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Converting Norway spruce stands with beech – a review of arguments and techniques

Zum Umbau von Fichtenbeständen mit Buche: Ein Überblick über Argumente und Verfahren

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Keywords: Picea abies, *Fagus sylvatica*, mixture, climate change

Schlagworte: Picea abies, *Fagus sylvatica*, Mischung, Klimawandel

Summary

After 25 years of introducing beech into pure Norway spruce forests some foresters, economists, but also forest scientists are concerned about the increasing proportion of beech. We therefore reviewed the existing literature on the ecological and economic consequences of an enrichment of Norway spruce stands by beech. From this review it can be concluded that, though generalisations are difficult, beech improves soil properties, biodiversity, and

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productivity of pure spruce forests in many cases. Moreover, recent financial considerations revealed new and tangible arguments for the replacement of pure stands of Norway spruce by mixtures of Norway spruce and beech. In addition, introducing beech or other broadleaved species into Norway spruce stands is strongly recommended because of the high vulnerability of the latter species against climate change.

In the second section of the paper we refer to silvicultural strategies for the conversion of Norway spruce stands and discuss the relevant techniques, planting and direct seeding. Factors which may affect the success of planting and direct seeding of beech are summarised.

We conclude that converting pure spruce stands into mixed ones by the introduction of broadleaved tree species such as beech is still a sound option and that there are cost effective methods to realize this. However, the decision in favour of a substantial percentage of beech should not be hampered by the demand of conservationists to ban forestry from beech forests by arguing that these forests represent the natural vegetation type in Central Europe.

Zusammenfassung

Nach nunmehr rund 25 Jahren des Umbaus von Fichtenreinbeständen in Mischbestände, vor allem mittels der Vorausverjüngung von Buchen, wird vereinzelt eine weitere Zunahme des Buchenanteils sowohl aus ökologischer Sicht, insbesondere mit Blick auf den Klimawandel, vor allem aber aus ökonomischer Sicht in Frage gestellt. Vor diesem Hintergrund versucht der vorliegende Beitrag eine Bestandsaufnahme der von einer Beteiligung der Buche an Fichtenbeständen ausgehenden ökologischen Wirkungen und ihrer ökonomischen Konsequenzen.

Im Ergebnis zeigt sich hierbei, dass die Beteiligung der Buche zu einer Verbesserung der Bodenfruchtbarkeit sowie einer Erhöhung der Artenvielfalt und der Produktivität führen kann. Es wird jedoch auch deutlich, dass Verallgemeinerungen zu den ökologischen Auswirkungen von eingebrachten Buchen in Bestände mit führender Fichte schwierig sind. Im Gegensatz dazu lassen die Ergebnisse neuer ökonomischer Analysen den eindeutigen Schluss zu, dass Mischbestände aus Fichte und Buche aus finanzieller Sicht erfolgsversprechender sind als Fichtenreinbestände. Dies gilt im Hinblick auf den aktuellen Klimawandel in besonderer Weise, da die ohnehin große Anfälligkeit der Fichte gegenüber biotischen und abiotischen Schadfaktoren im Zuge des Klimawandels vermutlich zunehmen wird.

In zweiten Teil des Betrages werden waldbauliche Strategien für den Umbau von Fichtenreinbeständen in Fichten-Buchen-Mischbestände und die entsprechenden Techniken dafür, namentlich die Pflanzung und die Saat, diskutiert und die Faktoren, die den Erfolg dieser Techniken beeinflussen, in einer Übersicht zusammengestellt.

Insgesamt betrachtet erscheint der Ersatz von Fichtenreinbeständen durch Fichten-Buchen-Mischbestände auch weiterhin als eine ökologisch wie ökonomisch sinnvolle Maßnahme. Kostengünstige Möglichkeiten zu ihrer Realisierung sind vorhanden. Die Entscheidung von Waldbesitzern für eine substanzielle Beteiligung der Buche sollte unserer Auffassung nach allerdings nicht durch Bestrebungen konterkariert werden, Buchenwälder als natürliche Waldformation Mitteleuropas grundsätzlich unter Schutz zu stellen.

