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Growth Reaction of Norway Spruce (*Picea abies* (L.) Karst.) and European Beech (*Fagus silvatica* L.) to Possible Climatic Changes in Germany. A Sensitivity Study

Wachstumsreaktionen von Fichte (*Picea abies* (L.) Karst.) und Rotbuche (*Fagus silvatica* L.) auf mögliche Klimaveränderungen in Deutschland. Eine Sensitivitätsanalyse

HANS PRETZSCH and JÁN ĎURSKÝ

Abstract

The paper presents scenario calculations for the growth of Norway spruce (*Picea abies* (L.) Karst.) and European beech (*Fagus silvatica* L.) under climate change. Simulation runs with the individual tree model SILVA 2.2 show that the present increment increase in German forests under strong climate change may lead to severe increment reductions and shifts in competition between tree species. The current observed growth trends as well as the simulation results confirm that the reactions of Norway spruce stands to climatic changes vary widely. In addition, the reaction of Spruce and Beech may be quite different. The recent temperature increase as shown for the northern hemisphere and the prolongation of the vegetation period provides a probable explanation for the increment increase over large regions. The extent of the increment reaction depends on the species specific ecological amplitude and is superimposed by locally and regionally influences, such as soil characteristics, element inputs and biotic stressors. This superimposition generates a number of increment reaction patterns including positive and negative deviations from an expected development of an age typical increment. It delivers an explanation for the seemingly paradoxical result that even hypertrophic growth, increment reductions and death of stands can occur concurrently.

Keywords: climatic changes, growth reactions, scenario calculations, sensitivity analysis, Norway spruce, *Picea abies* (L.) Karst., European beech, *Fagus silvatica* L.

Zusammenfassung

Im Mittelpunkt des Beitrags stehen Szenariorechnungen zum Wachstum der Baumart Fichte (*Picea abies* (L.) Karst.) und Rotbuche (*Fagus silvatica* L.) bei Veränderung des Klimas. Die mit dem Waldwachstumssimulator SILVA 2.2 ausgeführten Simulationsrechnungen zeigen, dass der gegenwärtig in den Wäldern Deutschlands beobachtete Zuwachsanstieg bei fortschreitender Klimaänderung je nach Standortbedingungen in Zuwachsdepression und Abnahme der Konkurrenzfähigkeit der Fichte gegenüber anderen Baumarten münden kann. Die beobachteten Wachstumstrends in Wäldern lassen wie die Ergebnisse der Szenarioanalysen für die Fichte eine breite Variation von Wachstumsreaktionen auf Klimaveränderungen erkennen. Die Reaktionen von Fichte und Buche auf die selben Klimaänderungen können sehr unterschiedlich sein. Der Temperaturanstieg auf der Nordhalbkugel und die nachgewiesene Verlängerung der Vegetationsperiode bieten eine plausible Erklärung für die großregionale Veränderung des Waldwachstums. Das Ausmaß der Wachstumsreaktionen auf großregionale Klimaänderungen hängt von der artspezifischen ökologischen Amplitude ab und wird von lokalen und regionalen Einflüssen, wie u.a. den Bodeneigenschaften, Stoffeinträgen und biotischen Stressoren überlagert. Diese Überlagerung unterschiedlicher Einflussfaktoren bringt eine Vielzahl von Reaktionsmustern hervor, die von positiven bis zu negativen Abweichungen vom normalen alterstypischen Zuwachsgang reichen. Damit erklärt sich der scheinbar paradoxe Befund, wonach hypertrophe Zuwächse, Zuwachsdepressionen und zur Bestandesauflösung führende Absterbeprozesse gleichzeitig und nebeneinander zu beobachten sind.

Schlüsselwörter: Klimaänderung, Wachstumsreaktionen, Szenariorechnungen, Sensitivitätsanalyse, Fichte, *Picea abies* (L.) Karst., Rotbuche, *Fagus silvatica* L.

1 Introduction

The analysis of spatially and temporally widely differing forest growth data shows that the increments in forest stands have been increasing across large regions for a number of decades (KENK et al. 1991, RÖHLE 1994, SPIECKER et al. 1996, PRETZSCH 1999). Long-term measurements on experimental sites that started as early as 1870 can be used for a quantification of relationships between site and productivity as well as for calibration of models that predict growth responses to changes in site quality (KAHN 1994, KAHN and PRETZSCH 1997). Thus, it is possible not only to provide meaningful results about the actual growth development, but also to formulate if-then statements about the prospective growth trend (ĎURSKÝ and PAVLIKOKOVÁ 1997, PRETZSCH and UTSCHIG 1998, ĎURSKÝ, POMMERENING and POTT 1999).

