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Regional impacts of climatic change on forests in the state of Brandenburg, Germany

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Abstract

The changes of climate projected for the next century will most likely alter both the environment and the growth of forests. In a regional case study, the two forest gap models FORSKA and FORCLIM were applied to simulate vegetation composition using spatially differentiated site data on a 10 × 10-km grid across the state of Brandenburg, Northeast Germany. Three climate scenarios were used to investigate the possible consequences of a changing climate on the environmental constraints of forest growth in the state. To test the plausibility of the forest composition simulated by the two models, their results were compared with a map of potential natural vegetation as well as with each other.

The simulation results show that both models respond realistically to the spatial variability of the environment and thus are suitable for regional applications. However, there are a number of quantitative differences between the simulation results of the models. FORSKA's strength is in simulating the ecological effects of the spatial variability of soil water holding capacity and nitrogen availability, whereas FORCLIM realistically portrays the climate-induced distribution limits of trees, e.g. beech (*Fagus sylvatica* L.).

The study suggests that climatic change could have considerable consequences for future competitive relationships between species. According to the two models, the main driving force of vegetation change would be the increased occurrence of drought, which already today determines some distribution limits of tree species in Brandenburg. Under the strongest change of climate investigated in the present study, none of the species currently present on the landscape could grow any more in certain areas of Brandenburg.

Conclusions are drawn concerning the importance of regional model applications for testing model performance under a wide variety of environmental conditions as well as for forest planning. Regional analyses of the impacts of climate change on forests may help to develop forest management strategies to cope with the risk of changing environmental conditions.

Keywords: Climate change; Forest gap model; Potential natural vegetation; Regional analysis

1. Introduction

Most forest landscapes are heterogeneous with respect to topography, soils, climate, and the prevailing forest types. Climate changes as projected for the

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next century (Houghton et al., 1992) will most likely alter both the environment and the growth of forests. Effects will probably occur at a number of scales in time and space, influencing e.g. plant physiology (Mooney et al., 1991; Linder and Flower-Ellis, 1992), competitive relationships between species (Solomon, 1986; Williams et al., 1986), or the global distribution of major vegetation zones (Prentice et al., 1992; Neilson and Marks, 1994). Many investigations on the ecological impacts of climate change have focused on the physiological level, and most studies on the sensitivity of ecosystems have been limited to single sites or transects. Forestry, however, requires more general information about likely future trends of environmental conditions and growth relations between tree species. Moreover, for planning purposes, regional sensitivity and risk analyses at the spatial scale of larger administrative units are required.

The experimental analysis of the possible impacts of climate change on forests is generally limited because of the longevity of forest trees, and the complexity of processes and feedbacks in forest ecosystems. Therefore simulation models have often been used to investigate the possible responses of forests to climate change (Solomon, 1986; Landsberg et al., 1995). A variety of models have been constructed in recent years (Bossel, 1991; Ågren et al., 1991; Landsberg et al., 1991). Typically, these models were tested and applied only at scattered sites, but not at the regional scale. In this study, we will test whether a widely used type of forest models, the so-called 'gap' models (Botkin et al., 1972; Shugart, 1984), can be applied to simulate the pattern of vegetation in a spatially explicit manner at the regional scale.

This study forms part of a larger effort to assess the possible impacts of climatic change on natural and anthropogenic systems in the federal state of Brandenburg, Germany (Stock and Toth, 1996). Here we report on how different climate scenarios would influence the environment and the species composition of unmanaged forests in the state. Current forest management practices in Brandenburg aim at reducing the amount of planted pure pine stands and increasing the proportion of broadleaved species and mixed forests. The success of this shift of management practice is likely to be affected by future trends of changing environmental conditions. We used forest gap models to investigate possible changes in the pattern of natural forest vegetation under three different climate scenarios.

To make projections of the future fate of ecosystems, validated models should be available (e.g. Shugart, 1984). Unfortunately, the scarcity of data on the long-term dynamics of forest ecosystems makes the validation of gap models very difficult. Since the forests of Central Europe have been subject to century long intensive forest management, observational data on the species composition of natural forests exist only for a few isolated forest reserves, but not at a regional scale. To test the plausibility of the model results, we compared the simulated forest composition of the present climate with a map of today's potential natural vegetation (Krausch, 1993). Moreover, we compared the behaviour of two independent gap models both under current climate and under the scenarios of climatic change. We chose the models FORSKA (Prentice et al., 1993) and ForClim (Bugmann, 1994, 1996b), which were previously applied to simulate the species composition at a number of sites within the study region (Lasch and Lindner, 1995; Bugmann, 1996a). The two models cannot be used to validate each other's simulation results under a changed climate, of course, but the robustness of the conclusions from the simulations is greater if the projections from both models agree.

2. Methods

2.1. Study area

The state of Brandenburg is situated in the Northeast of Germany, surrounding the city of Berlin (approx. 52.5°N, 13°E; Fig. 1). At present, forests cover 37% of Brandenburg, i.e. about 1.1 million ha. The state lies in the transition zone from maritime to subcontinental climate. Because of differences of climate and soils, some tree species have their distribution limits within the state, e.g. beech (*Fagus sylvatica* L.). Under natural conditions broadleaved species (e.g. *F. sylvatica*, *Quercus* spp., *Tilia cordata* Mill.) would prevail, whereas Scots pine (*Pinus sylvestris* L.) would occur only on those sites most poor in nutrients (cf. Fig. 4).

