

Adaptation strategies in forest management under the conditions of climate change in Brandenburg

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ABSTRACT

The ecological stability of forests in the face of extremes of climate is primarily determined by the adaptability of the current tree species, the diversity of forest structures and the influence of additional stress factors (phytophagous, phytopathogenous, eutrophication and others). Against the background of the local conditions in the North-eastern German Lowlands, the adaptability of the main tree species for the period of the present climate scenarios (max. 50 years) will be evaluated, using the example of the federal state of Brandenburg. During this period, the Scots pine will remain the most important tree species from an economic point of view. The significance of pioneer tree species will grow in the future, for example due to their short generation time and their high rates of fructification. The competitiveness of the oak species and the common beech will continue to differ in terms of location. Different risk provisioning options for action for forest management will be introduced.

KEY WORDS

Adaptability, climate change, risk management, tree species selection

STARTING CONDITIONS

According to analyses of regionalised climate models, the northeast lowlands belong to the four risk areas most affected by climate change in Germany (Zebisch et al. 2005). Now, already, the climate in Brandenburg is dry, the influences in the northwest are oceanic and in the southeast continental. There are relatively large temperature fluctuations between the seasons and from region to region, for example a long-term average of up to 19.3 K between the warmest and coldest months in the southeast (Riek and Stähr 2004). The annual average temperature is 8.7°C with an average yearly precipitation of 557 mm. In the period 1951–2000, the an-

nual mean air temperature increased by between 0.7 K and 1.5 K. The largest amount of warming occurred in northern Brandenburg (Gerstengarbe et al. 2003).

In the same period, a reduction in precipitation in the summer months was recorded, while in winter there was an increase (Wechsung et al. 2008). The precipitation is countered by potential evaporation rates of 600 mm on average per year (Wattenbach et al. 2005). In the drier areas in the centre and east of Brandenburg, the climatic water balance is more negative and smaller than – 60 mm, in the wetter north and south it is positive and greater than 10 mm (Riek and Stähr 2004).

Primary producers such as agriculture and forestry, whose production is directly dependent upon climate

factors such as temperature and water supply, as well as on climate-influenced secondary factors (phytophagous, phytopathogenous), are particularly affected by changes to the climate. Due to the long-term periods of production, the restricted possibilities to react, the close proximity to nature and the multitude of different and, in part, competing objective targets (timber production, nature conservation and recreational function), the scope of action in forest management is much smaller than that of agriculture.

From an economic point of view, forestry is the second most important land use in the federal state of Brandenburg after agriculture. The proportion of forest is 37%, of which around 1/4 of the area is owned by the state. In 2002, forestry, including the processing industry, achieved a proportion of 4.1% of gross domestic product. In the entire forest and timber cluster, approx. 23,000 are employed in sparsely populated and structurally poor Brandenburg (Seintsch 2007).

Given the ecological and economic importance of forest and forestry, an analysis must be made of the potential threat from climate change and adaptation strategies must be developed. According to current knowledge, these observations can only be made for a few decades in advance, which barely represent half of a forest generation. This short time period is unsatisfactory in view of the temporal dimension of forest development.

As well as the climatic and edaphic features of the north German lowlands, the vulnerability of the forests is determined, above all, by the forest structure. 77% of Brandenburg's forests are planted with coniferous species, particularly pine, and only 23% with deciduous species (beech, oak, alder, ash, birch). With regard to the area size, 45% of the forests are between 41–80 years old (Müller et al. 2005). Therefore, timely, forward-looking and highly varied measures to reduce risk are urgently required.

EVALUATION OF THE RISK POTENTIAL

An efficient climate change risk management requires an evaluation of the vulnerability of forest ecosystems in the face of climate stress factors, which arise from the strength of the impact, the sensitivity / stability / elasticity of the system (of the objects / trees / tree species) and their adaptability.

On the side of the risk factors, periods of drought during the growing season, warm winters, early and late frosts, storms, forest fires and the changed population dynamic of harmful organisms are primarily relevant for future forest development.

