

# APPLICATION OF A FOREST SUCCESSION MODEL TO A CONTINENTALITY GRADIENT THROUGH CENTRAL EUROPE

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**Abstract.** The forest succession model FORSKA was applied to a west-east transect across Central Europe using points from a global climate data set. Climate change experiments were undertaken for two general circulation model scenarios and two different site classes. The simulated climate changes lead to reduced forest productivity and a changed species composition on most sites. Under current climate, the broad scale pattern of the climatically driven distribution of forest communities is quite realistically reproduced. However, the resolution of climate data imposes limitations on the simulation of forest dynamics in subcontinental climate, because climate variability and extreme events are not well represented.

## Introduction

Forest succession models have been applied to study possible impacts of climate change on forests in the transition zone from maritime to subcontinental climate in Central Europe. Initially we compared the two forest succession models FORECE (Kienast 1987) and FORSKA (Prentice et al., 1993), which had been developed in Europe for alpine or boreal forests, respectively. In the FORSKA model, the formulation of a number of processes is more mechanistic than in traditional gap models (Bugmann et al., 1996). Therefore this model seemed to be more appropriate to simulate impacts of changing climate on forest dynamics and it was chosen for further development and applications. Some model modifications have been made, in order to realistically simulate species composition and forest productivity of the major natural forest communities in northeastern Germany. Among other changes, establishment rates were increased, some environmental response parameters were adjusted, and the function to account for resource depletion was altered (Lasch and Lindner, 1996).

In this study, some points from the global climate data set of Leemans and Cramer (1990) were used to run the modified FORSKA model on an extended west-east transect across Central Europe from The Netherlands to Poland. The objective was to test the model performance on a larger regional scale than before. We also wanted to discuss the results with emphasis on limitations imposed by the resolution of climate data as well as by the representation of environmental factors in the model. The transect from maritime to continental climate coincides in Europe with a moisture availability gradient. It was chosen because forest dynamics in temperate continental climate usually are strongly influenced by water limitations,

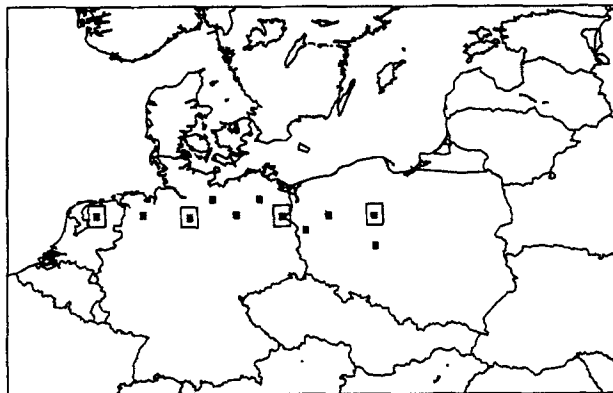


Figure 1. Map showing the location of the investigated transect in Central Europe.

which under a predicted climatic change may have increasing importance for European forests.

### Selected Sites and Climate Characteristics

Simulations were run for two soil classes (soil water capacity 100/150 mm) at 11 sites, using the data of Leemans and Cramer (1990) for the current climate and the two climate scenarios of the GFDL and OSU General Circulation Models (see Lauenroth, 1996 for a description of the scenarios). Here, more detailed results are shown of 4 grid points from 6° E/53° N to 18° E/53° N.

The climate data in Table I clearly show increasing temperature amplitude and decreasing precipitation towards more continental climate in the east. It has to be noted that the summer temperature of point 10° E/53° N is rather low in comparison to data from weather stations of that area.\* The two climate scenarios, especially the one by GFDL, project quite severe temperature increases for the region of interest. More recent projections of General Circulation Models indicate that these changes might be not as drastic.

### Simulation Model

In this study, we applied the FORSKA model (Prentice et al., 1993), as modified for applications in northeastern Germany (Lasch and Lindner, this issue). Most of the modifications are parameter adaptations in order to realistically simulate forest dynamics in the transition zone from maritime to subcontinental climate. Furthermore an exponential function is used to account for resource depletion,

\* The data point was left unchanged for the sake of consistency within the overall study. A later version of this global database has a higher degree of congruence between gridded and station data.

