

Silvicultural management in maintaining biodiversity and resistance of forests in Europe—temperate zone

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Abstract

In Europe temperate forests play a prominent role in timber production, nature protection, water conservation, erosion control and recreation. For centuries temperate forests in Europe have been affected by forest devastation and soil degradation. Applying great efforts to eliminate the severe wood shortage of those days, countermeasures were taken during the last 150 years by regenerating and tending highly productive forests. High growth rates and an increasing growing stock of these forests indicate that formerly stated goals have been successfully achieved. Coniferous species were often favoured because they were easy to establish and manage, and gave reason for high volume growth expectations. Today coniferous forests expand far beyond the limits of their natural ranges.

These changes have been accompanied by a loss of biodiversity, a shift to nonsite adapted tree species and reduce the resistance against storms, snow, ice, droughts, insects and fungi. Some of these hazards were further intensified by the increasing average stand age, as well as in some areas by severe air pollution. Climatic fluctuations, especially changes in the frequency and intensity of extreme warm and dry climatic conditions and of heavy storms, had considerable impact on forest ecosystems.

The changing demands of today require a widened scope of forest management. Society is asking for sustainable forestry emphasizing biodiversity and naturalistic forest management. It is of great economic and ecological relevance to know on which sites today's forests are most susceptible to climatic and other environmental changes and hazards. In those areas adjustments of management through a conversion the prevailing forests towards more site adapted mixed forests needs to be considered with priority. The high diversity in site conditions, ownership, economic and socio-cultural conditions require strategies adapted to the local and regional needs. Higher resistance of forests will increase economic and social benefits of forests and reduce the risks by maintaining sustainable forestry.

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1. Situation

1.1. History of temperate forests in Europe

Temperate forests in Europe cover a large bioclimatological range from oceanic to continental forests, from floodplain to mountain forests up to the alpine timberline. Temperate forest ecosystems seldom consist of just one tree species. Naturally pure stands can be found only on particular extreme sites (Mitscherlich, 1978; Schmidt-Vogt, 1991). Natural composition of tree species is governed by competition with other species, history of migration modified by mountain barriers, edaphic factors, and insects, which leads to an incomplete migration, by climatic conditions such as drought periods in summer, frost dryness

and late frost as well as herbivorous population density (Schmidt-Vogt, 1987).

The forests in the temperate zone of Europe span large parts of western and central Europe (Fig. 1). The Atlantic climate in the western part turns to a continental climate with decreasing humidity and higher temperature variation in the eastern part of Europe. Large areas in the temperate zone have been converted to agricultural land, and former forest area has been used for buildings, roads and other land uses. Some decades ago this development has changed. Forest area in Europe has increased from 1980 to 1995 by 4.1%, which is higher than increases observed in other developed countries (FAO, 1997). Similar increases in forest area can be found in almost all countries in the temperate zone of Europe. In some countries the area of forests available for wood supply has decreased while the area not available for wood supply has increased (TBFRA, 2000). In the European part of the Russian Federation

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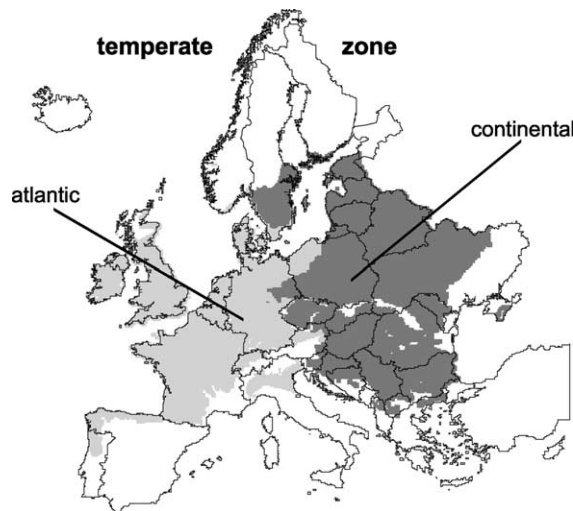


Fig. 1. Temperate forest zone in Europe. The ecological zone map has been developed, based on the Köppen-Trewartha climate system in combination with natural vegetation characteristics (FRA, 2000).

the area of forests has also increased by 1.2 mill. ha during the period from 1966 to 1998 (Pisarenko et al., 2001). Currently about 26% of the total area is covered with often fragmented forests (Fig. 2).