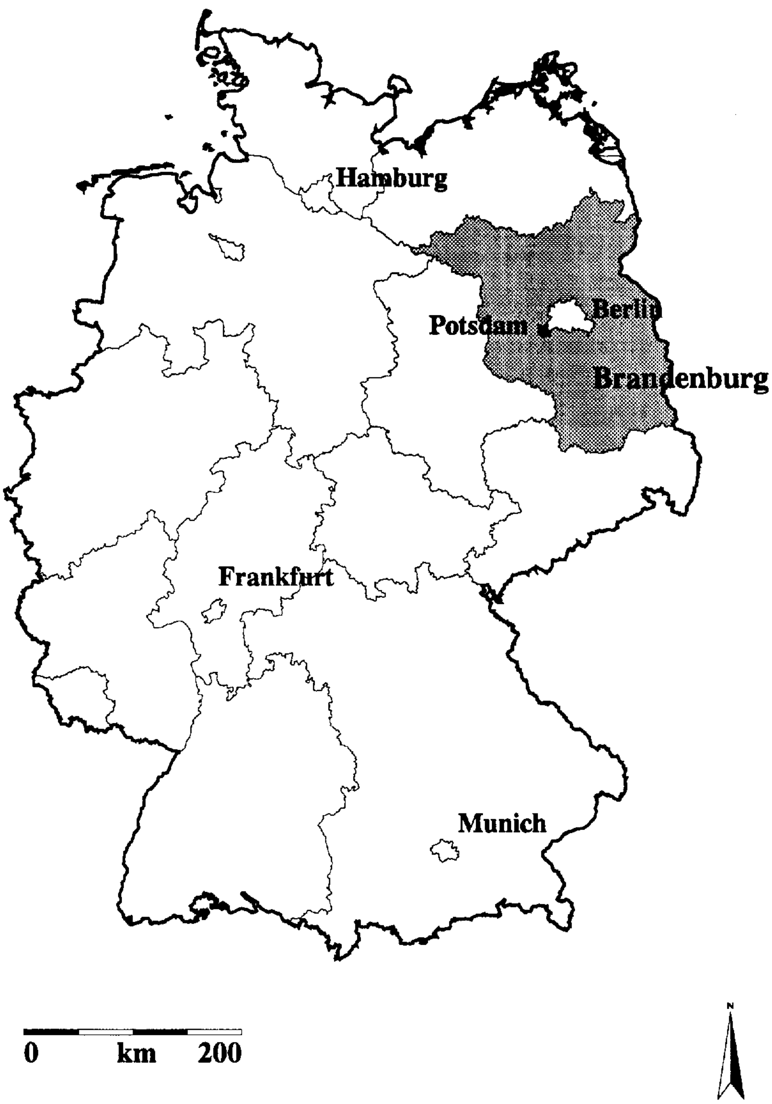

Fig. 1. Location of the state of Brandenburg within Germany.

2.2. Simulation models

Forest gap models simulate establishment, growth, and mortality of trees on small forest patches ('gaps', often 0.08 or 0.1 ha). These models have been in use for more than 20 years (Botkin et al., 1972; Shugart, 1984), and they proved to be capable of simulating the long-term dynamics of a wide range of forest ecosystems on several continents under current climate (Shugart, 1984). However, recent studies show that many current gap models are unsuitable for application under changing environmental conditions (e.g. Martin, 1992; Fischlin et al., 1995).

One of the models used in this study was a modified version of FORSKA (Prentice et al., 1993), which models tree growth and some environmental constraints of forest growth in a more mechanistic way than most earlier gap models. The model was used successfully to simulate forest dynamics in Scandinavia (e.g. Prentice et al., 1991, 1993), and it was adapted to sites in Northeast Germany by Lasch and Lindner (1995). The environmental factors considered in FORSKA are light, temperature, water availability, and optionally the CO_2 content of the atmosphere (Prentice et al., 1993). Nutrient availability is not explicitly modelled, it is only considered in terms of a site specific maximum biomass. Hence species specific responses to variable site fertility cannot be reproduced by the model. This simplification was acceptable as long as sites of identical soil fertility were compared with each other. For the regional application at sites with spatially variable nutrient availability, however, we additionally had to include a fertility response function (SNGF) into the model to modify tree growth (Eq. (1)). We implemented the approach of Aber et al. (1979), that has already been used in some other gap models (e.g. Pastor and Post, 1985; Kellomäki et al., 1992; Bugmann, 1994).

$$\mathrm{SNGF}(\mathrm{ntc}) = 1 - e^{-a(\mathrm{ntc})\cdot(\mathrm{avln} - b(\mathrm{ntc}))} \qquad (1)$$

where ntc is the nitrogen tolerance class, avln is the available nitrogen (kg ha^{-1} year^{-1}), and a and b are empirical constants. Instead of the three nitrogen response classes previously used, we parameterized five response classes to better differentiate the competition strategies of European tree species (Fig. 2). Each species thus is characterized by its response class which determines how well it can grow on soils of low fertility. Note that nitrogen availability is prescribed as a constant, site-specific value, since we have not added a model for the turnover of nitrogen in the soil as a function of litter quality and climate.