On the impact side, the discussion focuses on the climate-related danger to forests regarding tree species and the development of stable forest structures (mixtures, horizontal and vertical forms of forest creation). From the multitude of concepts that exists, we shall highlight three in particular.

Firstly, there is the concept of “climate plastic forests” (Jenssen 2009). According to this concept, the climate plasticity of forests is particularly large where the ecological amplitude of tree species overlaps in the prevailing climate and the immediate local conditions, thus enabling socialisation. However, every tree species should ensure for itself different areas of possible climate scenarios. Natural examples are linden-hornbeam-beech forests and oak-beech forests with different mixture ratios.

Another concept is the evaluation of tree species on the basis of bioclimate envelopes (Kölling 2007). The representations known as bioclimate envelopes show the incidence rate (as a % of the total area) of every tree species under European climatic conditions in the combination of annual mean temperature and annual precipitation. Thus, the vulnerability of a tree species, faced with a change in the two factors observed (precipitation, temperature) would be low where the concrete location of the tree species is as far away as possible from its “ecological niche border”, i.e. with as large a survival buffer as possible. On this basis, the climate vulnerability of *Fagus sylvatica* (L.), *Fraxinus excelsior* (L.) and the oak species, for example, would be low, but for the four coniferous species *Picea abies* (L.) Karst., *Pinus sylvestris* (L.), *Abies alba* (Mill.) and *Larix decidua* (Mill) in contrast, high. The two-dimensional bioclimate envelopes cannot, however, take into account the fact that ecological niches are complex n-dimensional spaces and that the genetic norms of reaction of the woods are subject to evolutionary changes (Skelly et al. 2007).

The evaluation categories of Roloff and Grundmann (2008) differ from the two concepts mentioned above in that they include stress factors (dryness and frost) and site adaptability of woods according to cur-

rent knowledge (KLimaArtenMatrix-KLAM). In this respect, *Acer campestre* (L.), *A. platanoides* (L.), *Betula pendula* (Roth.), *Quercus petraea* (Mattuschka) Liebl., *Tilia cordata* (Mill.), *Robinia pseudoacacia* (L.), *Carpinus betulus* (L.), *P. sylvestris*, *Pinus nigra* (Arn.), *P. strobus* (L.) as well as *Sorbus aria* (Crantz), *S. domestica* (L.) and *S. torminalis* (L.) Crantz in dry to very dry locations, for example, will also be very adaptable in the future.

If we combine the three concepts of tree species evaluation and the criteria of adaptation and adaptability based on them, the survival prognosis, depending on location, of birch, hornbeam, common alder, field maple and robinia, for example, is large. There is also agreement on the critical development forecast of the Norway spruce (Spellmann et al. 2007; Kölling et al. 2009).

All three approaches for a forward-looking tree species selection are based on the assessment of current adaptation/stress tolerance as an evolutionary result of earlier and current environmental conditions. On the other hand, (1) the large individual, population- and origin-related variability of the adaptation of a tree species within its range and (2) the dynamic, evolutionary adaptability by means of mutation, genetic recombination and selection have not been taken into account.

Dynamic approaches, therefore, consider the changes in the genetic norms of reaction of individuals and populations in space and time. As well as considering mutation rates, the essential criteria of the genetic system that contributes to new recombination, distribution and the successful rejuvenation of “new” genotypes must also be taken into account (Kätzel 2008). During substantial changes in climate, evolutionary processes favour genotypes/populations that can quickly vary their genetic norms of reaction. During short-term climate changes, the types that can reproduce with minimum effort and a high individual number have an advantage. High speeds of adaptation call for short-lived generations, variable (high) fertility, early fecundity and changing high population densities. Population size, pollination and fertilisation mechanisms, generation length, fructification age and frequency, and the seed amount per tree are important criteria for evaluating the future adaptability of tree species. High, almost yearly seed production, short generational phases, wide pollen and seed distribution, a large genetic variety and much more predestine pioneer tree species (silver birch,

pine, poplar, robinia) in the process of selection when rapid and drastic environmental changes occur.

