roots.

A rapid decline of sap flow in the stems after a sudden interruption of the root water supply was observed, e.g. in fully grown oak trees on fast drying sandy soil (Cermak and Kucera 1991) and a similarly rapid increase occurred after the irrigation of large drought stressed beech trees (Cermak et al. 1993). In the mentioned beech trees, the sap flow responded dramatically on the irrigated side of the stem only, while there was no response on the opposite side which was not watered. Similarly, sap flow responded in the coarse roots of 14-year-old apple trees after supplying a single localized irrigation to just one root, while the other root remained unwatered (Green et al. 1997). Certain compensations of flow were observed in *Acer* and *Gossypium* following single and double-overlapping transverse cuts in stems (Mackay and Weatherley 1973). The sap was channelled around the cuts through the remaining intact xylem in surprisingly high amounts, assuring, to a large extent, continuing transpiration, a confirmation of the importance of compensating mechanisms for tree physiology. All the above results show that tree roots have the capacity to transfer water from local wet areas at much higher rates than normally occurs when the entire root zone or its part is supplied with water. They are also able to rapidly shift their pattern of uptake and begin to extract water preferentially from those regions where it is more freely available if in other regions water supply becomes limited.

4. Conclusions

When studying root damage caused by mechanical factors, physical parameters of wood provide background information about the conducting system, but this is useful only in connection with functional characteristics such as sap flow.

Positioning of sap flow sensors on the trunk basis should be close to particular individual coarse roots if their behavior should be studied, in order to prevent possible problems with non-straight sectorial conducting pathways. Conducting pathways must be exactly determined or sufficiently wide; this is difficult if only a single root is experimentally treated.

Sap flow in roots responds immediately to an abrupt damage of the conducting system, corresponding in extent to the importance of a particular part of the root system.

Experiments indicated that a compensation mechanism operates in trees, allowing for a temporary increase in the absorption of additional water (as reflected by sap flow in the trunk as well as in intact roots) by using only one part of the root system in cases where another part of root system is damaged or loses its water source. This mechanism evidently represents an important safety feature for tree survival.

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Technology for Planting Admixed Species in Norway Spruce Monocultures

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Abstract

One of the possibilities for achieving a change in the species composition of pure stands of Norway spruce and for establishing mixed stands with a sufficient proportion of soil-improving species is to use the planting stock of large-sized plants: large plants (semi-saplings) and saplings of broadleaved species. It is possible to form mixtures of these species while already establishing young plantations in an artificial regeneration of the forest, or additionally into established plantations and natural advance regeneration, in this case of Norway spruce. Some research results are presented of the grant project “Technology and technique of planting and production of the large planting stock of forest tree species” aimed at their application in the modification of species composition of spruce monocultures. Planting of large-sized plants can be carried out by the following technological procedures: traditional manual methods, using mechanised preparation of site, means for mechanised planting etc. Several new means of mechanisation and procedures created within the project are characterised and discussed (means for spot site preparation, hole-diggers, instruments for planting using an excavator etc.). The devices were tested in practice, their basic technical and economic parameters are available as well as results obtained from trial plots where the effect of planting methods on the survival and growth of plants was monitored. Basic results of the field study are given in this paper. In choosing technological procedures it is necessary to take into consideration planting conditions. The application of particular means of mechanisation has to be, therefore, differentiated, because only some of them can be used for a broader spectrum of conditions. A general, differentiated proposal for the set of means of mechanisation has been, therefore, prepared for particular activities.

Keywords: forest regeneration, large sized planting stock, production, planting, methods and technologies

1. Introduction

In the past, the planting out of large plants was particularly applied when extreme conditions for reforestation occurred on weed-infested areas after natural disasters or insect outbreaks. Such a situation happened e.g. in Germany (Helbig 1978) and in the Czech Republic (Peřina 1969). The plants rank among the quality group of large-sized planting stock: large plants (height of the above ground part 51–120 cm) and saplings (height of the above ground part 121–250 cm).

As the use of large plants facilitates rapid growth of young plantations from the zone of frost, weed and game danger, this method of forest regeneration appears to be topical also at present (Dušek 1980). New interest in large plants in Germany occurred in the 1960s in looking for optimum plants which could rapidly grow away from the endangered zone after planting out (Schmidt-Vogt and Gürth 1969). It is necessary to study the current problems of reforestation using large plants and the need to increase work productivity by suitable means of mechanisation (Huss 1993).

With respect to the current state of forestry, the present possibilities for using large plants in forestry in the Czech Republic are even a little better compared with the past situation. They can be particularly applied in:

- clear-felled areas reforestable only with considerable difficulties, i.e. old and weed-infested cleared areas, areas induced by air pollution, in the vicinity of watercourses, in frost pools, areas under the heavy impact of game etc.;
- beating up and improvement planting, particularly in young plantations with gaps and not fully established using plants of similar size and the same species as the young plantation;
- using admixtures of reinforcing and soil-improving species in present pure plantations. This is one of the most important possibilities for applying large plants by means of which a stable forest is established differentiated from the viewpoint of species, age and space (Zezula 1996). It is possible to already form mixtures of these species when during establishing young plantations in artificial regenerations of the forest or, additionally, into established plantations and natural advance regeneration, in this case of Norway spruce.

Expected benefits of using large plants include:

- lower number of plants for reforestation;
- rapid growing away from the effect of weed and game;
- lower labour consumption and costs for the protection of young plantations;
- quicker fulfilment of soil-improvement and reinforcing functions; and
- attaining the condition of an established plantation.

Problems in using large plants include:

- general shortage of quality large plants and higher costs for their production;
- considerable requirements for technological discipline in the whole process of obtaining; and
- using the planting stock, insufficient equipment for forestry practice with suitable technical means.

The use of large forest plants or saplings of desired quality using available machinery and equipment is, however, rather limited. Human factor plays an important role because it can reduce the positive role of using large-size plants (e.g. excessive shortening of roots before planting, insufficient size of planting stock root system in soil, careless handling, etc.). The main objective of the grant project No. 504/95/1205 “Technology of planting and production of large-sized planting stock“ is to design, on the basis of analysis, the modification and

completion of the system of technical means for the production and planting of large plants, and to test functional parameters of the new means. At the same time, three basic interrelated groups of requirements were taken into consideration: operational, economic and constructional.

2. Technical means for the production and planting

Technical means for the production of plants include (see Figure 1a and 1b):

- *a planting element for raising large plants* in forest nurseries equipped with the new type of a planting ploughshare improving the quality of the 2nd transplanting of standard plants. The number and arrangement of particular elements are variable according to the desired spacing of plant rows in nursery beds. The width of a furrow is 10 cm, operational speed is 300 m/hour;
- *an active cutter of nursery beds* equipped with an undercutter for plant roots (plants up to 60–80 cm in height) for raising large-sized plants by means of vertical and horizontal undercutting (no transplanting). Swath width is 1500 mm, depth of undercutting \leq 30 cm;
- *a large plant digger (lifter)* attached behind the tractor and lifting one row of plants at a depth of max. 40 cm;
- *a one-row root undercutter* designed for an one-axial tractor of 3.5 kW. It is an experimental machine, undercutting is carried out by a T-shape vibrating knife at a depth of max. 28 cm; and
- *an adjusting and packing stand* for bundling and wrapping the root parts of bare-root large plants into bags for predispatch preparation of planting stock. 2 operators, time for 1 packed bag is 15–20 s.