As site conditions, ownership and cultural, economic and social conditions vary at short distances in temperate forests of Europe also forest management differs locally. European temperate forests today are the result of centuries of human activities. In some countries, for example, Denmark, United Kingdom, Ireland and The Netherlands, the forest cover is only about 10% of the total area, while in other countries of the temperate zone, for example, Austria, Estonia, Latvia, Liechtenstein, Slovakia, and Slovenia the forest cover exceeds 40%. In Austria, Ireland, Poland and United Kingdom more than 60% of the forest area is coniferous dominated while in Bulgaria, Croatia, France, Hungary, Luxemburg, Romania and Republic of Moldova more than

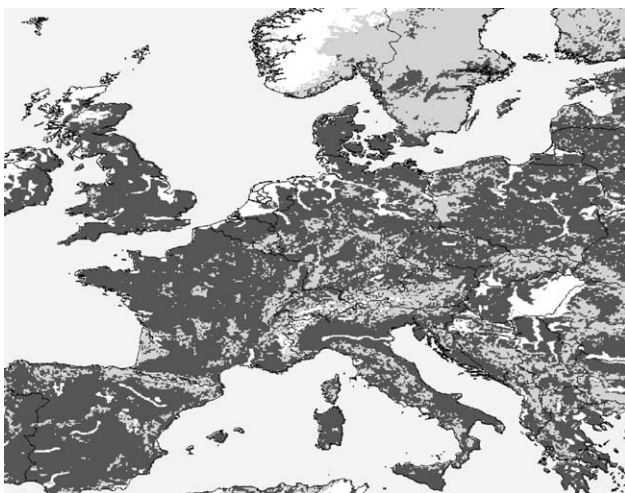


Fig. 2. Changes in forest cover of the temperate zone in Europe: original forests (dark grey) and current forests (light grey). Source: <http://www.globalforestwatch.org/english/interactive.maps>.

60% of the forest area is broadleaved dominated. In most countries 'high forest' is by far the most common silvicultural category. However, in Bulgaria, France, Liechtenstein, Republic of Moldova and Ukraine coppice forests and coppice with standards contribute to more than 40% of the forest area. Most high forests are even aged. Only in some countries, for example, in Croatia, Germany, Liechtenstein, Slovakia, Slovenia and Switzerland, the area of uneven aged forests amounts for 15% and more (data: TBFRA, 2000).

2. Problems

For centuries temperate forests in Europe have been affected by forest devastation and soil degradation by exploitation, grazing and litter racking. Applying great efforts to eliminate the severe wood shortage of those days (Kirby and Watkins, 1998), successful countermeasures were taken during the last 150 years by regenerating and tending highly productive forests. Coniferous species, primarily Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* [L.] Karst.), were often favoured because they were easy to establish and to manage and gave reason for high volume growth expectations. Also Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) has been introduced, driven by the same motivation. Additional advantages of coniferous species were the low cost of planting, including low repair planting required, relatively low deer browsing damage and solid knowledge of the management of these forests. By substituting faster growing species for less productive species not only has wood production increased, revenues have increased even more because of the higher softwood prices as compared to hardwood prices at that time.

Today the area covered by coniferous species expands far beyond the limits of their natural range. Consequently, the current species composition of temperate forests in Europe is mainly determined by former management rather than by natural factors (Ellenberg, 1986). European temperate forests today are the result of centuries of human activities. Most of the forests have been planted or seeded and species composition has been subject to drastic changes. In central Europe broad-leaved species dominated the forest by covering approximately 2/3 of the area until this was reversed on many sites by human activities (Mayer, 1984). The area of European beech (*Fagus sylvatica* L.), oaks (*Quercus* sp.) and other broad-leaved species has been reduced while the area of Scots pine and Norway spruce has been increased substantially.

Norway spruce and Scots pine today are common and economically most important tree species in the temperate forests of Europe. The highest coverage of Norway spruce in European temperate forests with more than 25% of the total land area is found in Austria where 350 000 ha are covered with Norway spruce and Scotch pine forests

outside their natural ranges (Prskawetz, 2000). A rather high coverage of Norway spruce of 15–25% of the total land and more than 25% of the forest area can be found in Czech Republic and Slovakia. In Switzerland and Germany Norway spruce covers 10–15% of the total land and more than 30% of the forest land. In these two countries spruce has been often planted within its natural range in the mountains but also outside, especially in hilly regions and lowlands.

The western border of the Norway spruce area has been moved considerable to the west. Substantial Norway spruce areas that extend beyond the natural range can be found in Belgium, Luxembourg, The Netherlands, and in Denmark, where Norway spruce covers about half of the 10% of forest land, but also in Great Britain, Ireland and in various parts of France. Best growth is often found outside of its natural range (Schmidt-Vogt, 1987). Although Norway spruce is said to be a species adapted to continental climate, warm winters seem not to have a detrimental impact on Norway spruce; long growing seasons may even increase growth rates. Scots pine has become popular on dry and temperate continental sites. In addition, these forests are also subjected to a variety of other anthropogenic influences such as atmospheric deposition, chemistry of the air, and changes caused by unbalanced game populations (Weidenbach, 2001).