Against this background, the potential for adaptation of some important economic tree species in the state of Brandenburg will be examined below.

SCOTS PINE (*PINUS SYLVESTRIS*)

Since the start of the Forest Condition Survey, the most common tree species in Brandenburg displays the lowest crown transparency, despite periods of regional foliage loss due to phyllophagous insects. Intensive examinations of long-term, permanent observation areas show that the pine did demonstrate short-term physiological drought stress reactions in the extremely dry years 1999, 2003 and 2006, but that this did not lead to any increased dying off phenomena. In comparison to all other tree species it demonstrates the highest adaptability in the face of summer drought and warm winters. Tree ring analysis shows that the positive increases in the growth rate of pines are primarily attributable to high precipitation in February and mild temperatures in late winter or early spring (Schröder 2009).

Nevertheless, in terms of its distribution, the pine is a boreal tree species, which will, with higher temperatures and permanently recurring periods of drought, continue to react with increasing incidents of dying off in future decades. In Switzerland, at the south-western distribution border of the pine area, rejuvenation and competitive analyses show the beginnings of a reduction in pine, while at the same time, the pubescent oak (*Quercus pubescens* Willd.) spreads (Weber et al. 2008).

In Brandenburg, the dendroecological tree ring patterns also demonstrate pine’s increasing sensitivity to climatic signals (Schröder 2009). However, the actual stress-physiological limits of adaptability have not yet been reached under field conditions in Brandenburg (Kätzel 2008).

The actual danger to the pine consists particularly in its vulnerability to needle-feeding and bark-breeding insects. This was a fundamental argument for the reduction of the area of pine and the increase of the deciduous tree proportion. Some of these insect species will benefit from climate change and new insects and species of fungi will migrate to the region (Möller 2009). Nevertheless, due to its high degree of adaptation and

adaptability as a pioneer tree species, and with suitable pest management, the pine will continue to form the backbone of Brandenburg's forest and timber economy in the coming decades.

OAK (*QUERCUS PETRAEA* AND *Q. ROBUR*)

Due to their habitat requirements, the two native oak species (sessile oak, pendunculate oak) belong to the tree species of the future, particularly in southern Brandenburg, where they are being especially encouraged in the context of forest conversion. In terms of area cover, their proportion is currently approx. 5% of total forest area. The proportion will, however, grow, as pure pine stocks have been "mixed" on a large scale with oak in the last 10 years.

A critical view must be taken of the high proportion of damaged oaks. For over two decades, oak trees have belonged to the most damaged tree species in Europe. Their rate of damage is between 35 and 45%. Middle-aged (60–120 years) oaks are particularly endangered. The pendunculate oak, in locations close to the ground-water table, is more affected than the Sessile oak. In instances of ground-water table drawdown, the pendunculate oak is barely able to shift the root growth to deeper soil layers (Riek 2006). The sessile oak recovers only slowly from drought stress occurrences in distant locations (Kätzel et al. 2006). On the other hand, dendroecological surveys show no increasing sensitivity to climate compared to pine. In terms of growth, the oak benefits primarily from strong June precipitation and from cool summers (Schröder 2009). One cause of the high degree of damage to the oak could be attributable to the trunk-intensive cultivation, which leads to an underdeveloped crown with many consequential damages (Elmer et al. 2009).

COMMON BEECH (*FAGUS SYLVATICA*)

The focus of distribution of the common beech is in northern Brandenburg. For more than 30 years, the pine stands have been under-planted by the shade-tolerant beech, so that its proportion is growing. The tolerance of the beech towards extremes of climate is heavily disputed (Wolf 2008; Meier and Leuschner 2008; Kriebitzsch

et al. 2008). The beech belongs to those tree species that develop their greatest competitive capacity in humid and nutrient-rich locations, so that their adaptation and survival probabilities are often seen as critical under the conditions of climate change. On the other hand, an increasing natural rejuvenation of beech is taking place in the uncultivated natural forests in drier locations in central and southern Brandenburg. The adaptability of the beech was quite possibly underestimated in the past. Genetic examinations show clear differences between the individual beech populations in Germany (Bavaria, Hesse, northern Germany, Schlaube Valley in Brandenburg) (Maurer et al. 2007).