This article presents scenario calculations on a regional level for the predicted climatic changes using the growth model SILVA 2.2 (KAHN and PRETZSCH 1998, PRETZSCH 2001). By way of example, the effects of temperature increase in the vegetation period, precipitation decrease in the vegetation period and prolongation of the vegetation period on the growth of Norway spruce (*Picea abies* (L.) Karst.) and European Beech (*Fagus silvatica* L.) are analysed. We concentrate on the probable changes of volume production and value increment in different regions of Germany, the consequences for mixed stands of spruce and beech and silvicultural options to mitigate the loss of yield effected by climatic changes.

The underlying tool, SILVA 2.2, is an individual tree based stand growth model (PRETZSCH 1992, KAHN 1994, KAHN and PRETZSCH 1997). The general suitability of management models for climatic change research in forests as well as the central role of the SILVA 2.2 model in the Study "German Forest Sector under Global Change" is discussed in the introduction to this journal supplement (LINDNER and CRAMER 2002). Details about the model approach in general, the climatic sensitivity of the implemented difference equations and the model evaluation are given by PRETZSCH (2002) in this journal supplement. The main advantages of this model type compared with other approaches (e. g. ecophysiological process models, forest succession model) are: their advanced validation, the adaptation of their input and output variable list to the demands of forest management, their integration into the information flow of forest practice. The model control functions are defined causally or quasi causally via climate and soil characteristics. For this the site-productivity model (KAHN 1994) plays a decisive role, as it transforms the effects of the site factors into growth. Due to the temporal and spatial resolution scale, it can be applied to large areas and it can be used to test the information of climate induced changes in growth. Furthermore, the implications of changed growth conditions over large areas for the competitive behaviour of the dominant tree species can be investigated and thus contribute to a successful management of future forests. It is also possible to take into account the type and intensity of the tending of the stands, the stand stability, the quantity and quality of the wood products as well as the financial situation of the forest estate. SILVA 2.2 was applied by several partner groups, considering climatic change effects on silvicultural treatments (DÖBBELER and SPELLMANN 2002), forest enterprises (DUSCHL and SUDA 2002) protected areas (SCHLOTT and GUNDERMANN 2002) and on the forest product market (BARTELHEIMER 2002). As SILVA 2.2 is already established in forest practice as a management and decision support tool it offers the opportunity to transfer the results of the study into the planning process of forest practice.

2 Methodological approach and database

Two different analyses were performed. Firstly, scenario calculations were made for Norway spruce on the level of Germany. Secondly, for a selected growth region the effects of temperature increase on the growth of Norway spruce and European beech stands were compared.

2.1 Forest Inventory and Site Data

Data from the Federal Forest Inventory (BWI) and the East German Forest Data Base „Datenspeicher Waldfonds" (DSW) (WOLFF 2002) played a crucial role in the study. As the objective of the sensitivity study is to make site related assessments about the growth responses of spruce stands to climatic change in different regions of Germany the inventory data were used for a variety of purposes: Firstly, based on these data, the most frequently occurring site conditions were identified in the forest growth regions of Germany (WOLFF 2002). Secondly, these data were used to quantify the regionally specific intensities of thinning measures for use in the simulation runs.

For the Norway spruce calculations, the spruce sites, which occurred most frequently, were selected from the available data material. Clearly, this procedure is more appropriate for this study than just to choose the most frequent site types, because the distribution and importance of spruce differs in each growth region. For south-western points of the Federal Forest Inventory (BWI) WOLFF et al. (1998) succeeded in combining the information about forest structure with site survey data. In the case of the East German Forest Data Base (DSW) forest inventory information was combined with data of the Ecological Monitoring of Forest Condition (ÖWK). Unfortunately the site data were not available for each inventory point. Thus, only 1701 (37.1 %) data sets from the BWI and 1511 (57.0 %) from the (DSW), respectively, could be used. The point related site and climate characteristics served as a basis for the stratification of the inventory units. The selected variables for stratification characteristics of the site were as follows:

- Soil moisture (12-level scale according to WOLFF et al. 1998),
- Nutrient supply (5-level scale according to WOLFF et al. 1998),
- Elevation – temperature levels (planar-colline, sub-montane, montane, high-montane, sub-alpine etc., selected on the basis of mean annual temperature according to SCHLOTT and GUNDERMANN (2002),
- Continentality (sub-oceanic, sub-continental etc., selected in dependence of the maximum annual temperature amplitude according to SCHLOTT and GUNDERMANN (2002).