3. Objective

In this paper it will be reviewed and discussed the changes in the stand structure, growth and conditions of temperate forests in Europe, the causes of changes and measures how the forest structure could be converted by silvicultural measures towards more resistance structure in order to maintain the long term sustainability.

4. Recent changes and future perspectives for managing temperate forests in Europe

4.1. Recent changes in forest management aims

Forest management recently has been affected by the relatively decreasing importance of commodity functions of forests. Rapid changes occur in energy sources, changes in production and traffic technologies, as well as changes in the use of wood for construction work. In addition, with rising living standards, protective, environmental, social and cultural functions became more important. Changing social demands today require a widened scope of forest management and principles of sustainable forest management, forest laws, directions and regulations are being reviewed (see e.g. resolutions H1 and H2 of Helsinki Ministerial Conference, 1993). Society is asking for sustainable forestry emphasizing biodiversity and naturalistic forest

management. The discussion about the future of the forest sector has never been more intensive and politically-orientated than it is today.

Currently, a more ecological oriented approach of forest management is being applied (Rykowski et al., 1999). As management has formed the current forests it is justified to ask the question on how future management can scope with new objectives such as maintaining biodiversity and resistance.

Forest management affects biological diversity on various levels: genes, individual organisms, species, populations, biotic communities, ecosystems, landscapes and regions. As forest management affects directly the composition of structural species such as trees, shrubs and herbs, it affects mosaic patterns of forests in various development stages, the amount of dead wood in forests, the vertical structure of habitats, and forms edge habitats. Unfortunately only limited information about composition, structure and function of forest ecosystems is available on a large scale. Assessment of, and planning for, forest diversity requires a set of new methods that provide sound information on the current state of forests and their reactions to management activities. Currently, the implementation of management concepts is difficult because it is not easy to plan for aims that cannot be measured adequately (Köhl et al., 1998). It is assumed that forest structure such as tree species composition, tree age composition and standing woody biomass have strong impact on biological diversity and forest resistance. As information on these parameters is available on a large scale they will be discussed here in more detail.

4.2. Changes in tree species composition

Tree species composition in the temperate forests in Europe has been historically subject to drastic changes. Genetic diversity has been reduced during glacial times. Immigration during the warmer interglacials could not compensate for the extinction during the cold periods. Later on, land use had a major effect on tree species composition. While starting at the end of the thirteenth century and, more extensively, during the last 200 years, conifers have been introduced on sites naturally dominated by broadleaved species currently the question is raised whether these forests should be converted to broadleaved forests again. Motivation for the reverse change in tree species composition is the evidence of disadvantages associated with pure coniferous forests under certain conditions: the risk of increased mortality under drought conditions, relatively high susceptibility to storm, snow and ice, with rather high salvage cuttings as well as higher susceptibility to fungi and insects. In addition, a shift of tree species composition closer to that determined by the current climatic and edaphic conditions is expected to increase the capacity of forest to adapt to changing climatic conditions. Increased hardwood prices relatively to softwood and the popularity of close to nature forestry stimulate this

shift towards more broad-leaved species as well. Volume growth is judged as less important, while wood quality receives higher attention. Higher ecological and economic value of slower growing species may at least partly compensate for losses in volume growth (Ripken and Spellmann, 1979; Brandl, 1988).

Since conversion has an impact on almost every aspect of forest management, there is a great need for well-founded information regarding the conversion of secondary coniferous forests. In two conferences at the international level (Hasenauer, 2000; Klimo et al., 2000) the question of conversion has been discussed extensively and in various national research initiatives the consequences of conversion has been investigated. This includes-but is not limited to-improved comparative understanding of the functioning of pure coniferous forests vs. mixed forests with varying proportions of tree species and of the ecological and economic implications during the conversion phase, which will, in most instances, last many decades. Effects on the potential of forests for providing sustained productivity under ecological stability, i.e. stability in biodiversity, of water regimes, and of nutrient cycles have to be considered. Mixed stands may use resources differently and may be more resistant against physical and biotic stress factors (Cannel et al., 1992; Kelty et al., 1992). Some species combinations were found to increase wood production (Mitscherlich, 1978). Possible reasons include a change in canopy structure and light interception, the reduction in crown and root competition, increased litter decomposition rates and enhanced mineralization rates (Kreutzer et al., 1986; Rothe et al., 2002). Aspects of soil degradation need to be considered including soil acidification and the processes of decomposition as well as microbial and fungal populations and the effect on the carbon budget and finally the future timber supply.