The other model we used was version 2.6 of FORCLIM (Bugmann, 1994, 1996b), which is based on an earlier gap model, FORECE (Kienast, 1987).

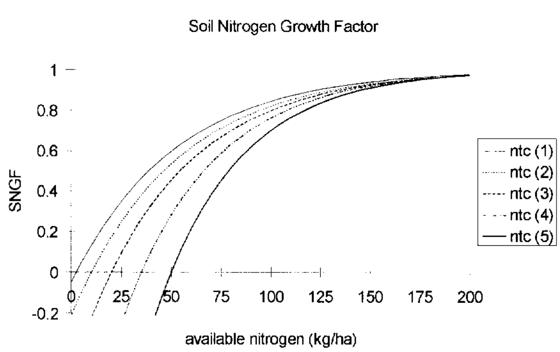

Fig. 2. Fertility response function SNGF as implemented in the modified FORSKA model with five response classes.

For the derivation of FORCLIM, all the factors included in FORECE were scrutinized carefully; some of them could be omitted, and the formulation of the remaining ones often could be improved, but the basic structure of the predecessor model was not changed. FORCLIM was used with two submodels in this study: (1) FORCLIM-P, a submodel of the population dynamics of trees based on the gap dynamics. It calculates establishment, growth, and mortality of the trees as a function of light availability, growing-season temperature, winter temperature, drought occurrence, and nitrogen availability (Bugmann, 1994). (2) FORCLIM-E, a model for the calculation of the inter-annual dynamics of the weather based on a stochastic weather generator and a simple 'bucket' model of soil water dynamics (Bugmann, 1994; Fischlin et al., 1995). Version 2.4 of FORCLIM yielded plausible results for forests in the European Alps (Bugmann, 1994) as well as for eastern North America (Bugmann and Solomon, 1995), but it did not behave satisfactorily along drought gradients (Bugmann, 1994), e.g. in the state of Brandenburg. To correct this, an improved submodel of soil water dynamics was developed, and a few species-specific parameters had to be estimated more precisely. The resulting model version was found to yield plausible results also along a gradient from maritime to subcontinental climate such as in Brandenburg (Bugmann, 1996a).

It should be noted that we did not fit any model parameters to improve regional patterns of forest composition. Both models were used with parameters from previous applications to few individual sites in the study region.

2.3. Site data

Soils data were derived from a digital soil map with a resolution of 1:1 000 000 (Federal Institute for Geosciences and Natural Resources, Hannover 1995). The map differentiates 18 major soil types within the state. For each soil type, typical soil profiles are provided, including information about maximum soil water holding capacity as well as nutrient and humus content of different soil layers. The water capacity of each soil type was calculated for a soil depth of 100 cm, except for (drained) bog soils, with an estimated soil depth of 50 cm. Since the soil profile information did not allow a differentiation of agricultural and forest soils, data on nitrogen availability were taken from the literature to exclude the influence of fertilization: fertility classes were assigned to each soil type according to Kopp and Schwanecke (1994), and for these classes the available soil nitrogen was estimated from other sources (Zöttl, 1960; Ellenberg, 1977; Heinsdorf and Tölle, 1991).

2.4. Vegetation data

Model results were compared with a map of potential natural vegetation (PNV) of Brandenburg (Krausch, 1993). This map is based on vegetation and site analysis, and it describes the type of natural forest that would grow without human management considering the present site conditions (Tüxen, 1956). PNV is an expert model of the relationship between site conditions (soil, topography, and climate) and natural vegetation. Quantitative model comparison was not possible, because PNV does not quantify species compositions. However, it is the only available source of information on natural vegetation, because virtually all forests in Central Europe have been subject to management in the past and at the present time.

2.5. Climate scenarios

Climate data and scenarios were taken from two sources: spatially explicit data of the current climate of Brandenburg (i.e. monthly mean temperature, cloudiness, and precipitation sum) were derived from the CLIMATE data base (Cramer et al., 1996). This data base uses long-term mean climate data from weather stations to generate spatially interpolated data for any x, y, z coordinate of a digital terrain model by means of multidimensional spline functions.

Since the resolution of state-of-the-art general circulation models (GCMs) is still too coarse for reliable regional climate change projections, other methods must be used to derive regional scenarios of climatic change (e.g. Gyalistras et al., 1994). For the present study, climate scenarios were derived from long-term observations at the weather station Potsdam by Gerstengarbe and Werner (1996). Following the rationale that in a changing climate there is a high likelihood that the occurrence of extreme events will increase (Enquete-Kommission 'Schutz der Erdatmosphäre' des Deutschen Bundestages, 1992; Katz and Brown, 1992), Gerstengarbe and Werner (1996) generated synthetic extreme years based on observed weather patterns, and randomly inserted them into the weather record of the last 56 years of the climate station Potsdam, with an increasing number of extreme years per decade. The synthetic years were constructed so that all climate scenarios project a temperature increase of not more than 1.5 K until 2050. The scenarios differ from each other mainly in the amount and seasonal distribution of precipitation (Gerstengarbe and Werner, 1996).