Technical means for planting include:

- *a manual one-man hole digger* installed on a single-wheel chassis enabling one to use standard power hole-diggers for digging holes by one person. Production rate max. 250 holes/hour;
- *a self-propelled one-man hole-digger* with an additional fertilizer applicator is an attachment for a one-axial tractor serving for plant hole digging by one worker with the possibility of synchronized fertilizing. Production rate max. 300 holes/hour;
- *planting instruments for planting by an excavator* serve for planting out plants up to the size of saplings in the majority of sites. This new method (in the Czech Republic) of direct planting of large plants (50–200 cm in height) using a special device attached to the excavator boom makes it possible to use an excavator simultaneously both for soil preparation and planting. It is recommended to use a light excavator equipped with a boom of minimum of 7.5 m reach (e.g. Schaeff HS 40D, Mensi-Muck, Unimog etc.). The use of heavy excavators is also possible. In the clearcut area, the excavator moves along the lines, 15 m apart. The line planting consists of slash disposal from places of planting, hole digging, inserting plants into the holes and, finally, covering plant roots with soil. A planter closely collaborating with the excavator operator inserts plants into the holes. The new method makes it possible to increase the survival of big plants, shorten the time necessary for establishing young plantations, decrease work difficulty of manual planting and improve the total effectiveness of forest regeneration operations. The application of the new method in the CR does not require any particular measures and will be useful in many locations. Positive results of experimental tests proved the usability of planting by an excavator in completing large planting stock of admixed species into young Norway

Table 1a. List of technical means suitable for planting large-sized planting stock.

No.	Operation	Tech. means	Types of technical means	Origin	Basic technical and economic parameters	Mode of use	Use in terrain types
A. Site/soil preparation							
1	Line spot preparation with the possibility of additional fertilization	1, 2	SK-50 scarifier + VA-0.2 aggregable lime applicator	CR	spots 50 cm in width, length and depth selectable, basic production rate 1.0–1.5 ha/shift, production rate with lime applicator 0.7–0.8 ha/shift, 1 worker, 40 kW tractor	1	11, 12, /13/
2	Strip preparation of soil	3	disc trencher TPF-1	CR	strip 50 cm in width, production rate 1.0–1.5 ha/shift, 1 worker, 40 kW tractor	1	11, 12
3	Subsequent spot additional fertilization in strips	2	VA-0.2 aggregable lime applicator	CR	storage bin 0.2 m ³ , optional dose, production rate 0.7–0.8 ha/shift, 1 worker, 40 kW tractor	1	11, 12
4	Hole site/soil preparation by motor-manual hole-diggers	4	portable power hole-digger (e.g. Stihl BT 360)	import	production rate according to hole dimensions, soil conditions and weed infestation max. about 350 holes/hour, 2 workers, holes max. 35 cm in diameter	1,2,3	all the types
		5	manual one-man hole digger on a single-wheel chassis	import /CR	production rate according to hole dimensions, soil conditions and weed infestation max. about 250 holes/hour, 1 worker, holes max. 35 cm in diameter	1,2,(3)	11, 12, /13/
		6	self-propelled one-man hole-digger with an fertilizer applicator	CR	production rate according to hole dimensions, soil conditions and weed infestation max. about 300 holes/hour (reduced by about 20% in case of simultaneous additional fertilization), 1 worker, holes max. 35 cm in diameter	1,2,(3)	11, 12, /13/
5	Hole site/soil preparation by attached hole-diggers	7	Attached hole-diggers on multi-purpose tractors (e.g. JN-90U, WB 1, WB 3)	CR/ import	production rate according to hole dimensions, soil conditions and weed infestation, number and position of soil augers max. about 300 holes/hour (max. 500 holes/hour in triple version), 40 kW tractor, 1 worker, holes max. 50–60 cm in diameter	1,2	11,12

Table 1a continued. List of technical means suitable for planting large-sized planting stock.

No. Operation	Tech. means	Types of technical means	Origin	Basic technical and economic parameters	Mode of use	Use in terrain types
	8	Attached hole-diggers on special tractors (PK7-021)	CR	production rate according to hole dimensions, soil conditions and weed infestation, max. about 250 holes/hour, 1 worker, holes max. 45 cm in diameter	1,2,(3)	11, 12, 13, /14/
	9	Hole-digger with an additional fertilizer applicator LoBo	import	attachment for an excavator (crawler or walking, 40 kW), simultaneous additional fertilization, production rate about 180 holes/hour, hole about 35 cm in diam., 1 worker	1,2,3	11-/14/, 21-/24/
B. Mechanized planting						
6	Outplanting by planting machines	trench/furrow planter	CR	large-sized plants and saplings max. 80 cm in height, production rate according to site conditions max. about 3000 plants/hour, 3 workers	1,(4)	11, 12, /13/
	10	Quickwood II planter	import	large-sized plants and saplings max. 200 cm in height, production rate according to site conditions max. about 3000 plants/hour, 3 workers	1,(4)	11, 12, /13/
7	Outplanting by planting devices/implements installed on an excavator	11 prime mover: crawler excavator of 20 kW class	CR (implement)	holes: 40 cm in width, 30 cm in height, production rate 80–90 holes/hour (holes only), 60–70 holes/h (incl. planting), jib reach 4 m	1,2,3	11-/14/, 21-/24/
	12	prime mover: crawler excavator of 40 kW class	CR (implement)	holes: 45 cm in width, 40–60 cm in height, production rate 150–170 holes/hour (holes only), 100–120 holes/h (incl. planting), jib reach 8 m	1,2,3	11-/14/, 21-/24/
	13	prime mover: walking excavator of 40 kW class	CR	holes: 45 cm in width, 40–60 cm in height, production rate 120–140 holes/hour (holes only), 90–110 holes/h (incl. planting), jib reach 8 m	1,2,3	11-/15/, 21-/25/, 31-/35/

Notes: Origin of the means: CR domestic manufacture exists or is realistic

Operation performed: 1) line-established plantations incl. line-mixed plantations, 2) group-mixed plantations, 3) partial beating up of plantations and ensuring the admixture of soil-improving and reinforcement species, 4) ensuring species admixture possible only by line methods, ()application limited by machine parameters; use in terrain types: //...up to the limit slope and particular machine passability

Table 1b. Terrain classification “Lesprojekt” (since 1980).

Slope of terrain	1 Soils of acceptable bearing capacity		2 Soils of unacceptable bearing capacity		3 Terrain with obstacles	
	Type	Group	Type	Group	Type	Group
1	< 8%	11	21		31	
2	9–15%	12	22		32	
3	16–25%	13	23	D	33	E
4	26–40%	14	24		34	
5	>40%	15	25		35	

spruce monocultures (Neruda 1996; 1998). In closed stands, the excavator should move along laid out tracks about 15 m apart;

- *a scarifier with an aggregable lime applicator* attached to a tractor serves for spot site preparation with exactly defined parameters and with a possibility to loosen the centre of a spot as to dose loose materials synchronously. Width of the spots is about 50 cm, production rate 1.0–1.5 ha/shift;
- *feeding tongs for plants* in excavator planting for increasing work safety. A worker inserts a plant into the grapple jaws and holds it in a hole dug by a planting tool attached to the excavator jib;
- *a truck for hauling plants* equipped with a plastic container serves for the cautious tertiary transport of plants in the course of planting. The use of a truck enables one to protect plants against weather effects and difficult work for workers engaged in planting large-sized plants is reduced.