The vitality and stability of secondary coniferous forests is affected by a complex set of stress factors, which may be subdivided into three important groups: anthropogenic, biotic and abiotic factors. They put pressure on secondary spruce stands as well as on forests under conversion or new mixed forest and may entail forest management problems, economic losses, and changes in social functions. At present, the forest community has no integrated forest protection strategies to prevent impairment by the above factors during each stage of conversion. The risks inherent in the conversion process and outline measures that will increase the natural resistance and resilience of coniferous stands against the complex array of stress factors such, as the increase in windthrow and bark beetle risks by opening the canopy of old Norway spruce stands, need to be considered.

While the economics of various tree species in the temperate zone are well known under different scenarios, the economics of conversion itself have not been investigated adequately. This applies in particular to the conversion of secondary coniferous forests into mixed broadleaved stands (Hanewinkel, 1998; Knoke and

Plusczyk, 2001; Knoke et al., 2001). The conversion of even-aged coniferous forests not only require investments but will also lead to a significant change in cash-flow. However, the direction and dimension of this change will vary with the silvicultural target and the silvicultural conversion strategy. Regarding the political aspects of conversion, this issue has hardly been covered in surveys (Schraml et al., 2000; Stipp and Schraml, 2001) although several studies about opinions and attitudes toward forests and forestry have been made in individual European countries (Pelissié, 1992; Lafitte, 1993; Koch and Rasmussen, 1998; Kramer, 1998; Wiersum, 1998; Rametsteiner, 1999; Finnish Forest Association, 2000; Schmithüsen and Wild-Eck, 2000; Sondergaard and Koch, 2000; Terrasson, 1998).

Changes in species composition are occurring rather slow because of the long lasting life of forest generations. Only in exceptional occasions, such as after storm or serious insect attacks, may this process be accelerated. A good indicator of changes in the minds of the managers is the future plans of species competition. One example of such changes in long-term species composition planning can be seen in Fig. 3.

It shows that the former human induced changes are supposed to be at least partly reversed in the future. The impact of the planned changes will be visible in the overall species composition only after many decades, because the percentage of conifers in existing younger stands is relatively high. The area of young forests in this region is smaller as compared to 'normal' conditions, while the area of forests at an age of approximately 50 years is relatively high as a consequence of extensive clear-cuts at the end of World War II (see Fig. 4). The area covered with conifers in these reforested stands is relatively high and these stands will most likely not be cut prematurely in the near future. A conversion of the coniferous forests on sites which are naturally broad-leaved dominated to more stable, natural forests in foreseeable future seems only

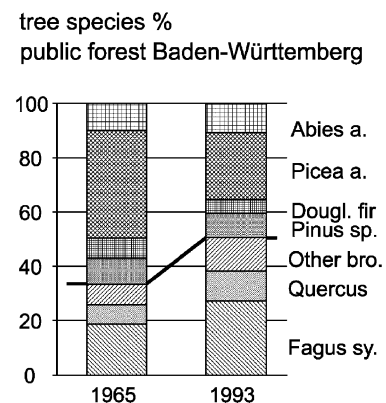


Fig. 3. Long-term planning of future tree species composition in the public forest of Baden-Württemberg in 1965 and 1993. While in 1965 the aim of Norway spruce area was about 40% in 1993 this area has been reduced to about 25% (Riedl 1978; Moosmayer 1993).

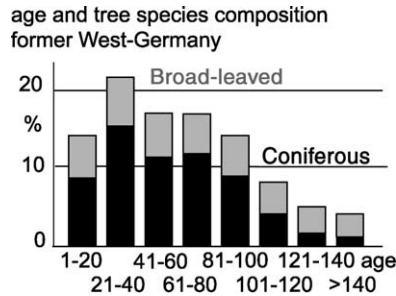


Fig. 4. Age and tree species composition of forests in former West Germany in % area. The area of young forests is smaller as compared to 'normal' conditions while the area of forests between 21 and 40 years (in 1990!) is relatively high as a consequence of extensive clear-cuts at the end of World War II. The relative area covered with conifers in the younger stands is high. In more recent years the conifer area has decreased (BML, 1993).

feasible through active intervention. The percentage of coniferous species, however, would still increase for some time if no active intervention by regeneration, tending, thinning and regeneration fellings would change species composition. Even the active conversion of some of the coniferous forests without cutting premature trees is expected to last longer than one century.