Table I  
Location of selected grid points and their climatic characteristics for current climate (CUR), GFDL, and OSU climate scenarios

Long./lat.	CUR		GFDL		OSU							
	Ann. prec.	Ann. temp.	Ann. prec.	Ann. Temp.	Ann. prec.	Ann. temp.						
6° E/53° N	728	8.5	1.4	16.1	885	15.7	9.0	22.5	799	11.7	5.8	19.7
10° E/53° N	630	7.4	-0.3	15.8	767	14.4	6.9	22.1	695	10.6	4.5	19.4
14° E/53° N	538	7.0	-2.3	16.6	655	13.8	4.8	22.7	604	10.4	2.6	20.3
18° E/53° N	522	7.2	-3.0	18.5	648	13.7	3.9	24.4	578	10.7	1.9	22.2

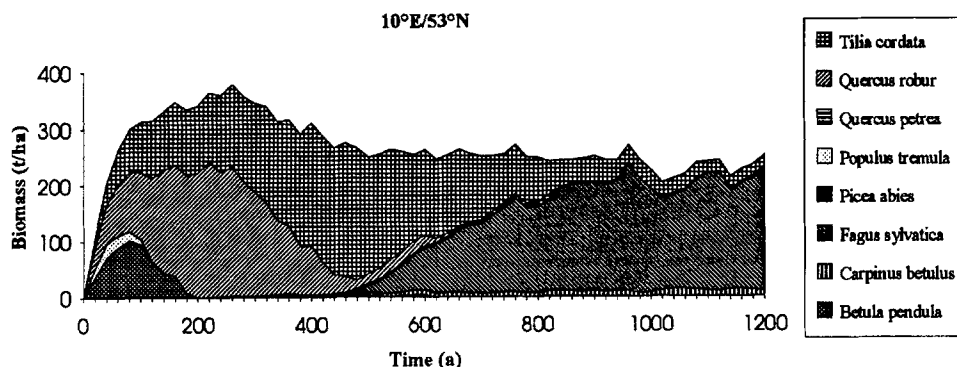


Figure 2. Simulated forest succession at the point  $10^{\circ}$  E/ $53^{\circ}$  N as subjected to the OSU climate change scenario that took place from year 400 to 500. Soil water capacity 100 mm, mean cumulative biomass of 50 patches.

instead of the original linear approach, which lead to very low simulated biomass. The present version of the model does not account for species specific responses to site fertility. Therefore, the model results reflect species compositions on mesic to fertile sites only.

## Results

For each run of 1200 years the model was initialized for bare ground (without trees). The results represent averages of 50 plots. The projected transient climate change of the GFDL and OSU scenarios took place from year 400 to 500 (Figure 2). In order to facilitate the comparison of results we determined equilibrium species compositions by averaging the output of the years 1000–1200 (Figure 3).

Under current climatic conditions three different groups of forest communities are simulated along the transect: almost pure beech (*Fagus sylvatica*) forests prevail on maritime sites, Norway spruce (*Picea abies*) dominates sites with high soil water capacity and cool winter temperatures, and mixed oak forests (*Quercus robur* and *Q. petraea* with *Tilia cordata* and *Carpinus betulus*) occur where both beech and spruce are not competitive. The simulation results for soils with low water capacity (Wc) roughly correspond to the expected potential natural vegetation on mesic and fertile sites, whereas the simulations for soils with higher Wc overestimate the abundance of spruce and beech in subcontinental climate.

Simulations with the two climate change scenarios from GFDL and OSU indicate major reductions in forest productivity. Species composition changes on many sites, with beech gaining abundance on soils with high water capacity. On drier soils in eastern Central Europe lime-hornbeam forests develop.

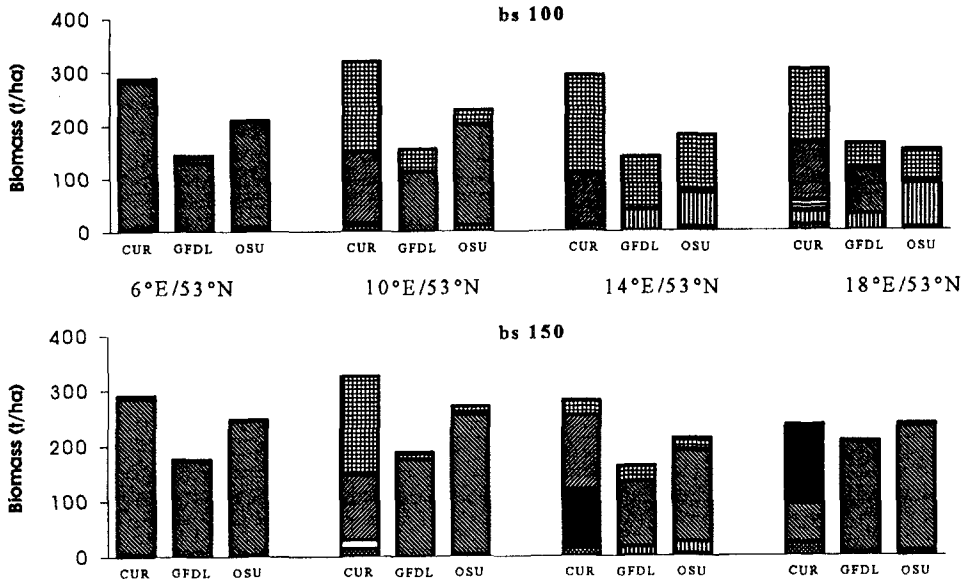


Figure 3. Simulated equilibrium species composition on different soils at 4 grid points of the Leemans and Cramer (1990) data base for current climate (CUR), the GFDL, and OSU climate scenarios. The 4 points represent a continentality gradient from The Netherlands to Poland. Soil water capacity 100 mm (above) and 150 mm (below), legend see Figure 2.