Technical means for planting large-sized planting stock have to be differentiated from the viewpoint of their usability according to various criteria, e.g. the method and time of creating species mixtures (either directly in the course of plantation establishment or into the established young plantation or into the main species advance growth), spatial arrangement of admixed species (spot, group or line arrangement), topography etc. Proposals for the systems of technical means for the implementation of major operations of planting both bare-rooted and containerised large plants have been prepared in Table 1a giving basic technical and economic parameters of recommended technical means including those mentioned above which are the result of research activities. The description of terrain types is given in Table 1b.

In evaluating the development of young plantations in experimental plots established in the course of testing the technical means it was found that the dynamics of growth in standard and large plants was comparable, i.e. that the large plants showed a trend to maintain their proportional advance (advantage) as compared with standard plants. In mechanized methods of planting, markedly lower losses occurred as compared with manual methods of planting large plants (Table 2).

3. Conclusion

The economics of using large plants in forest regeneration cannot be related only to reforestation proper. Using published information and own data from research plots, calculation of the technical-economical benefits connected to the use of large plants in forest regeneration were made. The results of these calculations are shown in Table 3. The

calculations accept not only the higher purchase costs of large plants, but also the differing technical-economical parameters of alternative technological processes of reforestation and culture management. The calculations were made for a model case of establishing a mixed forest culture on a 1 ha plot with a planned species composition of: spruce 70% (main tree species), beech 30% (admixed tree species). Several technological alternatives were selected: from pure handwork to a fully mechanised planting process.

Apparently, there are some significant differences in the parameters of the individual technologies in the results of the individual calculations. This is the case for cost units but also in the consumption of human labour, plants and fuel. Therefore, the cost of reforestation calculated per plant can be slightly higher than for standard plants. (e.g. the reforestation cost for technology 1b is 8.3 CZK/plant, for technology 1a only 7.40 CZK/plant; for technology 3c 7.70 CZK/plant and for technology 3a only 6.0 CZK/plant etc.). Therefore, it is always necessary to evaluate a longer time period in which their positive qualities can become effective. A substantial decrease of most cost parameters when using large plants in comparison to plants of standard size than becomes apparent for all technological alternatives (e.g. total costs up to establishment of the culture when using technology 3c makes only 50% of costs of technology 1a; the fall of labour consumption between the technologies 1 a and 3c makes more than 80%, etc.).

The calculations on basic economic parameters of the individual reforestation technologies and their modifications show that the use of large plants is particularly positive when we consider a longer time period, i.e. up to the establishment of the culture. This conclusion is in agreement with literature sources (e.g. Lokvenc 1978; Rosenstock 1991).

Improvement (enrichment) planting of the current monocultures, usually of Norway spruce by reinforcement and soil-improving species, appears to be a very suitable method for the application of large-sized planting stock. Another similar use of large-sized plants and saplings is very useful in interplanting natural seeding and advance growth (usually again spruce advance growth) with trees of the target species composition which do not occur in the natural regeneration. The research results presented, although they cannot be quite exhaustive, indicate methods for ensuring particular technological operations that can be suitably applied in forest practice.

Acknowledgements

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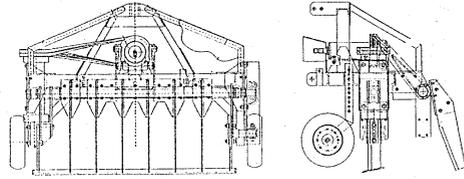
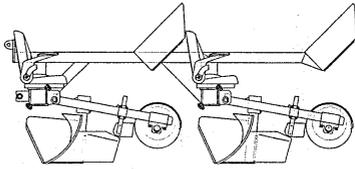
Table 2. The development of plants and percentage of losses in young plantations established on trial plots in the Krtiny Training Forest Enterprise.

Species/stand	Planting method
forest stand group, forest type	
term of planting	
Norway spruce / 295 B 11 autumn 1995 350 m a.s.l. deep loamy soil, without gravel	manually (standard plants) planting machine-into unprepared soil (standard plants) planting machine-into prepared soil (standard plants) hole digger (standard plants) manually (large-sized plants) planting machine-into prepared soil (large-sized plants) planting machine-into unprepared soil (large-sized plants) hole digger (large-sized plants) excavator (large-sized plants)
Norway spruce / 26 H 11 autumn 1995 320 m a.s.l. middle deep loamy soil with few gravel	excavator (large-sized plants) planting machine-into unprepared soil (large-sized plants) manually (large-sized plants) excavator (standard plants) planting machine-into unprepared soil (standard plants) manually (standard plants) hole digger (large-sized plants)
Pedunculate oak / 380 spring 1996 300 m a.s.l. middle deep loamy soil with few gravel	excavator (large-sized plants-protective tube) planting machine-into unprepared soil (large-sized plants) hole digger (large-sized plants) manually (large-sized plants) excavator (large-sized plants-free) planting machine-into unprepared soil (standard plants) hole digger (standard plants) manually (standard plants)
European beech / 39 A 14 autumn 1995 360 m a.s.l. loamy-sandy soil with gravel	excavator (large-sized plants) excavator (standard plants) hole digger (large-sized plants) hole digger (standard plants) planting machine-into prepared soil (large-sized plants) planting machine-into prepared soil (standard plants) manually (large-sized plants) manually into prepared soil (standard plants)
Sycamore maple / 280 B 7 spring 1996. 420 m a.s.l. loamy-sandy soil	excavator (large-sized plants-protective tube) excavator (large-sized plants-free) manually (standard plants-free)
European aspen / 308. spring 96 420 m a.s.l., loamy-sandy soil	excavator (large-sized plants-protective tube) excavator (large-sized plants-free)