4.3. Changes in tree age composition

The age composition of forests varies considerably with species, site conditions and historic events. Generally the average age of forests in Europe has increased during recent decades. While young forests are underrepresented the area of older forests has increased. In Switzerland this development is especially pronounced. In the former West Germany the area of the youngest age class has decreased in recent years while the area of forests older than 60 years has increased in all age classes. In the public forest of Baden-Württemberg, for example, the area covered with forests older than 80 years has increased in 20 years by 19%. The relatively large area of age class 21–40 relates to the clear cuts at the end of World War II (Fig. 4).

Increasing age and more active thinning led to a change in tree size distribution. While in former times thinning activities in young and medium aged forests provided large amounts of small sized timber these assortments are now getting scarce while the number of large sized trees increases.

The observed changes in age and size of the trees in many parts of the temperate zone in Europe affects the ecological, economic and social services provided by forests. It has an impact on nutrient cycling, the carbon budget as well as on animal and plant habitats.

4.4. Growing stock

According to national forest statistics of several European countries (Kuusela, 1994), the annual drain-thinnings

and final cuttings has remained at the same level during the last few decades, whereas the net annual increment being 40–50% higher than the fellings. Only in exceptional cases have fellings reached the level of net annual increment. Average growing stock in exploitable European forests has increased during the period 1950–2000 from 98 m³ per ha to 143 m³ per ha (Kuusela, 1994; TBFRA, 2000). European wood resources are greater now than at any time during the last 200–300 years.

Today in several countries in central Europe average growing stock exceeds 300 m³ per hectare. In Austria average growing stock per hectare amounts to approximately 250 m³ (FBVA, 1995) and in Switzerland to approximately 330 m³ (Schweizerisches Forstinventar, 1988). Cutting rates have been clearly below growth rates.

Mantel (1952) suggested a sustainable long-term growing stock of approximately 170 m³ per ha for former West German forests. From 1950 up to 1990 average growing stock increased in West Germany from approximately 105 m³ to about 300 m³ per ha (data 1950 rough estimate: Wiebecke, 1955; data 1990: BML, 1993). Even though annual removals increased considerably in the last century, average growing stock has continued to increase. Mantel suggested in 1952 a long-term annual allowable cut of 3.4 m³ per ha. Based on the first national inventory 1986–1990, Polley et al. (1996) suggested a long-term allowable cut of 6.2 m³ per ha. Taking into account annual fellings of approximately 4 m³ per ha and an increase in average growing stock of about 4–5 m³ per ha per year during the last few decades (assuming a rise in average growing stock by 160–200 m³ in 40 years) a growth rate of 8–9 m³ per ha and year has been accomplished. Compared with this estimate the suggestion of Polley et al. (1996) seems to be rather conservative and would presumably result in a further increase in growing stock.

While the average growing stock per ha today amounts to approximately 270 m³ (TBFRA, 2000) in Germany, in the southern states almost 400 m³ has been reached even though annual removals have been higher there than in other parts of Germany. This indicates the high productivity of the forests in this region. Growing stock as well as net annual increment has been systematically underestimated in former decades. This was partly due to conservative forest management planning but also due to unexpected changes in forest productivity.

The increase in the area of conifers in former times contributes to the observed increase in wood volume growth of European forests. The increased average growing stock and the unexpected high growth rate can be explained by several factors which have changed over time: inconsistencies in former inventory methods, changes in forest area, in tree species composition, in age composition, in site productivity and in management intensity (Päivinen et al., 1999).

4.5. Changes in environmental conditions

While natural changes always affected forest ecosystems large scale impacts of human induced environmental changes became more evident in recent decades. Changes in average air temperature, in precipitation, as well as changes in air chemistry, such as elevated CO₂ or changed Ozone concentration, and changes in N deposition. Besides changes of average conditions frequency of extreme events such as storms, droughts and frosts have an especially strong impact on forest ecosystems. These environmental changes have an impact on forest growth behaviour (Spiecker et al., 1996), species composition and ecosystem stability.

5. Impact of recent changes on forest resistance

5.1. Disturbances affecting forests in the temperate zone of Europe

The drastic shift in tree species and age composition, as well as changing site conditions, are changing forest resistance. In the temperate zone of Europe the two most important disturbances causing mortality are storm and snow while drought and frost generally cause less mortality. Furthermore, drought and frost may increase susceptibility to insect attacks. Major outbreaks of insects and fungi are closely related to the occurrence of dead and dying trees. For example, following wind and snow damage, trees are often more susceptible to other storms, and to fungal and insect pests (Schröter et al., 2000). Broken and uprooted trees stimulate insect attacks on the remaining trees because of the increased availability of breeding material (Schroeder and Eidmann, 1993).