ROBINIA (*ROBINIA PSEUDOACACIA*)

With around 9000 ha, Brandenburg has by far the largest robinia area in Germany. Due to its invasive shoot-bearing capabilities, the proportion of robinia will continue to increase in the future. Corresponding to its eco-physiological amplitude, the robinia is particularly suited to planting in nutrient-poor and dry habitats. The significance of the tree species, both for renewable and for energy use, could well grow in view of the predicted climate changes. The robinia produces very durable wood, which has developed a very high heat rating thanks to its high density and low heartwood moisture.

This is countered by the "negative experiences" in local cultivation with the tree species and features specific to it, mostly based on a lack of knowledge, which makes rejuvenation and cultivation difficult. Since the growth of the robinia as a light-demanding tree species culminated very early, the available potential has as yet hardly been used.

SOFTWOOD DECIDUOUS TREES (*SALIX SP.*, *BETULA PENDULA*, *POPULUS SP.*)

The adaptation tolerance of softwood deciduous species (willow, birch, poplar) to extremes of weather has not yet been satisfactorily examined. As common pioneer tree species with a high rejuvenation potential, high light demands and quick growth, some species have a comparably high adaptability. Due to their low age, the cultivation risk sinks with a shorter period of use.

For this reason alone, the proportion of these species could grow, not only on agricultural energy-producing wood plantations, but also in forests.

FURTHER TREE SPECIES

The future increasing significance of further thermophilic and drought tolerant tree species is under discussion. In this context, the area of the Douglas fir [*Pseudotsuga menziesii* (Mirb.) Franco] and Grand fir (*Abies grandis* Lindl), as alternatives with small-scale plantations, will grow. Trial cultivation of Sweet chestnut (*Castanea sativa* Mill.) and Turkish oak (*Quercus cer-ris* L.) is also being examined.

However, one problem of these tree species is the reduced frost tolerance. Even though the frequency of frost events will decrease in future, singular winter frosts and late frosts must still be expected. To combat this, frost-tolerant varieties must be won, for example by means of selective breeding. Until then, wood of this type will remain a niche product.

CHOICE OF PROVENANCE AND PHYSIOLOGICAL PLASTICITY

The discussion of suitable tree species remains unsatisfactory as long as the inner-species variability of tolerance towards weather extremes is not evaluated. It has basically been shown that the physiological adaptation potential of trees to extremes of weather is much higher than previously thought (Kätzel 2008). Climate-related changes in the structures of forests result from selection (survival or death) due to extreme environmental factors at the level of the individual. Until now, however, hardly any scientifically verified ranges of tolerance, e.g. for heat (critical thermal maximum — CTM) and dryness are known, although the establishment of physiological limits for each tree species is essential for the evaluation of climate risks. In this case, area size and the distribution density within the area should be considered.

Provenance experiments, for the most part originally designed with yield-based objectives, today form an important basis with which to examine ecophysiological questions on the adaptability of different provenanc-

es of the distribution area of a species. It is often shown that growth and physiological adaptation are competing processes (Herms and Mattson 1992).

Based on a 13-year pine provenance test, Rehfeldt et al. (2003) were able to show a correlation between the growth in height and the heat summation ($> 5^{\circ}\text{C}$) of the original region along the east-west gradient of the Russian distribution area. Corresponding to the large plasticity of the tree species, the growth contour lines merged, depending on provenance. This meant that the growth of some provenances accumulated at 1500 grd., while others required 2700 grd. Davis et al. (2005) got similar results for *Pinus contorta* (Dougl. ex Loud.) from different provenances in western Canada and conclude that the frequency of a currently growth-dominant provenance is reduced by neighbouring (better adapted in the future) populations, when gene replacement is ensured.