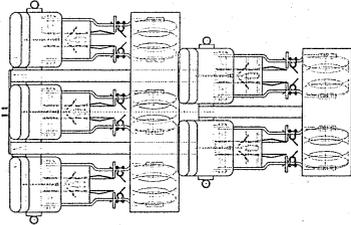
No of plants (pcs)	0 st growing season/1995		1 st growing season/1996			1 st growing season/1997			
	mean height	mean increm.	mean height	root collar diam.	losses	mean increm.	mean height	root collar diam.	total losses
	cm	cm	cm	mm	%	cm	cm	mm	%
200	30.0	11.4	41.4	8.9	3.0	16.1	57.5	10.6	5.0
200	38.3	7.8	46.1	8.5	3.0	20.6	66.7	11.5	5.0
200	38.5	11.9	50.4	9.3	3.0	19.6	70.0	11.9	5.0
200	38.9	11.3	50.2	9.5	4.0	20.0	70.2	12.2	6.0
200	68.6	10.0	78.6	12.0	3.0	19.3	97.9	16.3	5.0
200	62.8	12.8	75.6	12.8	5.0	11.9	87.5	16.2	8.0
200	63.1	13.3	76.4	11.7	3.0	9.7	86.1	15.3	5.0
200	63.2	10.1	73.3	11.7	3.0	18.0	91.3	15.3	5.0
200	70.6	8.8	79.4	13.4	0.0	10.2	89.6	17.2	5.0
200	58.7	9.8	68.4	11.3	0.0	20.1	88.6	16.7	3.0
200	61.4	10.4	71.8	12.3	0.0	16.4	88.2	16.7	4.0
200	55.3	8.6	63.9	11.9	10.0	17.1	81.0	16.7	15.0
200	35.9	12.6	48.5	8.3	0.0	18.1	66.6	12.4	5.0
200	35.1	9.6	44.7	8.7	0.0	23.6	68.3	11.7	4.0
200	32.0	7.3	39.3	7.7	5.0	20	59.3	12.0	10
200	58.4	8.2	66.6	11.6	5.0	15.3	81.9	16.3	9.0
150	72.2	9.3	81.5	10.3	0.0	65.1	146.5	13.6	3.0
150	71.3	10.6	81.9	10.7	5.0	53.5	135.4	15.2	20.0
150	73.7	13.7	87.3	10.2	5.0	44.2	131.5	16.3	20.0
150	69.7	13.0	82.7	12.0	25.0	39.8	122.5	15.2	28.0
150	64.2	11.7	75.9	9.6	5.0	44.5	120.4	13.5	12.0
200	35.6	7.7	43.3	6.3	5.0	31.9	75.1	9.4	12.0
200	34.0	11.6	45.6	5.6	5.0	23.7	69.3	9.4	50.0
200	31.3	7.9	39.2	5.5	5.0	20.3	59.5	9.1	50.0
150	66.9	12.9	79.8	13.2	2.0	31.5	111.3	18.2	8.0
200	31.6	8.2	39.8	7.7	0.0	25.3	65.1	11.6	5.0
150	67.5	14.3	81.8	12.5	5.0	25.9	107.7	17.9	10.0
200	39.0	14.7	54.7	8.6	5.0	22.5	77.2	12.7	8.0
150	64.9	19.0	83.9	12.1	5.0	25.9	109.8	16.8	10.0
200	27.7	15.4	43.1	7.3	5.0	21.2	64.3	11.1	10.0
150	59.3	22.1	80.3	13.1	10.0	21.4	101.8	17.3	20.0
200	24.9	12.5	37.4	6.8	12.0	20.5	57.9	11.4	15.0
150	69.6	7.3	77.0	10.1	0.0	60.0	137.0	11.8	0.0
150	69.2	8.5	77.7	9.7	0.0	19.1	96.8	12.5	0.0
200	41.8	2.5	44.3	5.7	0.0	7.3	51.7	7.3	0.0
100	109.7	51.4	161.1	11.6	5.0	148.5	309.4	21.2	10.0
100	104.2	48.0	152.2	10.7	10.0	138.3	290.5	25.7	10.0

Table 3. Recapitulation of some results of the calculation of reforestation and establishment of 1 ha are by various technological procedures.

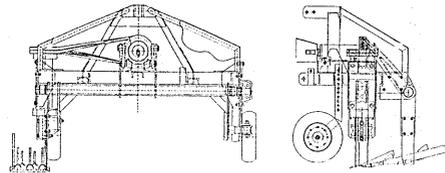
	Technological procedure of reforestation	Plants used	Total number of plants (pcs)	Planting stock cost (CZK)	Live work consump. (h)	Fuel consump. (l/ha)	Cost of re-forestation (CZK/plant)	Total costs (CZK/ha)
1a	Traditional manual method	main and admixed species, standard plants	5160	22440	918	29	7.4	63760
1b		standard main species, admixed species as semisaplins	3878	19656	826	29	8.3	56738
2a	Planting into soil prepared by mechanisms (strips + holes)	main and admixed species, standard plants	4945	21505	219	164	6.6	40448
2b		standard main species, admixed species as semisaplins	3702	18664	195	155	7.6	35524
3a	Planting by machines (main species planter, admixed species manually into holes prepared by a hole-digger)	main and admixed species, standard plants	4730	20570	155	181	6.0	36729
3b		standard main species, admixed species as semisaplins	3562	18104	146	186	7.5	33733
3c		standard main species, admixed species as saplings	3245	17270	136	183	7.7	32348



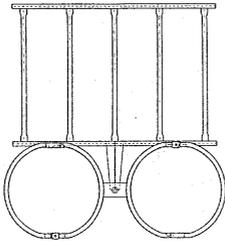
Active cutter of nursery beds



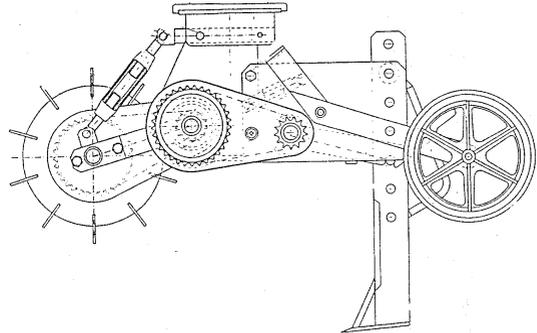
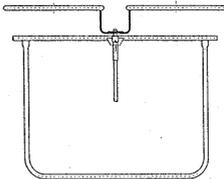
Planting element for raising large plants



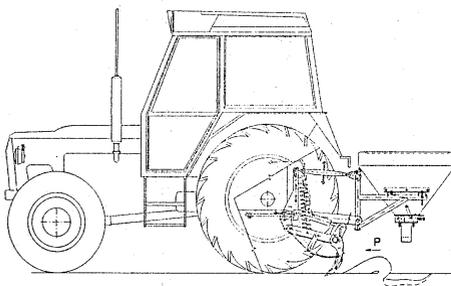
Large plant digger (lifter)



Adjusting and packing stand for bundling and wrapping the root parts of bare-root large plants



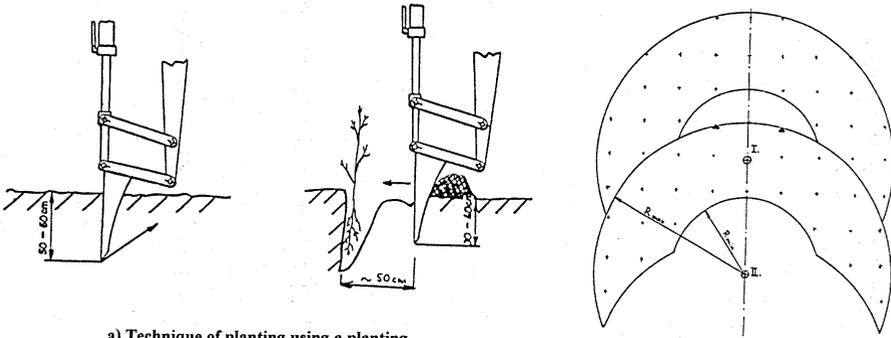
One-row root undercutter



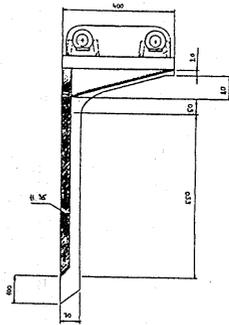
Scarifier with an aggregable lime applicator

Figure 1a. Some of developed and tested technical devices.