5.2. Storm

Storm is one of the major risk factors affecting forests in the temperate zone. Storm risk is highest in stands adjunct to newly clear-felled areas and within newly thinned stands, especially if stands that have not been previously thinned are suddenly thinned heavily. The risk decreases, however, with the time elapsed since thinning. This is the result of the increasing capacity of trees under various site conditions to resist wind due the enhanced growth after thinning and the increase in root mass and strength of roots (Nielsen, 1990). The risk of wind throw and wind breakage damage is thus related to the management and growth of trees.

An increasing tree age and higher standing volume of mature trees reduces the stability of forests. The risk of wind throw and wind breakage increases with the height of the trees. As an example, Fig. 5 shows the mortality due to storm in percent of the allowable cut during the last 45 years in the public forest of the Black Forest region. Norway spruce covers in this region about 50% and silver

salvage cut in % of allowable cut in the public forest of the Black Forest

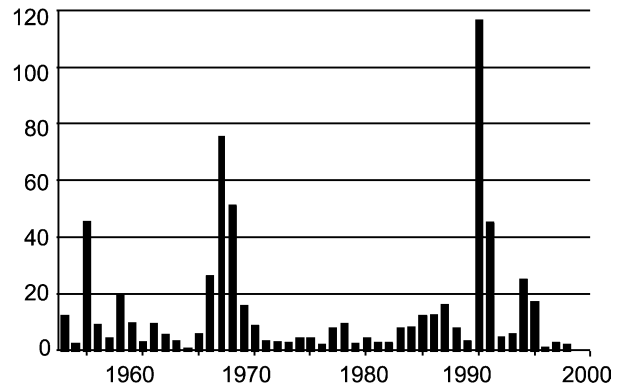


Fig. 5. Salvage cuttings due to storm in public forests in the Black Forest, Germany. The cutting volume is expressed in percent of the allowable cut. The year-to-year variation is high (Landesforstverwaltung Baden-Württemberg, 1953–1998).

fir about 20% of the public forests which have a total size of 240 000 ha (Landesforstverwaltung Baden-Württemberg, 1953–1998). The annual variation of the salvage cuttings is rather high (Fig. 5). Even though there is no clear trend the maximum wind throw seems to have increased through time. One reason for the increased salvage cuttings due to storm in recent years (the high volume of the wind throw in December 1999 is not shown in Fig. 5) may possibly be related to higher wind speed in recent years but also to a higher standing volume per ha and to a higher proportion of old coniferous trees. It is difficult to draw general conclusions from the frequency and severity of these events because they seldom occur, the observation period is relatively short and the local wind speed is not known. The visible increase in salvage cut volume can however be explained by the increase in standing volume during the observation period. The large salvage cut volume in the temperate zone of Europe results in irregular harvesting procedures with increased costs and disturbed timber markets with imbalances between the supply and demand of timber.

In the future, risk of storm-induced mortality may increase as trees continue to age throughout Europe. Also wide spread selective cuttings may lead to sudden openings of the canopy and therefore on sites generally susceptible to wind throw may increase storm-induced mortality. Finally possible changes in occurrence of extreme windspeeds along with climate changes may affect storm risk (Thomasius, 1988; König, 1995).

5.3. Snow and ice

A higher stand density generally destabilizes individual trees. Their crowns are shorter and the height/diameter ratio is larger. These types of trees are more susceptible to snow and ice breakage, in particular, in pole-sized stands. In these

stands branches of neighbouring trees grow into each other and lead to a closed canopy, which does not allow the snow to pass through between the crowns. In dense stands heavy loads of snow may lead to simultaneous breakage of larger groups of trees. Long crowns may also break because of heavy snow fall in their upper part, the trees however will recover with less severe impacts on their vitality (Thomasius, 1988).

5.4. Frost

Tree response to climatic influences varies with species, provenance, competition status and site conditions. Changes in average climatic conditions, such as air temperature, affects the length of the growing season and influences site productivity (Fabian and Menzel, 1999). A positive correlation between air temperature increase and plant growth seems likely in the boreal and temperate climate zone. Extreme and unusual events, such as late spring frosts, unusual cold and wet or hot and dry summers, as well as extreme and abrupt temperature changes, may reduce growth and increase mortality. Extreme climatic events not only have a direct effect on trees, but also on insects or microbial pathogens, and on biological as well as chemical and physical processes in the soil. In the temperate zone, the timing of spring budburst of many species is dependent on both high temperatures in spring and the sequence and duration of low chilling temperatures during winter. Minimum winter temperature can be critical for the survival of some species with low maximum winter frost hardiness, for example silver fir (*Abies alba* Mill.) and beech (*Fagus sylvatica* L.). The increase of winter temperatures may broaden the potential distribution range of such species in Europe, but may, however, also increase the risk of late frost damage.