1. Introduction

During the last 25 years the introduction of European beech into pure coniferous secondary forests, mainly Norway spruce (*Picea abies* (L.) Karst.), has been one of the major objectives in many forest management units throughout Central Europe (von Lüpke et al. 2004). Particularly in public forests the conversion of pure Norway spruce forests into mixed stands with a considerable amount of beech was promoted (Knoke et al. 2008). As a consequence, in Germany (the Federal Republic before the reunion in 1990) for example the area of Norway spruce stands decreased between the first (1987) and the second (2002) Federal Forest Inventory by 218,658 ha whereas the area of beech increased by 150,866 ha (Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz 2004). However, after 25 years of introducing beech there are ecological and economic concerns about the increasing proportion of beech (Rennenberg et al. 2004, Möhring 2004, Spellmann 2005, Geßler et al. 2007). Some forest scientists (e. g. Spiecker and von Teuffel, pers. communication) are even afraid of an "invasion of beech" and question the future promotion of beech on the expense of spruce.

Against this background we briefly (i) review some well known ecological and some recently derived economic arguments for the introduction of beech into spruce. Focusing on climate change we then present some new arguments for the further enrichment of pure spruce stands with beech or other broadleaved tree species. The second part (ii) of our overview will give a short review of silvilcultural strategies and appropriate silvicultural techniques for the introduction of beech.

2. Arguments for the introduction of beech into pure Norway spruce stands

2.1 Ecology

2.1.1 Soil properties

In contrast to monocultures mixtures are thought to increase ecosystem productivity but also to improve soil functioning if species exploit nutrients at different times of the season or depths in the soil or if the mixtures increase rates of nutrient recycling (Rothe and Binkley 2001). In fact, there are many studies indicating beneficial effects of admixed broadleaved species to nutrient concentrations in the forest floor or reduced N leaching as nitrate to the groundwater. For example Heitz (1998) found that, depending on the supply with base cations in the subsoil, an admixture of especially European ash (*Fraxinus excelsior L.*) and Sycamore maple (*Acer pseudoplatanus L.*) but in some cases also of European beech (*Fagus sylvatica L.*) substantially increased the amount of exchangeable cations in the topsoil of Norway spruce stands. In addition, the N-export in the seepage water was significantly lower under the mixed species-stands due to a reduced N deposition of the broadleaves and a higher N-fixation in the topsoil (Heitz, 1998). The concentrations of nitrate in seepage water in spruce dominated forests are twice as high as in broadleaved forests (Rothe 2005). Therefore, in sensitive areas like ground water protection zones, forests with a substantial share of broadleaves are strongly recommended (Rothe 2005). However, Rothe and Binkley (2001) argued that empirical studies on nutrition and nutrient cycling of mixed-species stands allow few generalizations about the influence of tree-species in mixtures as systematic studies of particular mixtures across gradients in soil types are rare (Knoke et al. 2007). Actually different patterns of soil nutrient pools, nutrient availability and litter quality of mixed-species stands and monocultures as described for instance by Wittich (1939), Morgan et al. (1992), Heitz (1998), Brandtberg et al. (2000), Berger et al. (2002), Prietzel (2004) and Prescott and Vesterdal (2005) and interactions between forest stand type, litter quality, environmental factors and soil nutrient status, which vary from site to site, complicate generalisations (Rehfuess 1990). Moreover, the evaluation whether beech introduced into spruce stands positively influences the foliar nutrient status of spruce or improves the soil nutrient status and/or soil hydrological properties strongly depends on many different factors such as site quality, stand management and stand age (Binkley and Valentine 1991, Binkley 1992, Prescott et al. 2003, Rothe and Mellert 2004, Binkley and Menyailo 2005, Jansen et al. 2005, Jones et al. 2005, Bens et al. 2007). Finally the effect of any mixture depends on the type of mixture (single tree mixture, mixture of groups, group size) and the time between the introduction of a species and the evaluation of its impact. Although we are therefore aware that simplifications such as "soils beneath converted former spruce stands generally show a better supply with nutrients than soils beneath pure spruce stands" are not appropriate for forest ecosystems, it can be stated that at least native tree species will basically not degrade soils (Zechmeister-Boltenstern et al. 2005). Hence, an admixture of beech is supposed to have a positive effect on soil properties particularly on sites where Norway spruce in contrast to beech does not belong to the potential tree species composition without an interference of men. In fact, the idea to alter soil properties by introducing beech into pure Norway spruce stands is one of the main reasons for the recent conversion initiative throughout Europe (Fritz 2006).