Based on these four assigned site characteristics, for the BWI/DSW sample plots with spruce as the dominant tree species, a frequency analysis was carried out and appropriate strata (defined by combination of four assigned site characteristics) were selected. Table 1 shows the results of this stratification and characterises those strata which occur most frequently in single growth regions of Germany. The selected strata are more or less homogenous in terms of site and growth conditions, what enables a reasonable site dependent prediction of the forest development stands with the growth model SILVA 2.2.

As initial situation, for each growth region a typical representative forest stand in age class II. (age 20 to 40 years) was generated using special tariffs constructed by ĎURSKÝ (2002) and the structure generating routines of SILVA. These tools allowed computation of typical spruce stands on typical sites in the growth regions. As well as for setting up the start situation the tariffs were also used to define typical basal area developments for stand treatment in simulation (corresponding to the tariff for the mean basal area).

For the comparision of the growth reactions of Norway spruce and European beech growth region 12 was selected because both tree species are very important there. For each species a typical 30-year old stand was constructed. Both stands were assumed to show typical site conditions for spruce and beech in growth region 12.

2.2 Climate data and scenarios

For the Norway spruce analysis summary climate data for the present situation were processed on the basis of climate data for the years 1961 – 1990, compiled by the Climate

Table 1. Characteristics of typical sites for the growth regions 1–17 selected from the Federal Forest Inventory (BWI) and the East German Forest Data Base (DSW)

Tabelle 1. Merkmale der typischen Standorte, die für die Wuchsregionen 1–17 aus der Bundeswaldinventur (BWI) und dem Datenspeicher Waldfonds (DSW) für die Szenarioanalysen ausgewählt wurden

No.	Growth region	soil moisture	nutrient supply	Altitude/ temperature level	continentality
1	Nordsee-Küstenraum	moderately fresh	moderate	planar-colline	suboceanic
2	Ostsee-Küstenraum	waterlogged	moderate	submontane	subcontinental
3	Heide und Altmark	moderately fresh	moderate	planare-colline	subcontinental
4	Ostdeutsches Tiefland	wet	very rich	planare-colline	subcontinental
5	Ostdeutsches Lößtief- und Hügelland	wet fresh	moderate	submontane	subcontinental
6	Ostdeutsches Berg- und Hügelland	moderately fresh	very rich	Submontan	suboceanic
7	Harz	wet	moderate	montane	subcontinental
8	Rheinisch-Westfälische Bucht	fresh	poor	planare-colline	suboceanic
9	Rheinisches Schiefergebirge und angrenzende Hügelländer	moderately fresh	poor	submontane	suboceanic
10	Rheintal und angrenzende Hügelländer	moderately fresh	moderate	planare-colline	suboceanic
11	Vogelsberg, Odenwald, Spessart	moderately fresh	poor	planare-colline	suboceanic
12	Bayerischer-, Oberpfälzer-, Franken-, Thüringer Wald und Erzgebirge	wet	moderate	montane	subcontinental
13	Württembergisches-Fränkisches Hügelland	moderately fresh	poor	planare-colline	suboceanic
14	Schwarzwald	moderately fresh	poor	submontane	suboceanic
15	Schwäbisch- Fränkische Alb	moderately fresh	poor	submontane	subcontinental
16a	Alpenvorland	moderately fresh	rich	submontane	subcontinental
16b	Schwäbisch-Bayerische Jungmoräne und Molassevorberge	very fresh	rich	submontane	subcontinental
17	Bayerische Alpen	very fresh	rich	montane	subcontinental

Research Unit East Anglia (UK). They were interpolated according to the inventory points of the BWI and DSW/ÖWK (LINDNER and CRAMER 2002). The climate change scenario was calculated for the years 2041–2070 by the Potsdam Institute for Climate Impact Research and also transferred to the inventory points of the BWI and DSW/ÖWK (LINDNER and CRAMER 2002) by interpolation. This climate change scenario is based on an anomaly approach of the global climate model of the Hadley Center (HadCM2, transient course IS92), presuming a doubling of the CO_2-content in the earth atmosphere within 100 years (MITCHELL et al. 1995).