Since forest dynamics operate on the time scale of decades to centuries, it is unlikely that the species composition of forests will show a response within the next 50 years to a gradually changing climate. Therefore, to study the long-term effects of the projected climatic changes, we examined the steady-state forest composition in response to a hypothetical constant climate, which was assumed to correspond to the climate at the end of the 1995–2050 time period. The linear trends of the scenarios by Gerstengarbe and Werner (1996) for the site Potsdam were used to generate new constant climates from the year 2050 onwards (Table 1).

Finally, the monthly climate anomalies between current climate and the three scenarios at the station Potsdam were added to the spatially interpolated climate data of the CLIMATE data base. Thus, it was assumed that climate change would show no regional variation within the state of Brandenburg.

Compared with the results of different GCMs (Houghton et al., 1992), the scenarios for Brandenburg are generally at the low end of the projections with respect to temperature. Regarding precipitation, the scenarios reflect the high uncertainty of GCMs

Table 1
Equilibrium climate at the Potsdam site for current climate and two climate change scenarios (year 2050)

Scenario	Annual mean temperature (°C)	Annual precipitation sum (mm)
1 (current climate)	8.8	589
2	9.6	638
3	10.2	471

concerning future trends; in Scenario 2 the annual precipitation sum increases by 8%, whereas in Scenario 3 it decreases by almost 20%.

2.6. Simulation experiments

We ran the two gap models on 351 cells of a regular 10 × 10-km grid across the state of Brandenburg. Soil information was assigned from the dominant soil type of each grid cell, and we assumed neither a change of water holding capacity nor of nitrogen availability under the scenarios of climatic change. For each grid cell, we computed steady-state species compositions for the three climate scenarios as aggregated values of the simulation results. These are much easier to handle in the regional analysis than transient simulations, and at the same time they integrate information about competitive relationships between species (which is lacking in other model approaches). For technical reasons, the steady-state species composition was estimated differently for the two models: FORSKA – simulations were run over 600 years starting from bare patches without trees. The steady-state forest composition was determined by averaging the output of the years 400–600 on 100 patches. For FORCLIM, a new method was used where the simulation covers 31 000 years starting from a bare patch, and the steady-state composition is estimated by taking equidistant samples from this single run every 150 simulation years after discarding the first 1000 years of the simulation. The method was derived and described in detail by Bugmann (1994).

For better comparison of the results, forest composition was classified by the dominant species with respect to standing biomass into forest types similar to those of the German Forest Inventory (Bundeswaldinventur).

3. Results

3.1. Bioclimatic factors

In both FORSKA and FORCLIM, a number of bioclimatic variables and indices are calculated to model the effect of climate and site conditions on tree growth (Prentice et al., 1993; Bugmann, 1994). The temperature sum of the growing season as well as minimum and maximum temperatures of the coldest and warmest month are used to define species specific range limits. Because of the relatively small changes of the temperature regime in the climate change scenarios (Table 1), there was little effect of temperature thresholds on the simulated species distribution.

Another bioclimatic variable, the drought index, is more critical in the state of Brandenburg (Lasch and Lindner, 1995). Within the state lies the transition zone between maritime and subcontinental climate. Along the gradient towards drier subcontinental climate, frequency and intensity of droughts increase strongly. Both gap models calculate an annual drought index as the complement to the ratio of actual to potential evapotranspiration (Prentice et al., 1993). Fig. 3 shows the regional pattern of the drought index for the three climate scenarios. In addition to climate, the water capacity of the soil also influences water availability at a site, and therefore the observed pattern under current climate reflects regional differences of both climate and soils. While in climate Scenario 2 drought stress decreases slightly in some areas, under Scenario 3 it is much more intense in the whole study area. In some areas under Scenario 3, the index exceeds the tolerance of the most drought-adapted tree species currently included in FORSKA and FORCLIM. Thus, in those areas, tree growth would not be possible any more for any of the species that are present in today's forests of Brandenburg (cf. Fig. 5).

3.2. Forest composition

The differences of drought intensity between the climate scenarios have distinct influences on simulated species composition and the classified forest stand types. Fig. 4 shows a map of the potential natural vegetation under current climate according to Krausch (1993). Fig. 5 contains the simulated forest composition in the state of Brandenburg under current climate and the two scenarios of climatic change.