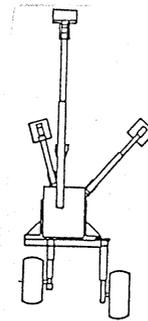
Planting using an excavator



a) Technique of planting using a planting instrument on the excavator boom

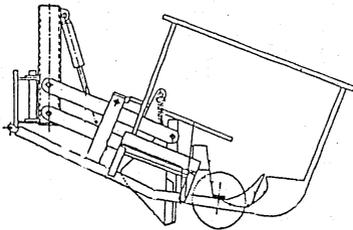


b) Construction of the planting instrument



c) Planting area created by the planting instrument on the walking excavator boom

Trench/furrow planter RL2-019



Self-propelled one-man hole-digger with an additional fertilizer applicator

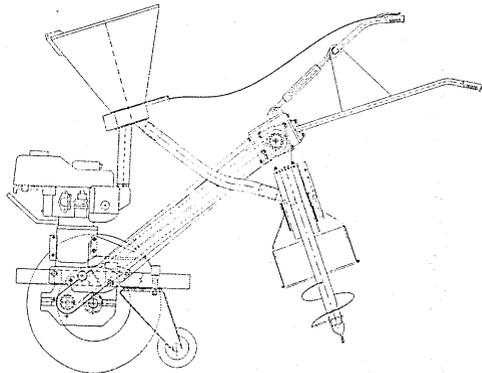


Figure 1b. Some of developed and tested technical devices.

Spruce Monocultures in the Mountain Region of the Pannonian Croatia

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Abstract

This paper discusses the advantages and disadvantages of spruce by comparing it with other species (larch and pine). Spruce is suitable for establishing cultures because of its large wood volume, good quality timber, and limited site requirements. However, its copious quantities of leaf litter have a temporarily degrading effect on the sites, thus making the return of autochthonous vegetation difficult. This paper discusses the culture structure, growth and increment of the studied species, the phytocoenological properties of the cultures and the adjacent natural stands, and chemical properties of the organic matter in the soil.

Introduction

Artificially raised stands cover 7% of the total forested area in the Republic of Croatia. The remaining forests are of natural origin in both high silvicultural forms and in degraded stages. Today, large areas of forest soil, 313,117 ha, do not support forest vegetation, and should therefore be reforested (Orlić 1986). The major part of these areas will be reforested with conifers. Until recently, the most frequently used species in reforesting new areas has been spruce, so that about 55% of the raised forest cultures in the continental part are composed of spruce. Apart from spruce, 20% of the areas were afforested with pine, 15% with black pine, 5% with Weymouth pine and 4% with European larch. After the initial large-scale afforestation activities in the 1960s, the disadvantages of afforesting with certain species, primarily with common pine and Weymouth pine, were discovered and thus, further afforestation has been done mostly with spruce and black pine.

In the Pannonian part of Croatia, which is similar to the Central European region in terms of climate and geology, spruce does not grow naturally. Therefore, 2,852 ha of forest cultures of common spruce has been established there. The area where the cultures were established are relatively small, ranging between one ha and several tens of ha at most, and they have

been previously covered with forests, but these forests have disappeared for different reasons (fires, uncontrolled fellings, and others). In the southern part of Croatia where limestones prevail (karst), spruce occurs naturally only in the higher mountainous regions as the third species in beech-fir forests, or independently under specific ecological conditions (frost-affected areas).

Research Area

Mount Medvednica, near Zagreb, is located between $45^{\circ} 50'$ and $45^{\circ} 58'$ northern latitude and $15^{\circ} 50'$ and $16^{\circ} 50'$ eastern longitude; its surface area is 720 km^2 and the principal ridge-crest in the SW-NE direction is about 42 km long and about 20 km wide. The main body of Medvednica is shaped like an ellipse, the terrain of the main peak is broken, cracked, irregular and very indented, hence there is a variety of expositions and inclinations (Majer 1980).

The geological base is mainly made up of green slate, argillaceous schist, dark grey limestone and sandstone in some places.

The climatic features of Mount Medvednica were determined on the basis of data obtained by two meteorological stations: Sljeme at 999 m above sea level, and Gric at 157 m above sea level. Medvednica has a humid climate. The mean annual temperature at its base is 11.7°C , and at the top it is 6.5°C . The mean annual relative air humidity is 70% at the base and 79% at the top. The annual precipitation on Sljeme is 1,297 mm at the top and 874 mm at the bottom. Mean precipitation values are characteristic for a continental precipitation regime. The maximum monthly rainfall occurs in June, mostly in the form of showers, and the minimum monthly rainfall occurs in February and March. Snow cover on the top lasts 178 days on average. The snow is abundant and very wet (heavy). In terms of wind frequency, the main wind directions are SE and NE, which are perpendicular to the main extension of the axis.



Figure 1. Schematic overview of the Pannonian region of Croatia.

Most of central Medvednica is made up of acid brown soils on slate, schist, and sandstone, within which there are two smaller enclaves with podzol brown soil on dolomites and hard limestones. Apart from these, there are also sporadic, geologically determined podzol brown soils on dolomites and hard limestones, and podzol brown soils on Miocene limestones, supported by brown carbonate soils on marl. There are also redzinas on Miocene limestones, and brown acid soils on sand and clay. Medium deep and deep soils prevail, while shallow soils (redzinas and rankers) are frequent mostly on steep slopes and on the crest of south and south-east expositions.

Methods

Experimental plots were established in the cultures of spruce, larch and black pine, and all three were of the same age. As no tending treatments were applied to the cultures, their development has been spontaneous since their establishment. The plots range from 0.21 ha (black pine) to 0.28 ha (larch). The size of the plots was determined by the terrain configuration, because we tried to include similar site conditions in all the plots. The basic structural elements – breast height diameter and tree height – were measured in the experimental plots, and were used to calculate the mean trees. Two of the mean trees were selected and cut down so that full tree analysis could be made (Klepac 1963; Oršanic 1995) including the growth in height, breast diameter, volume and increment. In each plot, seedlings and young growth were counted randomly in height classes of 25 cm.

Because of a poor return of autochthonous vegetation, another experimental plot was established in an 80-year-old spruce culture. A phytocoenological recording of the existing vegetation was made in spruce plots in order to carry out comparison with vegetation in natural forests close by.

The amount of the organic matter on the surface, the humus content, the pH values, the humus character and the adsorption complex were analyzed in spruce cultures.

Results and discussion

The cultures were raised at an elevation of 830 m in a higher mountain belt. The mountain vegetational belt in Croatia spreads between 400 and 1,000 m above sea level, with two distinct sub-belts. Up to 700 m, the pure Illyrian beech forests prevail (*Lamio orvale-Fagetum sylvaticae* Ht. 1938). Their luscious, floristic compositions place them into the richest European beech forests. They are of a specific floristic genetic development, the consequence of which is a wide variety of the Illyrian species, such as *Lamium orvala*, *Haquetia epipactis*, *Vicia oroboides*, *Erythronium dens canis*, *Euonymus latifolius*, *Lonicera caprifolium* and others. The Central European association (*Luzulo Fagetum sylvaticae* Mansel 1937) grows at the same height on silicates and Dystric Cambisols.