According to this scenario, the mean temperatures in Germany increase in the vegetation period by +2.15 °C in average (span: 1.4 to 3.4 °C). In contrast, the precipitation in the vegetation period changes only slightly (from −43.6 to 41.1 mm), the number of days with a temperature above 10 °C increases on average by 50.1 (min 29, max. 124), and the annual temperature amplitude decreases on average by 2.55 °C (min. −4.6, max. +1). In this context, it must be considered that the climate in different regions of Germany does not change in the same sense, but is regionally differentiated.

The development of the representative Norway spruce stands was simulated over 120 years, with staggered thinning as stand treatment. The present climate scenario assumed the recent regional climate conditions to remain constant. The climate change scenario assumed the changes shown above to be valid.

The spruce-beech comparison is based on simulation runs up to a stand age of 100 years without thinning measurements. Three climate scenarios were applied. Scenario 0 assumes the present conditions to remain constant, scenario 1, 2 assume an increase of mean vegetation period air temperature of 1 °C and 3 °C, respectively.

3 Results

3.1 Effects of climate change on the growth of Norway spruce stands

The results of the development of height, the mean annual volume increment in age 100 dGZ_{100} and the mean annual value increment $dGZW_{100}$clearly show differences between the selected scenarios (Table 2). Except for the growth regions 7 (Harz), 12 (Bayerischer-, Oberpfälzer-, Franken-, Thüringer Wald und Erzgebirge) and 15 (Schwäbisch-Fränkische Alb) all over Germany a marked reduction in growth arises for the climate change scenario. Within the natural distribution area of Norway spruce the effects of climatic change will be less formidable than outside. The changed climate not only decelerates height increment, but also reduces the diameter growth and increases natural mor-

Table 2. Sensitivity of spruce to climate change. For the growth regions 1–17 the percental decrease of top height growth (ho_{100}), mean annual volume increment in age 100 (dGZ_{100}) and mean annual value increment at age 100 ($dGZW_{100}$) is reported. $\bar{h}_{100}$ = mean height estimate at age 100 in the growth region, ho_{100} top height at age 100, dGZ_{100} = mean annual volume increment at age 100, $dGZW_{100}$ = mean annual value increment

Tabelle 2. Sensitivität der Fichte gegenüber Klimaveränderungen. Für die Wuchsregionen 1–17 ist die prozentische Abnahme des Oberhöhenwachstums (ho_{100}), des durchschnittlichen Gesamtzuwachses im Alter 100 (dGZ_{100}) und des durchschnittlichen Wertzuwachses im Alter 100 ($dGZW_{100}$) angegeben. $\bar{h}_{100}$ = Mittelhöhe im Alter von 100 Jahren, ho_{100} = Abnahme der Oberhöhe im Alter 100, dGZ_{100} = Abnahme des durchschnittlichen Gesamtzuwachses im Alter 100, $dGZW_{100}$ = Abnahme des durchschnittlichen Wertzuwachses im Alter 100

Growth region	$\bar{h}_{100}$	Percental change of yield characteristics under climatic change compared to the current climate (= 100 %).		
		ho_{100}(%)	dGZ_{100}(%)	$dGZW_{100}$(%)
1	26,7	−37	−40	−50
2	29,4	−35	−35	−37
3	21,8	−27	−21	−25
4	28,4	−100	−100	−100
5	26,2	−41	−44	−59
6	31,5	−16	−27	−47
7	27,1	0	−2	−1
8	32,1	−100	−100	−100
9	30,5	−23	−23	−25
10	31,4	−100	−100	−100
11	33,2	−42	−50	−76
12	27,9	0	2	2
13	31,6	−45	−58	−80
14	31,3	−13	−24	−43
15	30,7	−8	−17	−36
16a	32,4	−28	−29	−33
16b	27,8	−27	−28	−34
17	27,8	−13	−24	−40