Under current climate, according to the map of PNV, beech forests would prevail in the north of Brandenburg (Fig. 4) as well as in few scattered subregions in the east and southwest of the state. Pine forests would occur only on the sites poorest in nutrients. The rest of the area would be covered by mixed forests dominated mainly by oak. In FORSKA (Fig. 5), the extent of pure beech forests appears to be overestimated, possibly because the model underestimates the drought stress of beech in subcontinental climate (Lasch and Lindner, 1995). FORCLIM, on the other hand, simulates hardly any pure beech stands. As long as beech is present, the model also yields a considerable amount of silver fir (*Abies alba* Mill.). This probably is a model artefact (Bugmann, 1994). However, since the two species are ecologically similar, most notably with respect to their shade tolerance, silver fir was considered to be characteristic of beech forests, too. Apart from these model-specific divergences, both models capture the broad forest pattern qualitatively (Fig. 5). While the original FORSKA did not succeed in reproducing differences in site quality (Lasch and Lindner, 1995), the results of the new version with the fertility response function show a good correspondence be-

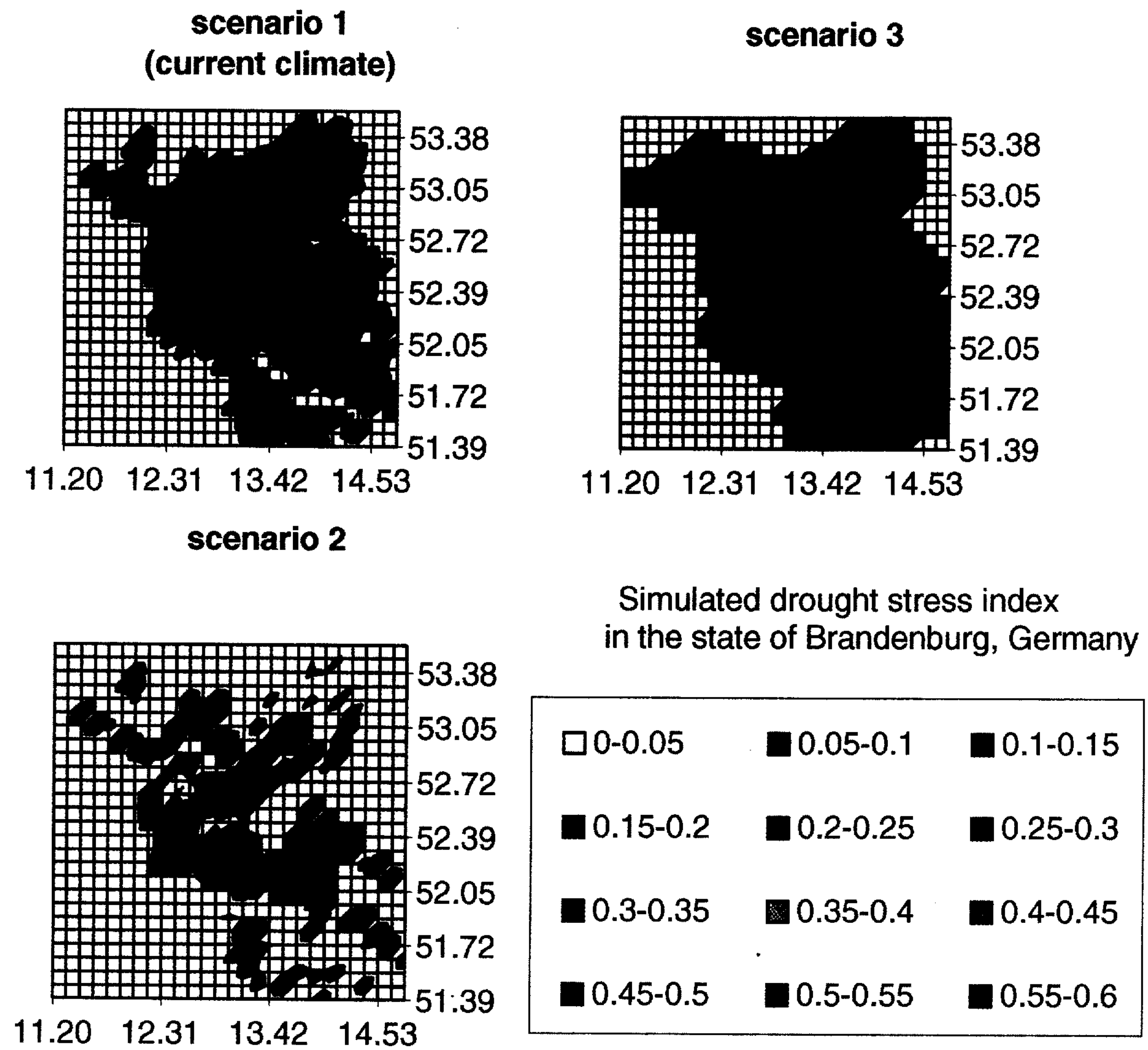

Fig. 3. Simulated drought index under the three climate scenarios according to the FORSKA model. The FORCLIM model yields a very similar regional pattern of drought index.