2.1.2 Biodiversity

Generally, biodiversity (α-diversity according to Jost 2006 and 2007) is supposed to be higher in mixed-species stands because they provide more different habitats, i.e. food resources, foraging niches, nest sites etc. (Smith 1992, Zerbe and Kempa 2005). Several faunal studies comparing pure spruce stands with converted spruce stands confirmed this assumption (Engel and Ammer 2001, Elmer et al. 2004). However, in line with the remarks on the effect of admixed beech on soil properties, generalisations on its effect on biodiversity are difficult. Different components of biodiversity can have different effects on ecosystem properties, ecosystem goods, and ecosystem services and thus ecosystem functioning (Hooper et al. 2005). Moreover, the term biodiversity itself is elusive. It is often neglected that biodiversity does not only mean counting species and individuals but requires also an evaluation of the genetic and habitat diversity (Hooper et al. 2005, Walentowski et al. 2005, Carnus et al. 2006). It is therefore not appropriate to compare the results of inventories on species numbers and the abundance of selected genera in different stand types and to assess subsequently e. g. their conservational value from the respective counts (Müller 2005a). On the contrary, the assessment of biodiversity requires a qualitative component (Walentowski et al. 2005). Hence, a stand type with a low number of species should not principally be classified as negative, if autochthonous, endemic, endangered or threatened species occur. Therefore, from a nature conservationist's point of view, the presence of native species such as European beech which is supposedly an important element of the natural forest community at a given site, may be more important than artificial stands which are diverse but far from natural.

Effects of mixed-species stands on biodiversity are often superimposed by the impacts of structure and hence stand management (Carnus et al.

2006). Thus, the response e. g. of songbirds and ground living-spiders may be more influenced by stand structure than by mixture (Junker et al. 2000, Müller, 2005 b). Another example is the finding that the floral species composition on the forest floor at a given site is primarily controlled by the amount of light penetrating the canopy and thus stand density rather than the overstorey tree species composition (Mosandl and El Kateb 1988, Simmons and Buckley 1992, Ammer 1996, Halpern et al. 1999). In addition to stand structure, soil type is an important factor modifying the impact of introduced beech on biodiversity. For example, the stimulating effect of an improved litter quality by beech on Lumbricids depends strongly on the soil chemistry and hence the geological parent material (Ammer et al. 2006). Thus the effect of an identical mixture of beech on soil fauna may vary widely depending on soil type. Generalizations are also restricted by the fact that the effect of mixtures vary with the species or group of species considered (Brown 1992, Scheu et al. 2003). Even within a specific group of animals (e. g. soil fauna) different responses occur. Scheu et al. (2003) found that mixed-species stands of Norway spruce and European beech were more similar to pure spruce stands with respect to the animal decomposer community, but predator soil invertebrates appeared to be more alike to that in mature beech stands.

In conclusion it can be stated that we still know very little of the effects of beech introduced into Norway spruce stands on biodiversity. As Smith (1992) pointed out, most studies, although well designed, have been, and will continue to be, forced to make use of whatever stands are available. Moreover, we know almost nothing about the ideal admixture of beech. For example, the diversity of fungi already increases if single but dominant beech trees are mixed into pure Norway spruce stands, whereas snails require at least groups of broadleaved trees of about 1000 m^2 in size which, however, is not enough for a significant increase of bird biodiversity (Utschick 2001). When mixing tree species rather large blocks should be used to establish the admixed, native tree species to address the issue of bird biodiversity. In contrast to the finding of Utschick (2001), Smith (1992) suggested that the maximum impact of broadleaves on birds in conifer stands is given when they are dispersed throughout the forest rather than in large groups. The contrasting conclusions of Smith (1992) and Utschick (2001) illustrate how little is known in this field. However, in accordance with other authors (Young 1992, Walentowski et al. 2005) we assume that a very fruitful way to enrich pure Norway spruce stands with respect to biodiversity is to consider native tree species such as European beech established in rather large units, which will be followed by their associated flora and fauna. Von Lüpke et al. (2004) refer on units of at least group size which means > 0.1 ha.

2.1.3. Productivity

A thorough investigation of the biomass (dry mass) production of mixed-species forest stands was recently published by Pretzsch (2003, 2005). By analysing a network of permanent experimental plots observed over more than 100 years he derived some fundamentals on the relationship between diversity and productivity in temperate forests. Older studies already showed the existence of basically three types of interaction in mixed-species forests: mutual "cooperation", "compensation", and mutual "inhibitation" (Brown 1992). Pretzsch (2005) distinguished the same growth interactions (unfavourable mixture effects, neutral effects and beneficial mixture reactions).

The most important finding of Pretzsch's analysis was that the productivity of mixed species stands of beech and spruce compared to that of pure stands of both species strongly depends on the site quality and the silvicultural treatment. According to Légaré et al. (2004) the proportions of the different species play an important role as well.