Some experiments in the pine provenance test “Chorin 85”, set up by Schwappach in 1908, underline the different adaptation and growth strategies of pines from climatically different areas of origin. The test considered eight pine provenances that range from Scotland in the northwest, France in the southwest and Russia in the east (Kätzel and Löffler 2007b; Schneck 2007). Periodic recordings of yield-based parameters show that pines of the Masurian provenance had the largest height and trunk diameter. The lowest growth success with, at the same time, the worst trunk shape was achieved by the pines of French provenance (Lockow 2002). On the other hand, in the three foliage years, the greatest water losses in dry periods occurred in pines with Latvian, Masurian and Russian provenance, while the provenances France and Brandenburg did not fall short of the needle-age-specific “critical values” (Kätzel and Löffler 2007b).

ADAPTATION STRATEGIES IN FOREST MANAGEMENT

Discussions about adaptation strategies are held for two different targets. From a physiological perspective, an adaptation strategy is considered to be successful when the survival of the individual/the population/the species is ensured. This means that the preservation of the forest ecosystem is possible. However, this does not nec-

essarily include a growth of biomass (wood and value increment). From the perspective of forest management, on the other hand, an adaptation strategy is successful when there is a simultaneous increase in value, respectively when all forest functions can be fulfilled. But physiological adaptation processes that are intended to secure survival are bound up with a loss of energy sources and biomass.

With regard to silvicultural strategies, therefore, Wagner (2008) differentiates between a classical „functional conversion” (facilitated migration) and a “sustainable conversion” (no regret option). The “sustainable conversion” is directed towards the increase of adaptability of forests and no longer towards concrete forest functions. While this strategy reduces the economic productivity of forests, it also reduces the economic and ecological risks.

DIVERSIFICATION OF TREE SPECIES

As referred to at the beginning, a decisive adaptation strategy focuses on the targeted promotion of certain tree species and provenances. The “forest conversion programme” began in Brandenburg as early as the 1990s, i.e. before the acute phase of the current climate discussion. The objective of the forest conversion is to transform pure pine stocks of the same age into well-structured pine-deciduous mixed stock. The diversification of tree species should lead to the reduction of damage risk. The planned increase of oak (mixed) forests by an additional 161,000 ha alone is a priority task that will last many decades. The timeframe of the programme results from, among other things, the necessary stock age of the pine stock to be converted.

The current climate discussion has not yet led to any changes in the selection of tree species for the targeted stocking of the forest conversion. There are many reasons for this:

- Forest management, in contrast to agriculture, is directed towards long-term periods of operation. A short-term change of tree species selection is not implementable, either organisationally or financially, and cannot be professionally justified based on current knowledge.
- Due to their physiological adaptability gained over the course of evolutionary periods, long-living for-

est tree species demonstrate high elasticity when faced with changes to the environment. They are hardly modified by breeding, as a population they are highly variable genetically and therefore much less vulnerable to environmental changes.

- In view of present climate scenarios, there are currently no forest tree species available for a large-scale plantation that are, according to verified knowledge, better suitable to withstand extreme climatic events and therefore justify short-term, far-reaching changes with long-term consequences.

DIVERSIFICATION OF FOREST STRUCTURES

The majority of target stock type is orientated towards mixed forests. In this instance, groups of mixtures are more economical, more secure and more effective than individual tree species mixtures (Bäucker et al. 2007). Horizontal mix forms (e.g. groups of trees) guarantee the buffer effect while growing, reduce the interspecific competitive problems and improve the microclimate. The preservation of old and dying trees in biogroups promotes niche diversity, creates habitats for zoophagous, beneficial organisms and stabilises the entire stock. Timely crown care encourages growth, blooming and fructification as well as an optimised root development. At the landscape level, forest gaps (e.g. on areas of catastrophe), underplantings and natural rejuvenation among vital old stock lead to variety-rich mosaic structures.