### Effect of Varying Temporal Resolution of Climate Data

Forest succession models may be sensitive to the choice of climate data that drive the model (Botkin and Nisbet, 1992). To test the effect of climate records with different temporal resolution, forest development at the site Potsdam (13.0° E/52.5° N) was simulated with four climate data sets (Lasch and Lindner, 1994). This site was selected because the local weather record is one of the longest in Central Europe and because average site conditions at Potsdam represent conditions just outside of the natural range of beech. The results (Figure 4) indicate that FORSKA overestimates the abundance of beech at this site if long term climate data are used to define environmental conditions in the model. The simulated forest composition becomes more realistic using climate data that include observed climate variability. It should be noted, that because of the relatively short weather record, we only compared forest development over 100 years in this experiment. To simulate forest succession, longer time series would be needed. However, we mainly wanted to compare the bioclimatic effect of the different climate data sets and these are quite obvious over short time periods as well. Major differences are reflected in the yearly integrated drought index (Table II), which is calculated in FORSKA as the complement to the ratio of actual to potential evapotranspiration (Prentice et al., 1993). While extreme drought events never occur in climate data sets based on long term means, the stochastic variation of monthly climate data at least partly shows the annual

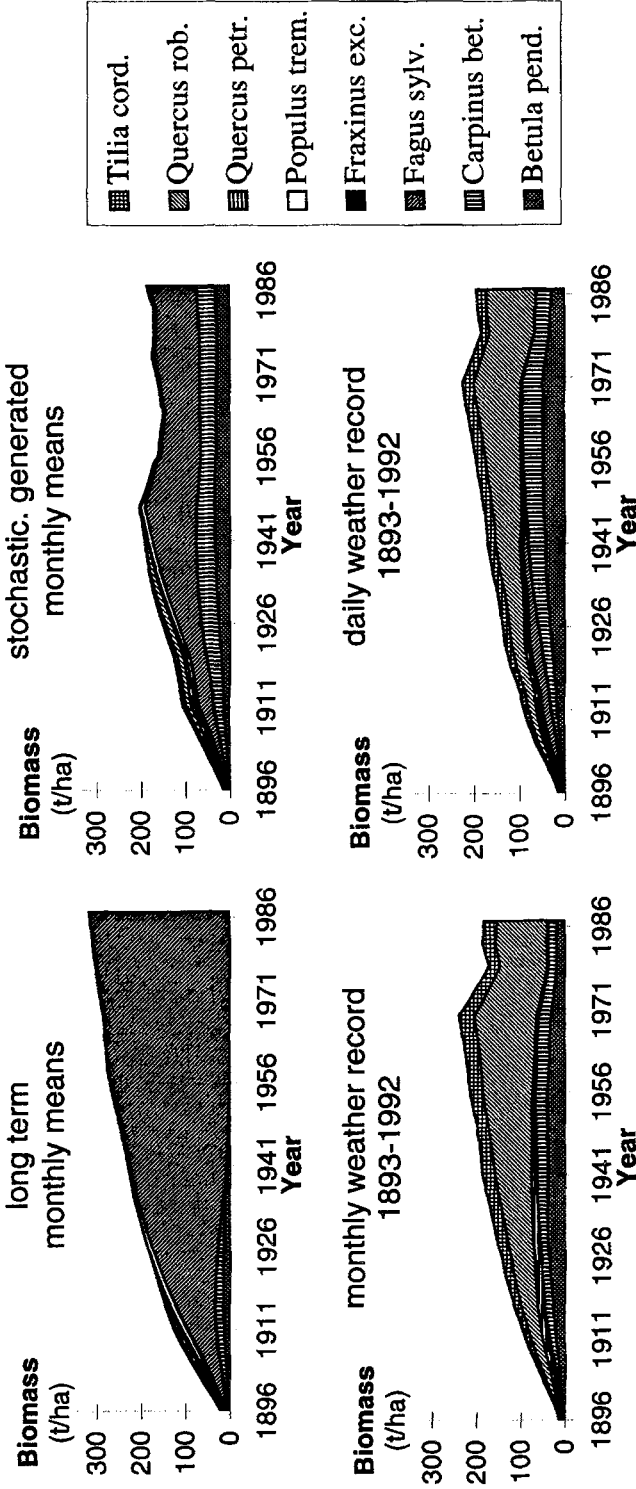


Figure 4. Simulated forest development at the site Potsdam with climate data sets of varying temporal resolution: long term monthly means, stochastically generated monthly means, a monthly weather record 1893–1992 and a daily weather record 1893–1992.