The productivity of mixed-species stands compared to that of pure stands is strongly affected by disturbances irrelevant whether caused naturally or by silviculture (Vilà et al. 2005). As Pretzsch (2003, 2005) showed, the yield of mixed-species stands is much less decreased by a reduction of stand density than that of monocultures. A more efficient space sequestration due to differences in crown morphology (see Bravo et al. 2001) enables mixed spruce- beech stands to compensate for the removal of trees more efficiently then pure spruce stands. Thus mixtures of Norway spruce and European beech showed no significant reduction in biomass production compared to the maximum biomass production of a pure Norway spruce stand (Pretzsch 2003, 2005). In conclusion Knoke et al. (2007) stated "that there is a specific potential for a higher yield of mixed-species stands when compared to monocultures particularly in the case of managed or disturbed forests, where species have complementary use of resources".

Summarising the short review on the ecological effects of introducing European beech into pure Norway spruce stands, it can be concluded that, though generalisations are difficult, beech improves soil properties, biodiversity and productivity of the former pure spruce forest in many cases. On suitable sites there are therefore cogent ecological reasons for the conversion of pure Norway spruce stands into mixed stands with a considerable portion of European beech. Of course this is true for other broadleaved species as well.

2.2 Economy

As Knoke et al. (2008) pointed out, in the past comparisons between the financial return of pure Norway spruce and pure European beech stands were done on a very simplified basis. Thus neither risks nor risk correlations, price fluctuations, risk preferences of decision-makers and interactions between the two species in mixed stands which were found to influence stability (e. g. König 1996) and productivity (see above) had been considered in those examinations (Knoke et al. 2008). Using the theory of portfolio selection Knoke et al. (2005, 2008) could demonstrate that just the integration of three of the above mentioned aspects (risk, risk correlation, and risk preferences by the decision-makers) influences the economically optimal admixture of spruce and beech. In fact, on a forest enterprise level a percentage of 10 to 50 % of beech resulted in an economic advantage (Knoke et al. 2005, 2008). For a woodland owner it is therefore economically reasonable to have both Norway spruce and beech. This does not necessarily result in mixed stands. However, Knoke (2007) could recently show that mixing spruce and beech on a stand leads to a further improved financial return although a reduction of beech timber quality was assumed. This effect was made up for by the positive effect ob beech on Norway spruce stability. Consequently it is evident that the introduction of beech into Norway spruce is not only justified by expected or proven ecological benefits. On the contrary, particularly financial considerations revealed new and tangible arguments for the replacement of pure stands of Norway spruce by mixtures of Norway spruce and beech.

2.3 Climate change

It is evident that climate change is not only a future threat but is already happening (Trenberth et al. 2007, Kölling and Walther 2007). In fact, compared with the period between 1960 and 1990 the mean annual temperature in Central Europe has increased by more than 0.5° C in the last decade (Trenberth et al. 2007). In Germany, a further increase of at least 2 bis 2.5° C and a decrease in precipitation during the vegetation period of around 10 to 25 % is projected (Spekat et al. 2007). This results in substantially changed growing conditions. As climate is a major determinant for the phenology, physiology, distribution and interaction of plants (Walther 2003) this change will affect tree species composition and forest functioning (Saxe et al. 2001). The question is whether the climate change reaches the ecological thresholds of specific species. According to Groffmann et al. (2006), an ecological threshold is reached, when a small change in a driver causes a marked change in ecosystem conditions. This may affect the maintenance of a particular species (Groffmann et al. 2006).

It is well known that Norway spruce is a boreal and mountainous species which is very well adapted to low temperatures. Besides temperature, annual precipitation is crucial for its natural range. The importance of these two factors for the distribution of Norway spruce (expected under natural conditions without the impact of men) is illustrated in Figure 1. Thus the natural range of spruce is reflected by its so called bioclimate envelope, which is determined by the mean annual temperature and the mean annual precipitation resulting in a two-dimensional description of the range of a species (Kölling et al. 2007, Kölling and Zimmermann 2007). Figure 1 shows the natural range of spruce as a function of mean annual temperature and mean annual precipitation. Note that the graph represents only 95 % of all records. Thus 5 % of all cases where Norway spruce could be found under natural conditions (i.e. without impact of men) were eliminated in order to exclude artefacts or unreasonable records. Though spruce has been and is still cultivated on large areas outside this envelope, it can be maintained there only by silvicultural interventions which control interspecific competition and pests. However, it is expected that elevated temperatures (not only in summer but also in winter, see Saxe et al. 2001) and increasing frequency of drought events will increase the vulnerability of Norway spruce against parasitic insects such as bark beetles and therefore restrict the areas suitable for its further cultivation (Thomasius 1991, Irrgang 2002, Lexer et al. 2002, Pretzsch and Durský 2002, Kölling et al. 2007, Lexer and Seidl 2007, Profft et al. 2007). In fact in some already relatively dry and warm regions of Bavaria Norway spruce has been nearly eliminated by bark beetles (Ammer et al. 2006).