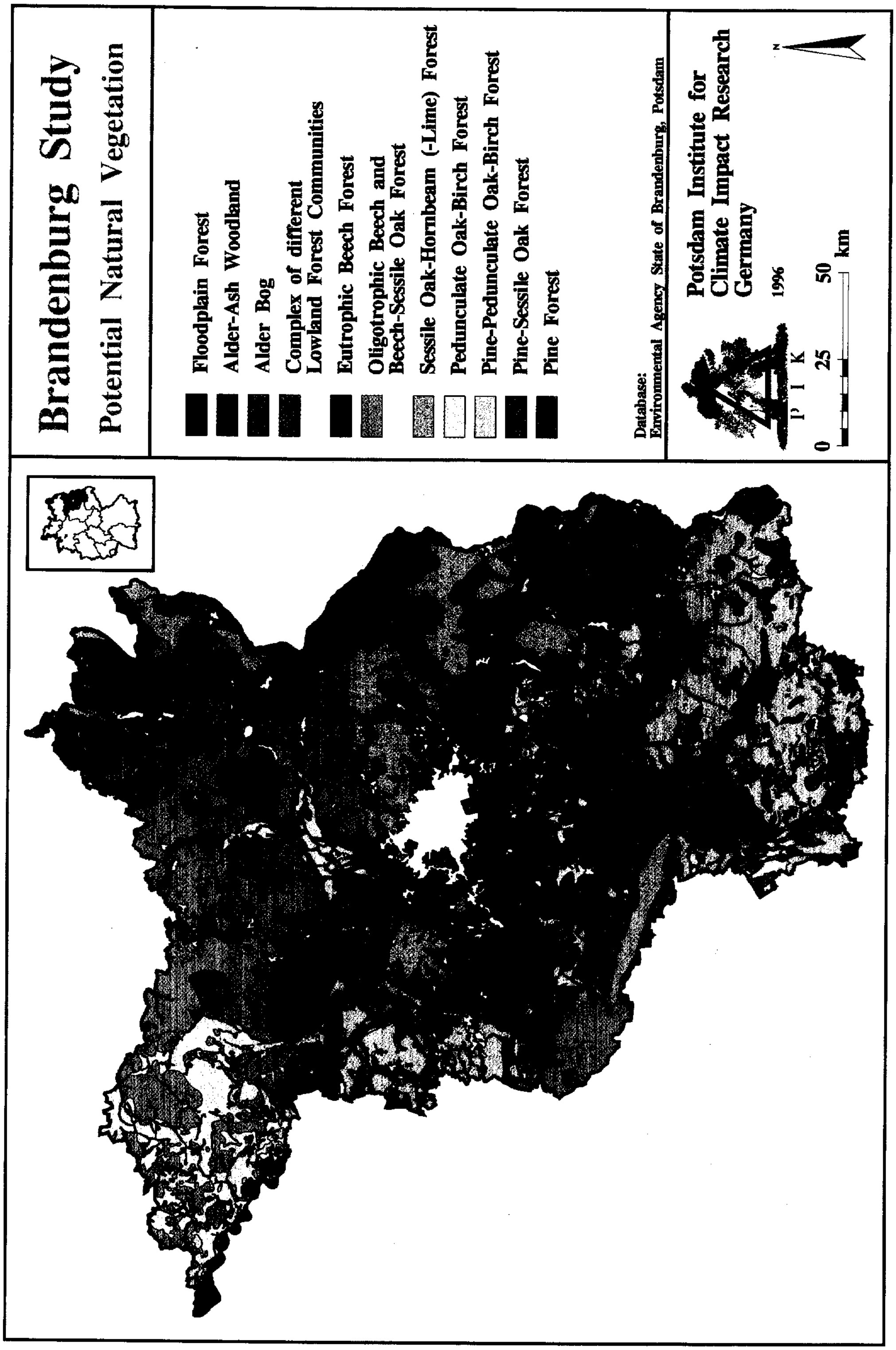

Fig. 4. Potential natural vegetation of the state of Brandenburg according to Krausch (1993).