5.5. Drought, insects and fungi

Effects of droughts on forest health have until recently been underestimated. In the temperate zone of Europe a growth recession due to drought occurred, for example, in the late 1940s. Another severe drought that attracted high attention occurred in the mid 1970s at the beginning of the discussion on defoliation and forest dieback. The long-lasting after-effects of such extreme events complicate the detection of possible effects of droughts. The impacts of drought may be reduced through wider spacing in plantations and more intensive thinnings. Climate changes as a result of the enhanced '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 functioning of ecosystems and decrease biodiversity. Climate changes affect the competition between tree species. This may lead to major

disturbances in natural as well as in managed ecosystems. Also, nutrient cycling will be largely affected by climate changes.

Trends in forest productivity are generally associated with climatic variation, particularly with variation in precipitation. High air temperature associated with low precipitation during the growing season reduced growth even at higher altitudes of the Black Forest where average precipitation is high and average temperature is relatively low (Kahle and Spiecker, 1996). High summer temperature and associated drought increase the growth of insect populations through accelerating their turnover. A decreasing growth rate therefore is associated with increased tree mortality (Fig. 6). Suppressed trees in dense stands are especially susceptible to drought (Spiecker, 1986, 1995b). As compared to salvage cuttings due to storm and snow the volume of desiccated trees and trees killed by insects is generally rather low. It has been shown that growth rates and mortality are closely related to climatic fluctuation, and especially to drought conditions, as for example, in the 1940s, the 1970s or the 1990s.

There are indications that in some regions in the temperate zone of Europe Norway spruce is showing an increased sensitivity to climate variation (Kahle, 1994). Changes in the frequency and intensity of extreme warm and dry climatic conditions during the last few decades and the effects of increased atmospheric depositions have been discussed as possible causes for this observation. The shift in the tree species composition may have changed the balance between host species and populations of phytophagous organisms.

5.6. Nutrient availability and soil chemistry

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 coniferous than in broad-leaved stands and coniferous litter is in general less hospitable for

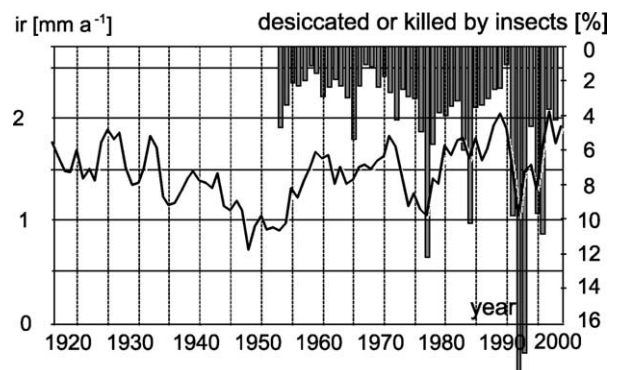


Fig. 6. Salvage cuttings of desiccated trees and trees killed by fungi and insects in % of allowable cut (bars) in public forests and annual variation of radial growth (ir: solid line) of Norway spruce (*Picea abies* L.) in the Black Forest region, Germany. Annual radial increment of 45 Norway spruce trees and mortality are correlated.

decomposers (Mitchell and Kirby, 1989). However, the changes resulting from forest management, for example, from site preparation, fertilization, thinning and felling, are probably larger than those caused by tree species. Liljelund et al. (1986) showed in a literature review that a replacement of deciduous forests by coniferous induces a soil acidification and that new coniferous plantations on formerly open land have similar effects. Remarkable loss of nitrogen from the ecosystem have been noticed through the change of deciduous tree species to Norway spruce in Germany (Kreutzer, 1981; Feger, 1993).

As a consequence of higher forest productivity intensified harvesting, including removal of forest biomass, may potentially affect site productivity. Traditional timber harvesting is not considered to lead to the impoverishment of the 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 removal of slash except needles. According to Kreutzer (1979) the nutrient losses by intensive whole-tree utilization are similar to that of litter utilization and may affect the production conditions on poor sites. Increased N deposition stimulates growth and enhances humus decomposition. If NH_4 becomes the main source of N supply accelerated rhizosphere acidification results from NH_4 consumption (Evers and Hüttl, 1990–1991).

In the temperate zone of Europe, the forested areas are the main source of the ground water. Water for human use from forested areas is generally preferred to water from agricultural land because of its quality. Forests absorb precipitation and reduce the risk of floods. In the mountainous areas, forest cover reduces the risk of erosion, landslide or avalanches. Forests sequester CO_2 and wood-based products store CO_2 over longer periods.