Table II

Drought stress index at the site Potsdam (13.0° E/52.5° N) as calculated over a period of 100 years for a soil water capacity of 240 mm. Climate data sets of varying temporal resolution were used: long term monthly means (1), stochastically generated monthly means (2), a monthly weather record 1893–1992 (3) and a daily weather record 1893–1992 (4)

	Mean	Minimum	Maximum	Standard deviation
Data set 1	0.019			
Data set 2	0.07	0.018	0.381	0.071
Data set 3	0.1544	0.018	0.496	0.119
Data set 4	0.123	0.018	0.414	0.102

variability of climate. The highest drought stress is simulated by the model that uses time series of monthly or daily weather data.

### Discussion and Conclusions

The broad scale pattern of the climatically driven distribution of forest communities along the continentality gradient is quite realistically reproduced by the modified FORSKA model. However, on soils with higher soil water capacity the abundance of beech and spruce in current subcontinental climate is overestimated. We argue that the misrepresentation is mainly caused by the spatial and temporal resolution of the applied global climate data set. But there may also be some influence of threshold effects that are due to the formulation of environmental response functions in the model.

The investigated transect is situated close to the transition zone from temperate deciduous forest to boreal forest and it is approaching the eastern limits of many deciduous species of Europe. Because of the coarse resolution of the climate data base, results of single grid points have to be interpreted carefully. For the current climate, e.g., the simulated species composition at point 10° E/53° N is unrealistic, just because summer temperature is slightly underestimated in the interpolated climate data base and therefore the minimum number of growing degree days for beech is not achieved. With a simulated increase in temperature from year 400, beech invades the site and then dominates the forest (Figure 2). Another temperature threshold, the mean temperature of the coldest month, determines the southern and western limit of Norway spruce, excluding the species from sites where warm winters limit its regeneration (Prentice et al., 1993). A number of grid points have January temperatures that are just below this threshold, allowing spruce to thrive on sites with sufficient soil moisture, whereas in reality natural occurrence of spruce in this area is very rare. This deviation may partly be explained by the climate data base, because some weather stations in this area show slightly higher January temperatures. But the high sensitivity of the model to the precise value

of single climate variables indicates a weak point of many current patch models. Other authors have also pointed out that unrealistic threshold effects may occur, e.g. at the southern range limit of tree species (Prentice et al., 1993) or when gap models are applied to environmental gradients (Bugmann, 1994). Further research is needed to identify physiologically based growth limits instead of the often arbitrary range limits, which in many cases reflect the realized ecological niche and not the fundamental niche of a species (cf. Austin and Smith, 1989).

Besides temperature, climate-related factors such as drought or late frosts also change in frequency or severity along the continentality gradient. Both factors may have strong influences on forest dynamics and they are thought to be responsible for the eastern limit of beech (Jahn, 1991). The comparison of different climate data sets indicates how much the simulated species composition can be influenced by the representation of climate variability. Since climate variability and the importance of extreme events may change with the projected climate change (Katz and Brown, 1992), it is essential to improve the representation of the response to such weather patterns by the succession model. In its present version, FORSKA is not calibrated to use daily or monthly weather data. The preliminary results shown here demonstrate, however, that more research concerning the sensitivity of forest dynamics to extreme events is required and that this would contribute to the development of dynamic patch models.

A global climate data base such as the one by Leemans and Cramer (1990) is very useful to simulate broad scale distribution of forest communities that are mainly determined by temperature. However, the use of long term mean climate data is not satisfactory, where natural forest dynamics are considerably influenced by water availability and climatic extremes, which at least in subcontinental climate show greater annual variability. Moreover, close to the climatic limits of dominant forest species like beech or spruce, forest succession models are very sensitive to the precise values of certain climate variables. Misrepresentations of species range limits could have a large influence on the assessment of climate change impacts, regardless of whether they are caused by the coarse resolution of climate data or by incorrect estimates of autecological growth limits. Therefore, simulated species composition of transient climate change experiments at single grid points should be interpreted carefully. Projections of forest dynamics for climatic regions (and scenarios) characterized by the frequent occurrence of climatic extremes need improved methods to realistically reproduce climate variability.

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