In contrast to spruce European beech is hardly threatened by herbivore insects (Schmidt 1991). Moreover it is known to have a more sophisticated rooting system than Norway spruce (Bolte and Villanueva 2006, Fleischer et al. 2006) with less belowground intraspecific competition (Fleischer et al. 2006). Besides European beech tolerates higher temperatures than Norway spruce (Figure 1). For example Felbermeier (1994) and Czajkowski et al. (2006) pointed out that the present north-eastern border of European beech does not mark its potential area. Actually it is very likely that adapted beech provenances would have occupied dry and poor sites as well, if silvicultural interventions in the past had not restricted its dispersion. In contrast to Rennenberg et al. (2004) and Geßler et al. (2007) many authors therefore do believe that beech is less affected by climate change than spruce (Felbermeier 1994, Pretzsch and Durský 2002, Lexer et al. 2002, Ammer et al. 2005, Kölling et al. 2007, Profft et al. 2007). In fact beech responded much less to the severe drought in 2003 than spruce. In Figure 2 the growth responses of a Norway spruce stand and an adjacent European beech stand in southern Bavaria (near Schongau, E 10°47'46", N 47°52'44") before and after 2003 are given. It is evident that the spruce stand suffered from the drought not only in 2003 but also in the following years, whereas the increment in the basal area of beech was hardly affected at all. The high vitality of dominant beech in the extremely dry year 2003 was documented by Kohler et al. (2006) as well.

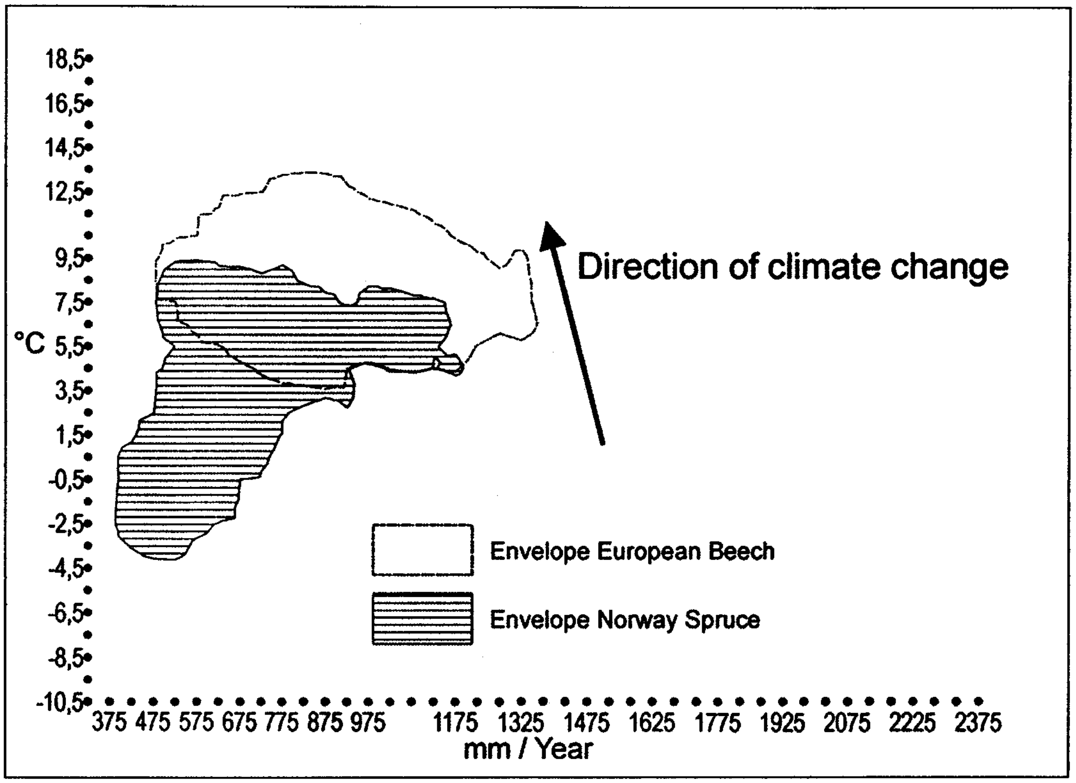

Figure 1: Bioclimate envelope of Norway spruce and European beech. The figure was created using information on the climate and the natural range of European beech and Norway spruce in Europe (for details see Huntley et al. 1995, Kölling et al. 2007, Kölling and Zimmermann 2007).