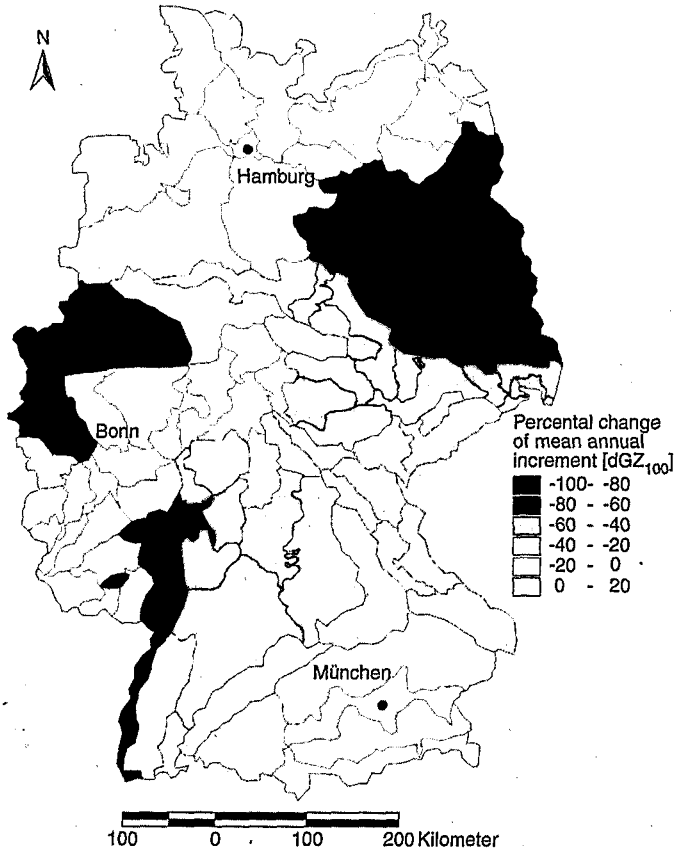

Fig. 1. Growth reaction of Norway spruce on climate change. Percental change of mean annual increment at an age of 100 years (dGZ_{100}) in the growth regions 1–17 under changed climatic conditions.

Abb. 1. Wachstumsreaktionen der Fichte auf Klimaveränderungen. Angegeben ist die prozentuale Veränderung des durchschnittlichen Gesamtzuwachses (dGZ_{100}) in den Wuchsregionen 1–17 bei definierter Veränderung der Klimabedingungen.

tality, which in turn leads to a decreased total stand productivity expressed by a lower stand increment.

In growth regions which presently provide the climatic optimum for spruce, the volume growth changes by 0 to −30 %. The most considerable changes for the climate scenario presented here are expected for the growth regions 4 (East German lowlands), 8 (Rheinisch-Westfälische Bucht) and 10 (Rhine valley and bordering uplands). In these growth regions spruce (with respect to the temperature in the vegetation period) has already reached the upper limit of its ecological amplitude. Therefore the increased mean temperature in the vegetation period (higher than 18 °C) causes the death of all individual trees of this species. In general, the area related calculation shows a clear connection between the typical regional temperature increase in the vegetation period and the decrease of the yield rate. This change, however, differs widely dependent on seasons and regions and has partly far-reaching effects on forest growth. The growth of spruce will be strongly endangered in the lowlands at sites with a very low water supply. In some montane regions with sufficient water supply but suboptimal radiation availability it can be expected that the growth potential of this tree species will increase. But at most of the sites where spruce occurs frequently growth and yield rates will diminish under the assumed climatic change (cf. BAYERISCHER KLIMAFORSCHUNGSVERBUND 1999).

The difference between the current mean annual value increment ($dGZW_{100}$) under present conditions and under climatic change varies between +3 and −345 €/ha/year. This monetary value not only includes the low production rate but also the changes in the stand density and the timber assortment structure. The monetary calculations were based on the average proceeds generated by the Bavarian State Forest Service for skidded and non-stripped logs in the years 1987–1997.

3.2 Effects of climate changes on the mean annual value increment of Norway spruce and European beech

Climate change may have different effects on different tree species, dependent on whether they move towards or away from their optimum conditions. The question whether a given change has a strong or a weak effect also depends considerably on the shape of the ecological response curve for a specific tree species and a specific climate factor. For example, a tree species with a wide flat response curve will normally show a weaker response to the same environmental change than a species with a steep curve and a narrow optimum range. The results of the simulation runs for Norway spruce and European beech in growth region 12 may very well illustrate this. The target variable is the mean annual volume increment at age 100 years (dGZ_{100}). For comparing the results the dGZ_{100} obtained from the present climate scenario is set as 100 % reference.