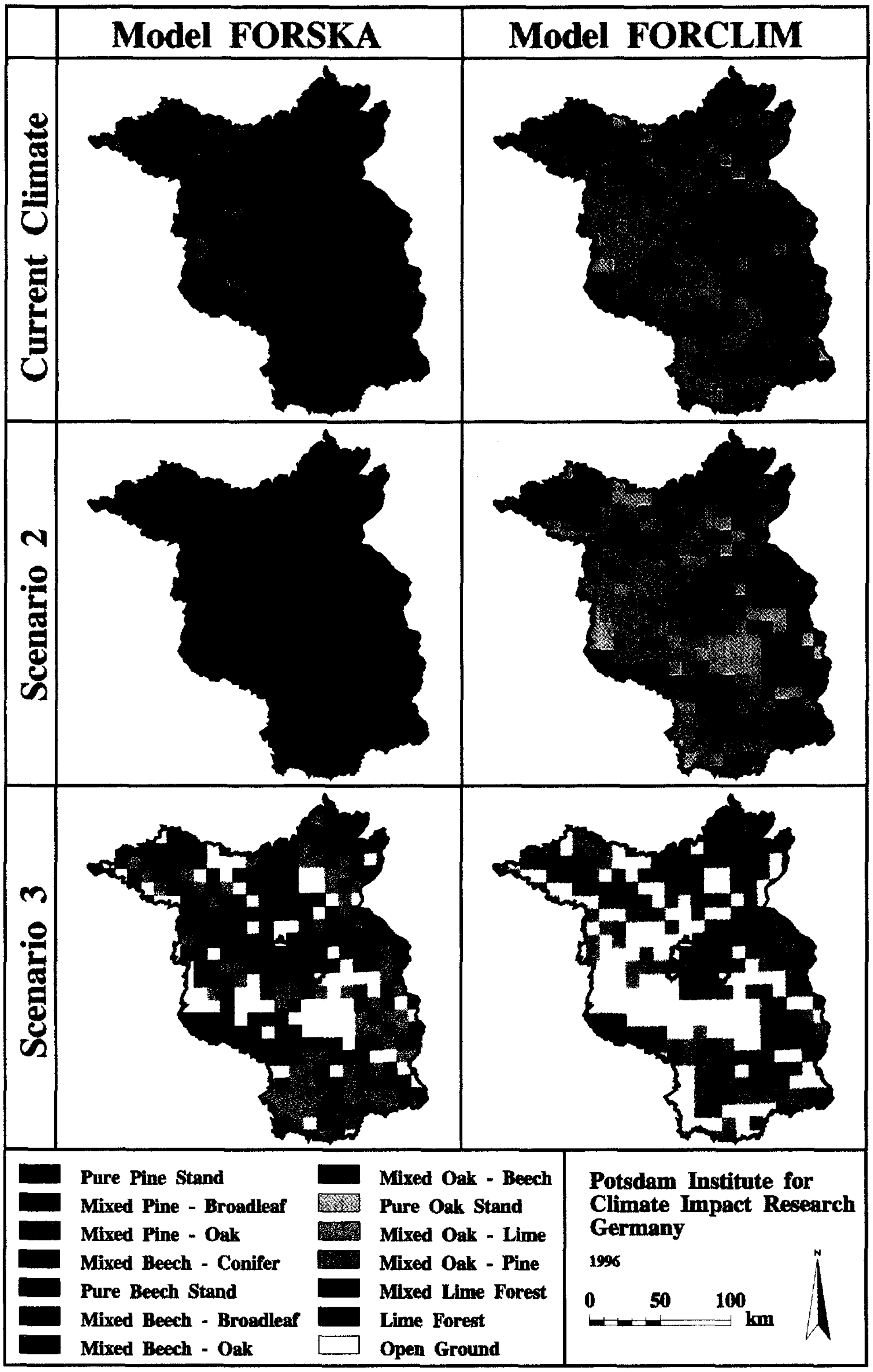

Fig. 5. Simulated forest composition in the state of Brandenburg under three climate scenarios. Classified steady-state species composition simulated by FORSKA (left) and FORCLIM (right).

tween simulated and mapped distribution of pine and pine/oak forest that occur only on sites of poor fertility.

With decreasing drought in Scenario 2, the abundance of beech increases in both models significantly compared with current climate. Pine is restricted to a small area to the southwest of Berlin. Whereas in FORSKA most forests would be almost pure beech forests, in FORCLIM the abundance of beech increases less strongly, and oak forests still dominate most of the area.

On the other hand, when drought increases (Scenario 3), in both models the simulated share of beech decreases to negligible values. According to both models all forests within the state are composed of drought tolerant species such as pine, oak, and lime. Moreover, in some areas forests are no longer simulated at all, as has already been indicated by the large drought index (Fig. 3). Again, there are some quantitative differences between the two models: FORCLIM tends to simulate a larger area of Brandenburg to be non-forested under this dry scenario, and the remaining forests consist mainly of pine, whereas in FORSKA oak and lime still have a considerable share on more fertile sites within the forested area.

It is also notable that the regional pattern of forest composition varies across the scenarios, i.e. there is no spatially uniform response to climatic change of these forests. For example, in the FORSKA results there is a higher degree of spatial differentiation under the dry climatic conditions of Scenario 3 as compared with the warm and humid Scenario 2.

4. Discussion

4.1. Simulated regional forest composition compared with a map of potential natural vegetation

Numerous studies have been conducted to study possible impacts of a changing climate on forests using succession models (e.g. Solomon, 1986; Pastor and Post, 1988; Kienast, 1991; Prentice et al., 1991; Lauenroth, 1996), but to our knowledge none of them investigated impacts at the regional scale. Some spatial applications of gap models have addressed small-scale influences between neighbouring patches (Urban et al., 1991; Bossel and Krieger, 1994), but they restricted their analysis to homogeneous site conditions and small areas. The landscape to regional scale heterogeneity of soils, climate, and topography may have a strong influence on forest growth and species composition. Therefore Luxmoore et al. (1991) have pointed out that in regional model applications (what they called extended range modelling) additional phenomena need to be accounted for by the simulation models. In our case study we considered the spatial variability of climate, soil water holding capacity and nitrogen availability to simulate regional patterns of forest composition in the state of Brandenburg. The results suggest that the models respond realistically to the spatial variability of the environment, and thus we believe that in general they are suitable for regional applications.

At the first glance, there seems to be little agreement between the simulation results of the two gap models and the map of potential natural vegetation. However, we could not expect to find perfect correspondence for various reasons: some differences stem from the forest classifications that do not match each other in the models and the map of PNV. For example, there are two separate classes of rich and poor beech forests (which also includes mixed beech–oak forests) in the PNV. Moreover, neither gap model is able to simulate the effect of waterlogging of soils or flooding in river plains, and consequently those areas should not be compared with PNV, (i.e. instead of red alder forest or flood plain forest the models simulate mixed or pure beech forest). Finally, the forest classification of PNV is mainly based on floristic maps, it does not include information on species abundances (e.g. pine–oak forests can be dominated by oak).