Abbildung 1: Klimahüllen für Fichte und Buche. Für die Abbildung wurden Klimadaten aus Europa und Daten zur potentiellen natürlichen Verbreitung von Fichte und Buche zusammengeführt (Details hierzu finden sich in Huntley et al. 1995, Kölling et al. 2007, Kölling und Zimmermann 2007).

In conclusion it can be stated that the conversion of pure Norway spruce stands into mixed stands with a substantial proportion of beech or other more drought tolerant broadleaved tree species makes sense not only because of the ecological and economical reasons mentioned in the previous section. This is the inevitable conclusion from the high vulnerability of Norway spruce against climate change.

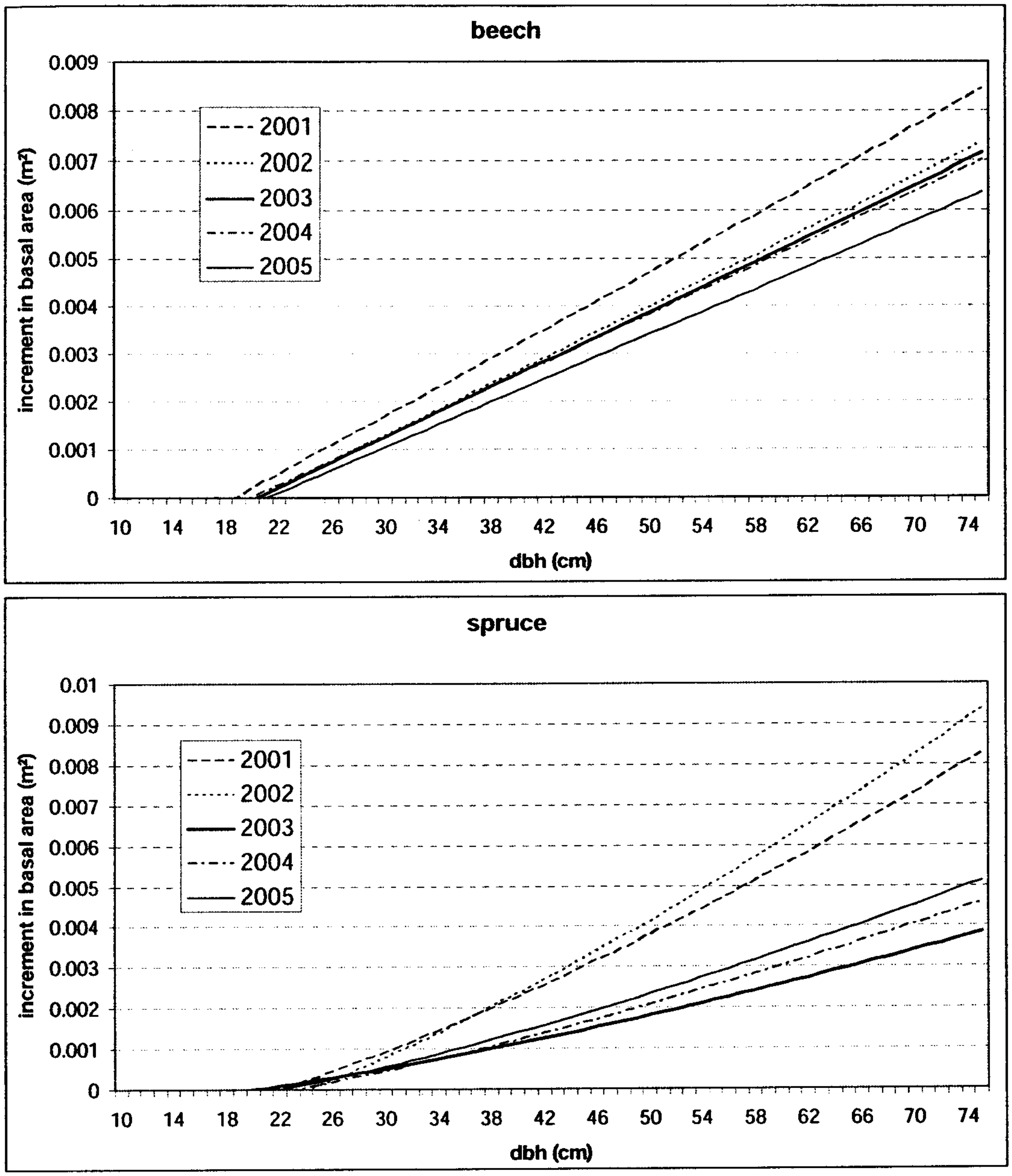

Figure 2: Annual basal increment of beech and spruce in relation to dbh in two adjacent stands in Southern Bavaria from 2001 to 2005 (regression equations not shown; r^2 varied for beech (N=77) from 0.69 (year 2004) to 0.84 (year 2005); r^2 for spruce (N=68) varied from 0.70 (year 2005) to 0.82 (year 2002).