Beech occurs in a higher sub-belt above 700 m, forming the Pannonian variant of a beech-fir forest (*Abieti – Fagetum pannonicum* Ht. 1938). It covers 15,000 ha, and its best samples are found on Mount Medvednica. Apart from beech and fir, other frequent species are *Acer pseudoplatanus*, *Acer platanoides*, *Ulmus glabra*, and *Fraxinus excelsior*, while the shrub and ground layers are very similar to those in which was mentioned above beech forests.

As all three cultures are of the same age (42 years old), it is possible to compare them in detail. The cultures were established with a large number of plants, often amounting to

10,000 plant units per hectare. Table 1 shows the results of comparison between tree volumes at the age of 40.

At the age of 40, the spruce cultures have achieved the highest volume, as well as the most trees per ha. We should point out that no silvicultural treatments (cleaning and thinning) were carried out, and that the present number of trees was only affected by natural deaths of trees. The number of trees per plot today concords to the ecological requirements of the species for height. Spruce, as the biggest sciophyte, is the most numerous in the plot, while pines and larches as distinct heliophytes, are considerably less numerous.

The total tree analysis provided indicators for height growth, diameter growth and increment of individual species, as well as their volume growth and increment. Table 2 shows the results of height growth and increment.

The analysis of height growth and increment shows that pine and larch grow faster, which is characteristic for heliophytes. After 15 years, pine lags behind in growth, while spruce and larch have approximately equal values. After 30 years, larch lags behind spruce. At the age of 40, the current increment in black pine dropped to only 4 cm annually, while spruce and larch continued to maintain relatively high values from 28 cm to 39.7 cm.

By comparing data from the table, we see that at the age of 40 spruces have the highest breast diameter of 30.42 cm, while pines and larches follow with 24 cm each. Current increment both in spruces and in larches is still high. Spruce has 4.65 mm/year, and larch 4.6 mm/year.

At the age of 40, spruce has the highest volume of 0.586 m³. Taking into consideration the culmination of volume increment occurring around 35 years of age in larches and around 60 in spruces, it can be concluded that the difference in volume will be even bigger. The rotation periods for all three species are 80 years in Croatia (Matic et al. 1992).

The comparison of tree quality, through tree deaths and falling of dried branches, shows that larch has the best quality tree, followed by spruce with a number of dried, but not fallen, branches. Black pine has numerous branches of considerable thickness in the whorl.

The quantity of autochthonous vegetation occurring spontaneously in a culture is a sure indicator of the amelioration of the species for the return of autochthonous vegetation. Table 5 shows that black pine and larch are highly suitable species for the return of autochthonous vegetation, unlike spruces, where few firs and maples occur. Maple characteristically occurs at the edge of the culture, while fir does so only in the lowest height classes. It is important to determine which species are autochthonous, so that the fir as a sciophyte and the maple as a semi-sciophyte with very light seeds, penetrate the cultures and survive there. In the beech belt, where beech forms almost pure stands, this aggressive species frequently outgrows and suppresses the spruce. There are numerous examples of this; many spruce cultures have disappeared, or only a few spruce trees have remained, after beech has entered these cultures. In the belt of sessile and pedunculate oak, autochthonous vegetation enters with much more difficulty, because oaks have heavier seeds and require much more light. Furthermore, the sites are much stronger, so that when the canopies are opened, many other species of no interest to us occur, or weeds cover the soil.

Phytocoenological research shows that a young spruce culture does not provide favourable conditions for the development of the flora from the adjacent beech-fir forests, mainly due to pedological conditions and relatively low quantities of light (2.4%). While common spruce distinctly dominates the tree layer, and fir dominates the edges, in the shrub layer there are only individual, up to 20-cm tall species of *Fraxinus excelsior*, *Sambucus racemosa*, *Corylus avellana*, *Abies alba*, and *Acer pseudoplatanus*. The majority of them will die, and only those growing along the firs in light open stands resulting from falling spruces, will remain. The ground layer only covers about 1% of the area, and consists of *Gentiana asclepisdea*, *Gallium odoratum*, *Glechoma hirsuta*, *Mycelis muralis*, *Sanicula europaea*, *Prenanthes*

Table 1. Stand structure.

		A			B			C			TOTAL		
		N	G	V	N	G	V	N	G	V	N	G	V
Spruce	Total	150	11.45	150.69	90	2.80	33.00	32	0.79	7.36	272	15.04	191.05
	Per 1 ha	600	45.80	602.76	360	11.20	132.00	128	3.16	29.44	1088	60.16	764.20
Black pine	Total	79	4.25	36.74	77	2.08	16.50	47	0.74	5.19	203	7.07	58.43
	Per 1 ha	375	20.18	174.52	365	9.88	78.38	223	3.52	24.70	964	33.58	277.60
Larch	Total	68	4.15	49.58	20	0.79	8.41	24	0.53	4.21	111	5.46	62.01
	Per 1 ha	272	16.60	198.32	60	3.16	33.64	92	2.08	16.72	444	21.84	248.68

N number of trees G basal area V volume

Table 2. Height growth and increment of *Abieti-fagetum illyricum*.

Age	10	15	20	25	30	35	40
Height, m							
Spruce	3.49	7.03	11.13	14.50	17.38	19.73	21.75
Black Pine	4.20	6.50	8.50	10.30	11.96	14.23	15.42
Larch	6.20	9.84	12.56	14.64	16.26	18.00	19.91
mean total increment, cm/year							
Spruce	34.9	46.8	55.5	58	58	56.3	54.37
Black Pine	48	43.3	42.5	41.2	39.8	40.6	38.5
Larch	62	65.6	62.7	58.56	54.2	51.4	49.7
height growth, cm/year							
Spruce	56.6	80	83.3	56.6	58.3	39.7	39.7
Black Pine	50	40	40	33	33	23	4
Larch	87	60	47	38	36	29	28

Table 3. Diameter growth and increment of *Abieti-fagetum illyricum*.

Age	10	15	20	25	30	35	40
Diameter, cm							
Spruce	4.95	11.83	17.21	20.32	24.28	27.83	30.42
Black Pine	8.88	11.58	14.78	17.98	20.42	22.80	24.24
Larch	7.08	12.09	15.15	17.19	18.98	21.52	24.00
mean total increment, mm/year							
Spruce	4.95	7.86	8.6	8.12	7.81	8.26	7.6
Black Pine	8.88	7.72	7.39	7.19	6.8	6.51	6.1
Larch	7.08	8.06	7.57	6.87	6.32	6.14	6.05
height growth, mm/year							
Spruce	9.84	13.24	9.10	4.30	10.34	4.92	4.65
Black Pine	4.40	4.60	7.60	5.60	4.40	5.00	2.00
Larch	13.50	7.00	4.70	3.30	3.90	6.10	4.60

Table 4. Volume growth and increment of *Abieti-fagetum illyricum*.