There is also considerable variation between the results of the two gap models, possibly because of differences in tree species parameters. Nevertheless, for the objectives of this study the accurate quantifications of species compositions may be less important. The main focus of this study was to investigate the importance of regional patterns of site quality and climate in the context of changing climatic conditions. Therefore we believe that qualitative comparisons between the models and PNV are sufficient, and they still allow a valuable plausibility test of the model results.

There are two major resource gradients in the study region influencing forest growth. One is the gradient of water availability, reflecting increasing evapotranspiration towards subcontinental climate from the north to the centre and southeast of the state; this gradient is considered to be responsible for the distribution limit of beech within the state. The second gradient reflects differences in soil fertility, which are mainly caused by the amount of time that has passed since the last glacier retreat. The younger moraines in the northern half of the region are generally more fertile, except for a few scattered areas where almost pure sand accumulated. According to the map of PNV, the natural abundance of pine (as well as birch in southern Brandenburg) is closely related to decreasing soil fertility. Whereas FORSKA reproduces the differences in soil fertility quite well, FORCLIM more realistically simulates the response of beech to the gradient of water availability. Although there are some disagreements with respect to the abundance and range limits of individual species, in general both gap models seem to capture major spatial patterns of the current potential natural vegetation of Brandenburg.

4.2. Robustness of impact assessments based on results from two gap models

Both FORSKA and FORCLIM are based on the gap dynamics hypothesis (Watt, 1947; Shugart, 1984). However, the models differ strongly with respect to the number of ecological factors included and their specific formulation. Therefore it is not surprising that there are many quantitative differences between the results of the two models.

The two succession models operate on a different temporal resolution with respect to the climatic input data. FORSKA is based on the long-term mean climate; Lindner et al. (1996) have shown that on water limited sites in subcontinental climate this resolution is not adequate to reproduce ecologically important climate extremes such as extended drought periods. Thus FORSKA tends to underestimate drought occurrence, which is an important limiting factor for the distribution of beech. Consequently the abundance of this species is overestimated in subcontinental climate, unless the model is tuned (Lasch and Lindner, 1995). FORCLIM, on the other hand, uses stochastically generated weather data instead of the long-term means to drive forest dynamics, and thus captures weather variability better. Hence the range limits of beech as produced by FORCLIM may be more realistic, although the model still overestimates the abundance of beech in southern Brandenburg compared with the map of PNV. The improved representation of climate variability in regional climate change analyses remains an important research need, especially if the transient effects of climate change are to be included in the study.

Another difference between the two models is that under current climate FORCLIM generally tends to simulate mixed forests, at sites where naturally one species, e.g. beech or pine, would form almost pure stands. In spite of such model-specific deviations it is reassuring to see that the qualitative behaviour of the two gap models under the climate change scenarios is quite similar. Both models show responses of the tree species to the changing environmental conditions in the same direction and in comparable order of magnitude. We conclude that the simulated shifts of the potential natural vegetation in Brandenburg under the scenarios of climatic change are independent of a specific model, and we surmise that these results may be characteristic of the true sensitivity of such forests.

4.3. Sensitivity of Brandenburg's forests to climatic change

We applied the forest succession models to analyse the regional impacts of two scenarios of climatic change on bioclimatic factors and the potential natural species composition of forests in the state of Brandenburg. Species composition appears to be quite sensitive to the amount of precipitation in the projected scenarios, because the state lies in a climatic transition zone with a gradient of water availability. Applications of forest gap models to such gradients have demonstrated that the sensitivity of plant communities to changes in the soil moisture regime is well represented by the models (Smith and Huston, 1989; Bugmann, 1994). However, due to threshold effects, the formulation of drought stress responses in some gap models may be unrealistically sensitive to small variations in water availability (Bugmann, 1994; Lasch and Lindner, 1995), which has to be taken into account when interpreting the simulations. Our results indicate that under climate scenarios with decreasing precipitation, the environmental conditions may change drastically, which would have severe consequences for the forest vegetation.

The comparison of the simulation results under the different climates reveals that the spatial patterns of forest composition may be different for each climate. The contrast is most obvious between the moist and dry climate scenarios (Scenarios 2 and 3). In a moist climate beech and oak dominate nearly the whole state on all soil types, except for sites that are very dry and poor in nutrients, whereas in a warm and dry climate, there is much more regional differentiation of forests between areas with mainly poor, mesic, or fertile soils. This finding again underlines the individualistic response of vegetation to climatic change.

4.4. Prospects of regional model applications

Many uncertainties are still inherent in global change simulation results of current gap models, which originally have been developed at individual sites with stable environmental conditions. Therefore, we believe that an important goal of regional model applications is in testing model performance under a wide variety of environmental conditions. At the same time, the results will also contribute in enhancing our understanding of the underlying processes of forest dynamics.

With increasing confidence in the robustness of model results at the regional scale, this type of model application will have additional practical relevance. Our analysis suggests that climatic change could have considerable consequences for the future competitive relationships between tree species in Brandenburg. Based on forest inventory data describing the initial states of forests for the simulations, the regional application of gap models may provide useful information for planning issues. Regional impact analyses could help to develop management strategies to cope with the risks of changing environmental conditions.

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