Abbildung 2: Jährlicher Grundflächenzuwachs von Buchen und Fichten in Abhängigkeit des BHD in zwei benachbarten Beständen in Südbayern zwischen 2001 und 2005 (die betreffenden Regressionsgleichungen sind nicht eigens angegeben, die Bestimmtheitsmaße schwankten für Buche (N=77) zwischen 0,69 (im Jahr 2004) und 0,84 (im Jahr 2005), für Fichte (N=68) zwischen 0,70 (im Jahr 2005) und 0,82 (im Jahr 2002).

3. Techniques for the introduction of beech into pure Norway spruce stands

3.1 Silvicultural strategies

In general silvicultural strategies in the context of conversion can be grouped into three types (von Lüpke et al. 2004). These are (i) plain conversion, (ii) conversion under a continuous cover scheme, and (iii) conversion focusing on structural change (von Lüpke et al. 2004). Whereas plain conversion focuses on a rapid change to mixed stands by clear cutting and subsequent planting, conversion under a continuous cover scheme requires the underplanting or undersowing of beech or other broadleaved species beneath the mature Norway spruce stand. The final harvest of the spruces can be done by many different cutting methods such as strip and patch cuttings, shelterwood, group selection and target diameter cuttings (von Lüpke et al. 2004, Röhrig et al. 2006). The appropriate method depends on the specific site conditions, tree species composition within the regeneration and intra- as well as interspecific competition. Conversion efforts which focus on structural change rather than on mixture effects (type iii) do not necessarily need an enrichment of a given Norway spruce stand by an additional (broadleaved) species. In fact such activities try to improve the stability of spruce by increasing its vertical structure through permanent regeneration and single tree selection cuttings (Röhrig et al. 2006).

3.2 Silvicultural techniques

Despite the fact that beech is easy to regenerate naturally, this possibility does not exist in very many cases as there are no mother trees present. Artificial regeneration methods i. e. planting or direct seeding are therefore often required. Whereas direct seeding was the dominating regeneration technique up to the middle of the 19th century (Diezel 1854, Müller 1857, 1858, Seidensticker 1863), planting, mainly wildlings or stock type 2/0 (two year old seedlings which have grown for two years in the seed bed and have not been transferred to a transplant bed) bare root seedlings, is the most common method at present. However, direct seeding of beech has recently been advocated for conversion purposes for several reasons (Gommel 1994, Baumhauer 1996, Leder and Wagner 1996, Küßner and Wickel 1998, Städtler and Melles 1999, Ammer et al. 2002). Firstly, if it is successful, it is cheaper than planting (Nörr 2004, Ammer and El Kateb 2007). Secondly, it avoids root deformations which have been proven to be the result of many inappropriate plantings (Nörr 2003). However, some uncertainties are inherent to direct seeding, such as predation by mice and birds (Willoughby et al. 2004, Madsen and Löf 2005). Moreover, successful direct seeding

Table 1: Factors affecting the success of planting and direct seeding with special consideration of European beech.

Tabelle 1: Zusammenstellung der für den Erfolg von Pflanzungen und Saaten relevanten Faktoren unter besonderer Berücksichtigung der Buche.