Figure 2 shows that in the considered growth region the air temperature is not at an optimum either for spruce or beech and that the temperature increase by 1 °C induces a positive change in dGZ_{100} (for spruce by 5.9 % and for beech by 11.7 %). This is different if the temperature is increased by 3 °C (long arrows parallel to the x-axis). In the latter case spruce is, for temperature, already in the sub-optimal range, so, its dGZ_{100} decreases by 8.9 %. Beech, in contrast, with a wider optimum range still responds positively to this change, which is reflected in a predicted increase in dGZ_{100} by 5.9 %.

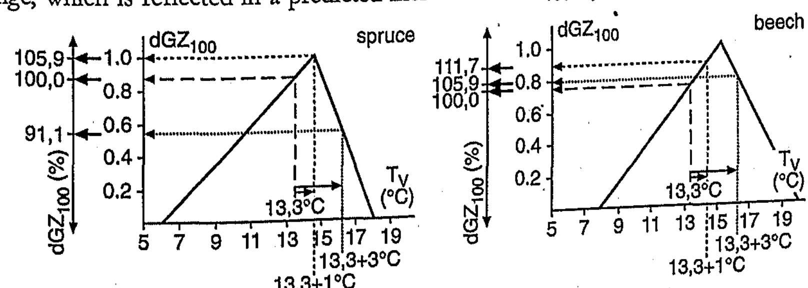

Fig. 2. Schematic presentation of the effects of an increase in mean temperature of the vegetation period on the mean annual volume increment at age 100 (dGZ_{100}) of a representative forest stand of spruce (left) or beech (right) in the growth region 12.

Abb. 2. Schematische Darstellung des Effekts eines Anstiegs der mittleren Temperatur in der Vegetationsperiode auf den durchschnittlichen Gesamtzuwachs im Alter von 100 Jahren (dGZ_{100}). Dargestellt sind die Zusammenhänge für einen repräsentativen Bestand der Baumart Fichte (links) und Buche (rechts) in der Wuchsregion 12.

The simulated reactions of the selected tree species as shown by these results are confirmed by THOMASIUS (1991). His investigations reveal, that spruce only tolerates a relatively narrow margin in the mean annual temperature between 5 and 8 °C. In many regions of Germany the annual mean temperature has already reached 7 – 7.5 °C, thus a very small change in temperature would suffice to push spruce out of the limits of its ecological range.

4 Discussion. Options for actions in Forestry and Forest science

4.1 Discussion of simulation results

The simulation results for Norway spruce in Germany, mostly showing a more or less distinct decrease of forest productivity, are confirmed by results of other research groups (cf. Bayerischer Klimaforschungsverbund 1999). But, the observed increment increase of the present forest stands and the simulation results as well show also that the reactions of forest stands may vary widely. The recent temperature increase as proven for the Northern hemisphere and the prolongation of the vegetation period provides a probable explanation for the present increment increase over large regions.

The extent of the increment reaction depends on the species specific ecological amplitude and is superimposed by local and regional influences, such as local site conditions, element inputs and biotic stressors. This superimposition generates a number of increment reaction patterns as well as positive and negative deviations from an expected development of an age typical increment (Pretzsch and Utschig 2000). It delivers an explanation for the seemingly paradoxical result that even hypertrophic growth, increment reductions and death of stands can occur concurrently. The scenario calculations for spruce show that the present increment increase with a stronger climate change in dependence of the ecological amplitude of the tree species may turn round to more severe increment reductions and shifts the competitive relations between the dominating species spruce and beech (Pretzsch 1999). This is revealed very well by the simulation runs for spruce and beech, where a given change of temperature leads to different species-specific growth reactions. Such simulation runs may be used to identify regions where different concepts for silvicultural treatment of mixed stands will be necessary.

Transferring simulation results into decision support for forestry practice may be enhanced by some technical developments. By linking a geographical information system with the growth model SILVA 2.2 it is possible to generate thematical maps with calculated indices (Pott and Fabrika 2002). By this, a comparison of the results can be improved and the spatial analysis is considerably easier. Hence it is easier to identify, for example, risk regions which resulted from specific climate scenarios.

4.2 Possible reactions

Planning in forestry for a long time has presumed constant site conditions (Assmann, 1961). In recent years, however, increasingly more indications (Spiecker et al. 1996, Pretzsch 1999, Bayerischer Klimaforschungsverbund 1999) have been suggesting that this basic assumption is no longer valid. Moreover it must be assumed that both the climate as well as the nutrient supply are subjected to a continuous change and as a consequence also the site quality is changed. The planning process in forestry has to consider these facts for maintaining sustainability in the coming decades.