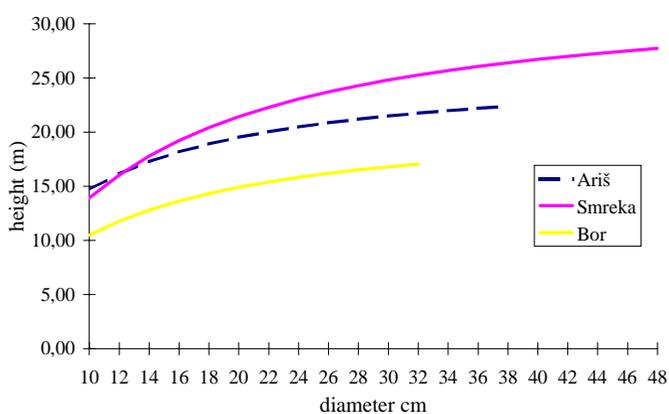
Age	10	15	20	25	30	35	40
stemwood, m ³							
Spruce	0.00038	0.0008	0.0443	0.127	0.2479	0.4164	0.5868
Black Pine	0.0168	0.0302	0.0659	0.1217	0.191	0.276	0.3437
Larch	0.0071	0.0442	0.0851	0.147	0.2177	0.3107	0.5312
mean total increment, m ³ /year							
Spruce	0.00003	0.0005	0.0022	0.0051	0.0083	0.0119	0.0147
Black Pine	0.0028	0.0334	0.0435	0.0055	0.007	0.0079	0.0085
Larch	0.0044	0.0057	0.0074	0.0088	0.0104	0.0122	0.0133
height growth, mm/year							
Spruce	0.00228	0.0093	0.0219	0.0317	0.0444	0.0411	
Black Pine	0.0021	0.0031	0.0098	0.012	0.0151		
Larch	0.0074	0.0082	0.0124	0.0141	0.0186	0.0231	0.021

Table 5. Number of seedlings and young growth by height classes.

Height (cm)	Black Pine		Larch		Spruce	
	Fir	Ash	Fir	Ash	Ahorn	Fir
seedling	79		18	230	9	15
0–10	255	102	251	18	3	3
11–25	265	160	80			
26–50	36		30			
51–75	16		21			
76–100	11		11			
101–125	6					
126–150	2					
151–175	2					
Total	672	262	411	248	12	18
Per 1 ha	53760	20960	32880	19840	960	1440
Total per 1 ha	74720	52720	2400			

Table 6. Pedological research.

Location	pH in H ₂ O	pH u 0.01M CaCl ₂	Content humus (g/kg)	Draz organic matter Olf-horizon (kg/m ²)
	A-hor.	A-hor.	A-hor.	Olf
Spruce culture	4.2	3.4	122.0	1.948
Abiet-Fagetum	4.4	3.7	141.4	2.059
Old spruce culture	4.3	3.6	153.4	2.772
Beech stand	4.6	3.9	148.5	2.074

**Figure 2.** Height curves.

purpurea, *Anemone nemorosa*, *Lunaris rediviva*, *Lamiaeum galeobdolon*, *Nephradium filix mas*, *Cardamine bulbifera* and *Geranium robertianum*. The same species are present in the adjacent natural stand of beech and fir in approximately 40% of the area, and, together with *Mercurialis perennis*, *Actaea spicata*, *Srophularia nodosa*, *Circaea lutetiana*, *Salvia glutinosa*, *Symphytum tuberosa*, *Lilium martagon* and some other thirty species, fully cover the soil.

As the vegetational picture in the younger culture was rather poor, another phytocoenological recording was made in an older spruce culture (80 years old) with much more favourable light conditions. In terms of flora, this culture is very different from the younger one. Apart from spruces, the tree layer is also made up of firs, sycamores, common hornbeams, firs and sessile oaks, while shrubs cover 30% of the area. There are also *Sambucus racemosa*, *Corylus avellana*, *Atropa bella-dona*, *Solanum dulcamara*, *Fagus sylvatica*, *Rubus idaeus* and *Ulmus glabra*. The ground layer, covering about 90% of the area, is of particular interest. It is dominated by *Senecio nemorensis*, *Atropa bella-dona*, *Salvia glutinosa*, *Nephradium filix mas*, *Athyrium filix femina*, *Rubus hirtus*, *Actaea spicata*, *Solidago virgaurea*, *Epilobium montanum*, *Sambucus racemosa*, *Urtica dioica*, *Ballium sylvaticum*, *Silene dioica* and other species of forest clearings and favourable light conditions. This is an indication that favourable conditions have been formed in the stand, thus enabling the return of autochthonous vegetation. Depending on the management goal and silvicultural treatments, it will develop in the next generation. These species are much less present in the adjacent natural forests with closed canopies. Along with these, there are a further forty species.

To conclude: in a younger, first spruce stand, the autochthonous vegetation from the natural adjacent beech-fir forest is only individually present, which is the consequence of unfavourable pedological and light conditions, as well as of spruce influence. The second spruce stand has a well-developed biomass, which reflects the character of a pioneering vegetation of mountain forest clearings, and has a favourable effect on site factors. Thus, it meets all the prerequisites necessary for the development of a plant community of natural composition in the next generation.

Conclusions

Research has shown that spruce achieves the largest wood volume at the age of 40, and that current increments (diameter, height, volume) have the highest values.

The spontaneous return of autochthonous (woody) vegetation occurs best with black pines, then with larches, and then with spruces. The results show that even at this age, black pine and larch have played their pioneering role, and that the existing quantity of autochthonous vegetation enables the establishment of an almost natural forest.

Phytocoenological research shows that in younger spruce cultures autochthonous vegetation from adjacent forests is only partially present, which is the consequence of unfavourable pedological and light conditions. In older stands with a poorer crown cover and better light conditions, the vegetation which reflects the character of pioneering vegetation of forest clearings in the mountainous belt is better developed, and has a favourable effect on site factors.

Since the soils are extremely acidic, spruce cultures create a negative impact by acidifying the surface.

In older cultures, raw humus is accumulated in the mineral part of the surface. Humification would be better if the stands are open at a younger stage.

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Transpiration of a Spruce Monoculture in Rajec (Southern Moravia) Free of Drought Stress

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Abstract

Diurnal and seasonal variation of sap flow in full-grown Norway spruce (*Picea abies* L.(Karst)) dependent on environmental factors was studied in a spruce plantation in the Czech-Moravian highlands in southern Moravia during the growth season of 1989. Sap flow was measured with the tree trunk heat balance technique. The scaling up from tree to stand was done using the forest inventory data. No significant water stress was detected. The estimated total seasonal stand transpiration (259 mm/season) represents 50.8% of total standard crop transpiration.

Keywords: spruce, monocultures, sap flow, Central Europe

1. Introduction

The experimental plot at Rajec in the Czech-Moravian highlands has been the object of a long-term study of forest growth and water balance in spruce monocultures since 1979. The present paper discusses the results of the most detailed period of measurements in 1989. During this season, detailed measurements of sap flow, micrometeorology and the measurements of gas exchange by the gradient method (Bednarova and Kucera 1992) were conducted. The aim of this study was to complete the long-term series of sap flow measurements under different weather conditions in order to appreciate the growth conditions of spruce outside of its natural area. The obtained data would be related to the results of gas exchange measurements.