6. Discussion

Today, in various European countries there exist on large areas numerous nonsite-adapted homogenous coniferous forests. In order to reduce the resulting risks a conversion of some of these forests to near-natural, site-adapted and often mixed forests has to be considered. The conversion process affects almost all activities in forestry including forest management, timber markets and forest policy. For planning a conversion, information about the technical alternatives of conversion and their ecological and economic impacts is needed on stand, landscape and regional level. The development and evaluation of strategies of the conversion of secondary pure coniferous forests to near-natural mixed forests and the assessment of its ecological and socio-economic impacts during and after the conversion is a research task in several European countries. Impacts are expected in the fields of forest ecology, silviculture, forest

growth, forest nutrition, biodiversity, roundwood production, wood quality, timber market, forest economics, forest planning and operations, employment and others, making clear that forest conversion is not only of practical relevance but also of political interest.

New planning and decision tools have to be applied to encompass uncertainty and risk in long-term forest planning. Traditional anticipation of goals and means may not be adequate to scope with risk and uncertainty. Adaptive planning on the other hand may lead to inefficient management. Flexible planning which takes into account all conceivable scenarios and allows various options for future development may be best suited. Forests should be adaptive for future demands of society, have multiple function ability and potential for multiple use. The amount and complexity of the scientific problems evolving from the observed situation show that solutions can only be developed by a multi-disciplinary cooperation of scientists and decision makers at an international level. This cooperation will lead to a more comprehensive understanding and will provide a more realistic and reliable information basis for decision support.

In the given situation, a conversion to stable, more natural, forests is only possible through active forest management. This includes the necessity to cut trees. Without intervention, forest health will decline (Spiecker, 1995a). Tending of young stands is aimed at creating a mixed stand structure. Growth of young stands may be strongly influenced by soil preparation, selection of species and provenances, quality of plant material and weed control. 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. An adjusted management regime is also required to counterbalance accelerating growth rates, otherwise the increase in average growing stock will continue and the stability of forests will be reduced.

Mixed stand structures can be maintained and improved by thinning. Thinning practices result in an increased total harvest. Thinning in particular increases the proportion of large-sized timber in total harvest volume. Intensified thinning may have some effect on site productivity by altering nutrient cycling and reducing competition for light, nutrients and water. In some areas of the temperate zone coppice and coppice with standards have a long tradition and will be of some importance in the future, as, for example, on various sites in France. These forests show high biological diversity by supporting light-demanding species. 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 or acid rain.

It is recommended to reserve parts of the forests for different kinds of conservation purposes. In addition to these special protected areas, where any forestry activity is prohibited, there exist small ecological valuable biotopes

within managed forests also worthy of protection. Forest management needs to consider explicitly diversity also on the landscape and regional level. Forest fragmentation in some areas needs to be reduced through afforestation and through establishing connections like ecological corridors between forests.

As site conditions, ownership and cultural, economic and social conditions vary at short distances in temperate forests of Europe, site adapted management will enhance diversity.

Variation in tree age and dimension, in forest density, and in species composition will help to increase diversity. New concepts have been developed in most of the countries in the temperate zone to enhance diversity through naturalistic forest management. Mixed forests with a high percentage of broadleaved species are favoured. Natural regeneration in small gaps are generally recommended, large scale clear cuts and planting of pure coniferous forests should be avoided. The preference of natural regeneration in management may increase genetic diversity when genetic characteristics of the seed are site adapted. Genetic diversity may improve the potential of forests to adapt to climate changes.

Wider initial spacing, more intensive thinnings and shorter production cycles, preference of drought tolerance species and provenances will increase drought tolerance. In many cases continuous cover forestry is favoured. The introduction of neophytes in some forests substantially reduces biodiversity and therefore the population dynamics of these neophytes need to be controlled. Cavity trees, dead biomass and decaying biomass are left in the forests. However, aging of trees in various parts of the temperate zone has reduced the space for light demanding and pioneer species and favoured climax species. Dense coniferous stands offer less space for light-demanding tree species and ground vegetation to exist and therefore biodiversity will be reduced (Mitchell and Kirby, 1989).

Sustainable forest ecosystem management aims to provide income to the forest sector, to provide renewable raw material for wood industry and to provide goods and services for the people. It is assumed that management towards higher diversity may increase stability of forest ecosystems, may reduce management risks, and may extend multifunctionality of forests, and means that ecosystem response is more predictable and less variable (Leemans, 2001). Mixed stands have been found to be more resistant against various forms of damage, more diverse in their fauna and flora composition than pure, single-species stands. Tree species composition changes the conditions for growth by affecting the root systems, litter quality, nutrient and carbon storage and soil acidity.

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