In regions where the economically most important tree species show clearly positive growth trend, forestry can react by passively increasing the density of the stands or increasing the harvesting rates. Steps against a negative growth trend can be a reduction of pollutants, a stabilisation of stands and a distribution of the risks. Decreasing increments due to site conditions for one tree species can be compensated by an admixture of better adapted tree species. This is illustrated exemplarily by simulation results for spruce and beech in the Upper Bavarian tertiary uplands (site unit 203, moderately fresh to fresh loam). A tree composition adapted to the site conditions has further advantages, such as the utilisation of actual potentials or a risk distribution with respect to unknown factors (diseases, insects).

Figure 3 (left, continuous line) shows the increase of the *dGZ* up to more than 20 m^3 per ha and a decrease from an age of 140 years onwards. This age development of spruce under present climate conditions is used as a reference (100 %-line) (Fig. 3, right) and compared to the growth of spruce in the stand under changed climate conditions (temperature increase in the vegetation period of 2 °C, precipitation decrease in the vegetation period by 10 % and prolongation of the annual vegetation period by 10 days). We observe that under warmer conditions the dGZ of spruce decreases by about 10 % (broken line).

It was tested further, to what extent the expected increment loss can be counteracted by a change in the proportion of beech between 30 and 70 %, respectively. In a stand with a proportion of 30 % beech, which grows better under the presumed climate conditions, the increment losses of spruce may be overcompensated if the rotation cycle is 100 to 150 years. A proportion of 70 % beech can not compensate the climate related increment losses of spruce until the age of 150 years is reached.

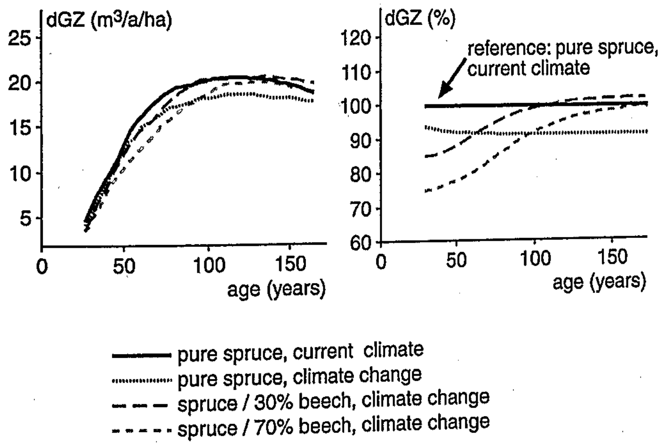

Fig. 3. Mean annual volume increment (*dGZ*) of pure spruce and mixed spruce-beech stands in Southern Bavaria (site unit 203) under current conditions (solid line) and climatic change (grey and broken lines). Development of the *dGZ* in m^3 per ha (left) and in relation to development of pure spruce under current conditions (right).

Abb. 3. Durchschnittlicher Gesamtzuwachs (*dGZ*) von Fichten-Rein- und Fichten-Buchen-Mischbeständen in Südbayern (Standorteinheit 203) unter gegenwärtigen Klimabedingungen (schwarz ausgezogene Linie) und bei definierter Veränderung der Klimabedingungen (graue und gebrochene Linien). Entwicklung des *dGZ* in m^3 pro ha (links) und in Relation zu der Entwicklung reiner Fichtenbestände unter gegenwärtigen, normalen Klimabedingungen (rechts).

Within the framework of the study "German Forest Sector under Global Change" the effects of specific climate scenarios on forests and forest economy were investigated with the help of SILVA 2.2. For model stands, selected forestry enterprises and the entire forest area of Germany different aspects of forest growth and forestry as well as various silvicultural treatments were analysed to assess and mitigate the effect of climatic change.

With an increase of the CO_2-content in the atmosphere the climate has a direct influence on forest growth. On the other hand, forests also function as a sink for CO_2, an effect which can be promoted by appropriate forest management activities and selected tree species. Society can respond directly to changes in the climate and reduce the causes by lowering the output of major climate influencing gases. However, a further alternative for action is possible. Society can try to cure symptoms of climate change by decreeing silvicultural guidelines leading to tree species composition and forest management which are suitable for the changed site conditions (DÖBBELER and SPELLMANN 2002, DUSCHL and SUDA 2002).

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