Method	Factor	Importance	Author
Planting	Vitality	Predetermines mortality and early growth	McKay (1997), Mattsson (1997), McKay et al. (1999), O'Reilly et al. (2002)
	Pre planting desiccation	Irreversible damages leading to mortality and/or reduced growth	Hartig and Rothe (2005)
	Root/shoot-relationship	Ability of the roots to provide the shoot with water and nutrients	Burschel and Stimm (1993), Rose and Haase (2005)
	Quality of planting	Predetermines mortality and root development	Dahmer (1998), Nörr (2003)
Direct seeding	Germinative capacity of the seeds	Predetermines possible seedling number	Leder (1998), Nörr (2004)
	Professional preparation of the seeds	Seed dormancy has to be broken, growth of radicle should be imminent	Leder (1998), Nörr (2004)
	Rapid delivery and placement	Germination in the field is negatively correlated with the time needed for seed delivery and placement	Ammer et al. (2002), Leder et al. (2003), Nörr (2004),
	Access to the mineral soil, sowing depth	Facilitates the survival in drought periods and is thought to hamper mice and birds from locating seeds; sowing depth should be between 2 and 5 cm	Gommel (1994), Städtler and Melles (1999), Ammer et al. (2002), Leder et al. (2003), Nörr (2004), Madsen and Löf (2005)
	Soil temperature	Should be below 15° otherwise secondary seed dormancy could occur	Leder (1998), Leder et al. (2003)
	Timing	Most studies reported more successful direct seedings in late spring (May)	Gommel (1994), Leder et al. (2003), Nörr (2004), Madsen and Löf (2005)
	Predators and diseases	Predation by animals or diseases can reduce or defeat the amount of germinated seeds and seedlings	Nörr (2004), Willoughby et al. (2004), Löf et al. (2004), Madsen and Löf (2005)
Planting and direct seeding	Resource competition	Germination and early growth is affected by competition for water caused by weeds or canopy trees	Burschel and Schmaltz (1965), Ammer et al. (2002), Coll et al. (2003), Coll et al. 2004, Löf et al. (2004), Löf and Welander (2004), Willoughby et al. (2004), Löf et al. (2005)

requires skilled managers and workers as a careful preparation of the seeds and their immediate delivery and placement in the field are crucial for the success (Nörr 2004). In addition, direct seeding should not be carried out in stands where highly competitive weeds or shrubs such as bramble (Rubus fruticosus) are already established and compete for resources. These aspects have often been neglected by foresters. As a consequence, direct seeding has often yielded unsatisfactory results (e. g. Drößler et al. 2005). Many foresters have therefore relied on planting as the most effective method of an artificial introduction of beech into conifer stands for conversion purposes. However, recent research has improved our knowledge on how to successfully carry out direct seeding (Leder 1998, Ammer et al. 2002, Leder et al. 2003, Löf et al. 2004, Nörr 2004, Willoughby et al. 2004, Madsen and Löf 2005, Jinks et al. 2006). Ammer and Mosandl (2007) showed that planted and directly sown seedlings of beech grew in a comparable way over an observation period of seven years. In their investigation height and aboveground biomass of planted and sown seedlings related to seedling's age were statistically indifferent between the two stock types (Ammer and Mosandl 2007).

The expected cost of planting beech (e. g. 5000 seedlings ha^{-1}, spaced 2 x 1 m) is around 4000 € ha^{-1}. In practice normally not the whole stand is meant to be converted. Therefore beech is often planted in three or four groups of at least 1000 m^2 in size beneath a spruce overstorey of mature trees. Thus the future stand is expected to consist of about 30 to 40% beech. The costs for direct seeding range from 2500 € ha^{-1} (direct seeding of 75 kg ha with machines) up to 3000 € (direct seeding by horse) and 5500 € ha^{-1} (manually operated).

In conclusion it can be summarised that both techniques are suitable for the introduction of beech into Norway spruce stands. The most effective method can however only be determined after a careful analysis of the specific situation. Factors which may affect the success of planting and direct seeding are highlighted in Table 1.

4. Conclusions

Although there are still many open questions such as the issue of genetic diversity in converted stands, there are reasonable arguments for the conversion of pure Norway spruce stands by introducing European beech. Since there are ecological and economic reasons for using beech (and other broadleaved species as well) for the conversion, and because its introduction in pure Norway spruce stands can be seen as a strategy to spread the risks of climate change (see Bolte and Ibisch 2007), we explicitly do not share apprehensions about an "invasion" of beech. In Germany Norway spruce stands presently dominate on 28 % of the woodland area whereas beech stands can only be found on 14.8 % (Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz 2004). Moreover there are some regions where the amount of spruce is much higher. For example, in Bavaria spruce is the dominant species on 43.8 % of the forested area (Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz 2004). Particularly in these regions conversion efforts in order to transform pure spruce forests into mixed stands are still needed. As summarised in the previous section, effective techniques for this task are available. However, conversion efforts by artificial regeneration will cause costs. Public and private forest owners have therefore to decide whether such an investment makes sense. We hope that the short overview presented here facilitates such a decision on a rational basis. The decision for a substantial percentage of beech should not be hampered by the demand of conservationists to ban forestry from beech forests by arguing that these forests represent the natural vegetation type in Central Europe.

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