DIVERSIFICATION OF THE GENETIC PATTERNS OF REACTION

Genetic variability, as a forest genetic resource, is the decisive security reserve in selection by extreme climatic factors (Kätzel 2009). In practice, this means a long-term approach in the natural rejuvenation of stocks, for example. Based on experiences of former disturbances or, where applicable, on ecophysiological/genetic inventories, it must be checked, in cases of doubt, whether reproducing stocks are suitable as seed sources for the natural rejuvenation and thus for the sustainability of the forests. It is possible that artificial rejuvenation measures with certified forest plants from genetically

characterised harvested stock will have a greater significance in the future. That said, an increase in seed supply fluctuation is to be expected, since the seed production is negatively influenced by extremes of weather. This particularly affects the critical phase of bloom formation, lack of water in the mature phase and the increasing danger of insect damage and infection of the seeds. In the case of artificial regeneration, all measures that guarantee a high genetic diversity must already be considered during seed extraction. If necessary, the seeds of original stands should come from a mixture of crop years.

REDUCTION OF SECONDARY RISK FACTORS

Most results of physiological studies lead to the conclusion that, in each case, forest trees' potential for adaptation to one stress factor is usually higher than expected. However, it becomes critical when further stress factors (insect feeding damage, acidification, emissions, soil compaction, ground-water table drawdown etc.) are added to the extreme climatic factors. Therefore, in the context of risk prevention, additional stress must be avoided. If necessary, pesticides must be applied earlier, or more often, than is currently usual (Möller 2009).

Excessive stocks of hoofed game are secondary damage factors. If, in the course of the selection processes, stress-tolerant tree individuals emerge, but are then quickly fed by herbivores or destroyed in forest fires, then the biological self-regulation processes are a failure.

ADAPTATION OF FOREST MONITORING

In order to recognise in time, and possibly to reduce, risks to forestry and damages that result from these changes, modern forest monitoring on a strong regional basis is indispensable. This applies both to the early indications of stress reactions and also to the recording of irreversible damages (Kätzel and Kallweit 2008). For the early detection of potential dangers, genetic and forest growth reactions must be more strongly connected to studies on adaptation-relevant characteristics in future (Kätzel et al. 2005). Extreme climatic factors will lead to an increased dying off of individual trees within

stocks. These trees or groups of trees must be detected early for different measures (timber use, forest protection, prevention of danger to ensure traffic safety etc.).

REDUCTION OF PRODUCTION PERIODS

With the accumulation of climatic extremes it will become necessary to increase the flexibility of forest management. This includes the reducing of the rotation age/target diameters as a measure to reduce the risks of long-term production periods. This process will be accelerated by the increasing proportion of fast-growing pioneer woods and the premature dying off of long-living trees.

MULTI LAND USE WATER MANAGEMENT

The availability of ground water during the vegetation period will be decisive in determining yields and survival. For this reason, the loss of water from above-ground aquifers must be prevented and water storage, e.g. in forest mires, must be used. The introduction of deciduous tree species should also improve ground water formation for all land uses (Müller et al. 2007).

CONCLUSIONS

Changes in climate, and weather extremes in particular, are radical selective factors that will change forest structure, including tree species composition, in the future in a regionally differentiated manner. Selectively effective extremes of weather will naturally shift competitive relationships and produce "losers", but also "winners" on all levels of the ecosystem (individual, population, ecosystem, forest community, landscape). In the medium term, this will have a negative impact on financial returns.

Under the aspect of the physiological capacity for survival, long-living tree species in particular have efficient adaptive reactions to stress caused by weather. For this reason, the current view does not foresee that the forest ecosystem in the northeastern region will become a forest steppe in the period of the available climate scenarios (to 2060). Currently, all recommenda-

tions for tree species suitability and risk management for this period are based on a qualitative assessment. For long-term strategies, a quantitative assessment of the adaptability is essential. Until now, there has been a lack of reliable research results on this point.

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