2. Material and methods

The sap flow of Norway spruce (*Picea abies* L.(Karst)) and meteorological parameters (air temperature, vapour pressure deficit (VPD), global and reflected radiation and wind speed) were simultaneously measured at the experimental site at Rajec in the growth season of 1989 from May to October with a time step of 1 hour. The site is situated in the Dražanská Vrchovina Uplands at an altitude of about 625 m (Klím 1992). The mean annual temperature is 6.6 °C, and the mean annual precipitation is 683 mm. The original forest type belongs to the *Quercus-fageta abietis* forest-type group (Vasicek 1984). The actual stand is a spruce monoculture planted around 1905 with the following characteristics (1995): density – 830 trees per hectare, mean diameter at 1.3 m (DBH) – 26.6 cm and mean height – 27.7 m. Six experimental trees were selected for this study. The sap flow rate was measured with the tree trunk heat balance technique (THB) by internal (direct electric) heating of tissues and sensing of temperature (Cermak et al. 1982; Kucera et al. 1977).

The transpiration of the total stand was estimated the following way. A period over one month was selected from the total period of measurements at the mid-growth season. The period totals for all experimental trees were then estimated and the linear dependence of sap flow totals for a tree diameter at 1.3 m (DBH) was derived. The stand total of transpiration for the same period was estimated using the obtained dependence and stem DBH distribution for the total stand measured in 1995. The ratio of total stand transpiration on the sum of transpiration totals of all experimental trees (a_{TS}) was then obtained. While no significant water stress had occurred during the whole growth season, the obtained coefficient was used over the whole growth season for the estimation of stand transpiration daily totals.

The time lags between the sap flow and meteorological factors were estimated by means of cross-correlation. Then a stepwise multiple regression of sap flow with lagged factors was done.

3. Results and discussion

3.1. Diurnal dynamics

An example of diurnal behavior of sap flow on a clear day is presented for three trees with the most contrasting curves on Figure 1 (other curves were just in between). Time lags of sap flow with radiation and standard crop transpiration (E_{TP} , Penman) were 1.5–2 hours for all sample trees and different periods of the season. This is similar to the observations of Cermak et al. (1995) in central Sweden and is slightly less than lags observed by Schultze et al. (1985) in large spruce and larch trees in Central Europe. No time lags of sap flow behind VPD and air temperature occurred, i.e. both VPD and temperature lag the same behind transpiration as sap flow. The approximation of diurnal courses of sap flow by regression equations with stepwise variable selection from shifted values of E_{TP} and actual values of VPD provided satisfactory results for all trees and periods ($0.7 < r^2 < 0.9$). The error of approximation is probably related to the stem water capacity (Schultze et al. 1985). The seasonal decomposition of diurnal courses showed that the reaction of sap flow on quick changes of weather conditions was not only lagged but partially buffered by stem capacitance (see Figure 1). The maximum daily stem water storage (stand level) estimated for sunny days without rain was 0.52–0.55 mm in June, reached a maximum of 0.68 mm in July and then decreased down to 0.50 mm in mid-September and to 0.16 in mid-October, which represents 18–24% of transpiration daily totals in June–July and 27–30% in late August–October.

Maximum diurnal water stress occurred at 14–16 h. in June, appeared earlier in July–August (13 h.) and again latter in September–October (16 h.).

3.2. Seasonal dynamics

Dependence of the sap flow daily totals on the potential evapotranspiration was the same during the whole growth season, i.e. no significant water stress occurred.

The seasonal course of stand transpiration (Q_{ws}) is presented in Figure 2. The estimated seasonal (April–October) total of stand transpiration (259 mm/season) represents 50.8% of total standard crop transpiration, 62.0% of total open field precipitation and 102.3% of stand precipitation (see Mrkva 1992). Maximal daily stand transpiration was $3.5 \text{ mm} \times \text{day}^{-1}$. The mean tree of the stand (with DBH 28 cm) transpired, during a clear day at the mid-growth season, about 50 liters of water and the seasonal average was 3.13 m^3 . The results were compared with the previous measurements conducted at the same site (Cermak 1992). The

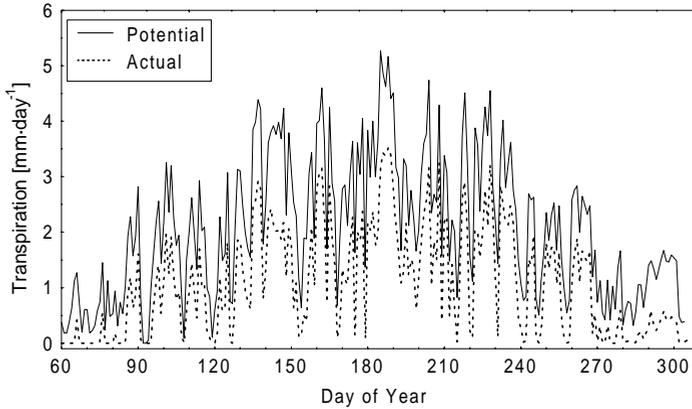


Figure 2. Potential and actual spruce stand transpiration.

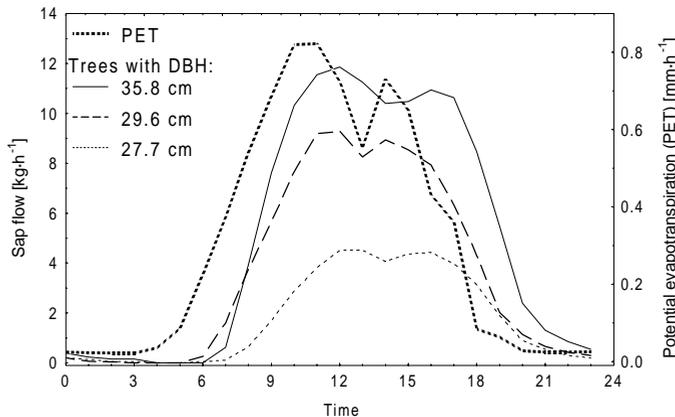


Figure 1. Example of diurnal course of sap flow during a clear day (July 8).

Table 1. Annual totals for meteorological parameters and sap flow (P – precipitation, T_{eff} – sum of effective temperatures).

Year	T_{eff} deg.days	E_{TP} mm	P mm	P- E_{TP} mm	Q_{WS} mm	$Q_{\text{WS}}/E_{\text{TP}}$ %
Mean 1979–1987	1496	476	461	-15	188	40.3
St.dev 1979–1987	199	45	61	93	59	14.5
1989	1565	503	441	-62	259	51.5

seasonal total of Q_{WS} during 1979–1987 oscillated between 136 and 296 mm (the mean was 188 mm, Table 1.) and the mean ratio $Q_{\text{WS}}/E_{\text{TP}}$ was 40% (see Cermak 1992). So, the water use during the growth season of 1989 was significantly higher than the local average. The other authors report a rather large scatter of spruce stand transpiration in Europe. Thus, in central Sweden (Cermak et al. 1995) the transpiration of 100-year-old spruce (stand level) represented 8% of standard crop transpiration under drought stress and 40% under normal water supply. The seasonal transpiration of 110-year-old spruce plantation in the Bavarian highlands at an altitude of 750–800 m was 163 mm, i.e. slightly less than the mean value on site (Alsheimer et al. 1998).

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