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SILVICULTURAL RESPONSES TO PREDICTED CLIMATE CHANGE

Increased concentrations of greenhouse gas emissions are causing a general warming of the global climate and altering the conditions for life on Earth. Changes in climate will likely have a considerable impact on forest structure and its resilience. The range of tree species, the interspecific competition and the interaction between species may alter. The paper compiles and summarizes already existing knowledge about observed and projected impacts of climate change on forests and likely responses of trees and stands with special respect to Germany and reviews silvicultural options for management on stand level to adapt forest stands to climate change.

Key words: *climate change, silviculture, impacts on forests, biomass, forest management strategies, forest conservation.*

Introduction. Over the last century, global mean surface temperature has risen by about 0.6 ºC [1]. Although not unprecedented, this rate of warming is likely to have been the greatest of any century in the last thousand years. Data collected over the past 150 years by 188 members of the World Meteorological Organization (WMO[1]) lead to an unmistakable conclusion: the observed increase in global surface temperatures is a manifestation of global warming. It has accelerated particularly in the past 30 years. Notably, the current period is one of exceptionally rapid warming [2].

Changes in climate variability and extremes of weather events have received increased attention in the last decades. By now we know that climate is continuously changing, with some periods comparatively stable, and others with great variation [3]. There is a number of factors that drive climate variability (changes in Earth's orbit, changes in solar output, sunspot cycles, volcanic eruptions, and fluctuations in greenhouse gases and aerosols). These factors operate over a range of time scales but, when considered together, effectively explain most of the climate variability over the past several thousand years. The global warming has been attributed to both natural and human forcings, that is undeniable, but most of the warming observed over the last 50 years is caused and attributable to human activities [4]. The recent changes in climate can only be explained when the effects of increasing atmospheric concentrations of greenhouse gases are taken into account. But understanding changes in climate variability and climate extremes is made difficult by interactions between the changes in the mean and variability [5].

It is not our intent to figure out possible causes for the current situation more in detail. In this context we would like to refer to the relevant publications of the IPCC [6]. Simply essential is the fact that the scientists have evidence for the climate changing and that we do not longer have a controversy discussion among experts. Therefore silviculturists must be aware of the implications of climate change in order to establish stands being adaptable, sustaining health and productive in the future.

Uncertainty in predicting.

A) Uncertainty in predicting the most likely scenario

Globally averaged surface air temperature likely increases during 21st century under different scenarios. Figure 1 shows the time-series of globally averaged annual mean surface air temperatures from all the IPPC-experiments [6]. Compared to the temperature at the end of 20th century (years 1990–1999, black curve), the surface air temperatures at the end of 21st century (years 2090–2099) is predicted to increase by 3.7, 2.5 and 1.5°C under the A2, A1B and B1 scenarios, respectively. Furthermore, the surface air temperature keeps increasing even under the stabilized radiative forcings beyond year 2100 at all the greenhouse gases stabilization levels. Under the overshoot scenarios, the glo-

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[1] The specialized agency of the United Nations and authoritative voice on the state and behaviour of the Earth's atmosphere

bally averaged surface air temperature decreases to almost the same level as the B1 level. The A2, A1B and B1 scenarios show respectively 3.7, 2.5 and 1.5°C. The surface temperature keeps increasing even after the greenhouse gas concentration (GHG) is stabilized, and it takes very long time for climate system to be stabilized (fig. 1 and 2).

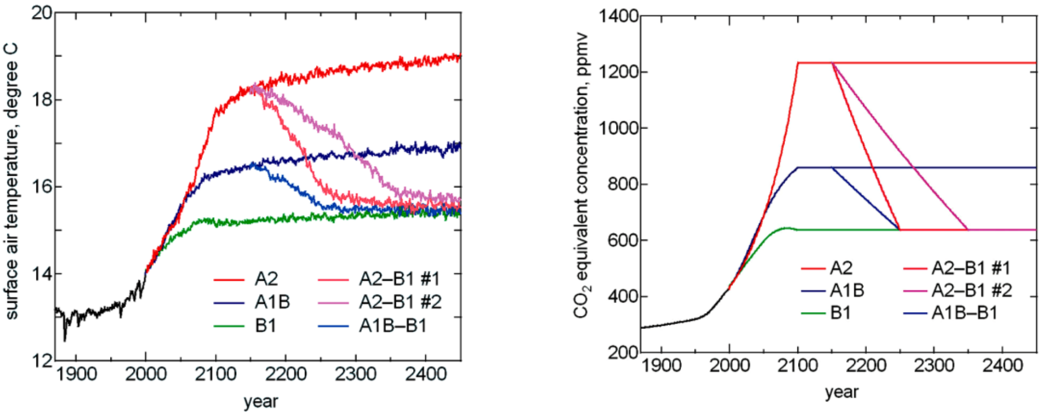

Fig. 1 and 2. Time-series of globally averaged annual mean surface air temperature (left) and GHGs concentration profiles used in numerical experiments (right); (mod. IPCC, 2007)

Even if these and other climate forecasts seem to be better and better - intensity and frequency of disaster occurrences are still open and interaction with other dynamical environmental factors are doubtful (see C).

B) Regional climate scenarios for Germany: downscaling from global scale to local scale

In principle, the simulation of climate scenarios is performed at global scale using a global circulation model because atmospheric system is a single system. Even though there are efforts towards developing custom-fit climate scenario at global scales, most of today global climate models still generate future climate scenarios at large grid size of several hundred kilometres.

In contrast, performing silvicultural strategies in principal is a task on stand level. Therefore, downscale process to get information regarding climate change at specific locations for specific forest sites is required for the assessment of climate change impact. Up to now the regional climate models are even more uncertain, the more the smaller the scale is. Up to now we cannot await an accurately fitting climate model on local scale. Nevertheless, an adaptation of climate planning data in forestry is needed, i.e. climate zones (= update).

Anyway, we will never have a model predicting extreme single weather condition on the scale of a forest stand. Ergo the situation of uncertainty will be a long-lasting basic condition for the manager responsible for local forest stands.

C) Interactions are doubtful

In addition to climate change a dramatic increase in nitrogen inputs over the last century has resulted in major changes to the German ecosystems including changes in plant species dominance and diversity, increases in plant productivity and altering conditions of site-specific competition for natural regeneration of trees. Such changes are comparable in scale to those of increased temperature and CO_2. The clearing of forests, draining of wetlands and the cultivation of forest soils for agriculture lead to significant increases in atmospheric CO_2 as organic carbon in the soil and above ground biomass was decomposed [7]. Although ecologists acknowledge the importance of these changes, a thorough understanding of interactions between nitrogen deposition and global change and the mechanisms responsible are lacking [8].

D) changes in interspecific competition

Another uncertainty regards the outcome of interspecific competition. The evaluation of every today’s interspecific competition has a limited significance for future conditions because the today´s analysis is retrospective in every time.

E.g: the response to warming temperatures is typal. As a result, new interspecific relationships are likely to develop where species with life cycles responding to temperature interact with species controlled by photoperiod [9, 10]. Some investigations show, that the competition between evergreen plants (like *Rubus fruticosus*) and beech seedlings alters under the conditions of climate change because longer growing seasons are advantageous for the photosynthetic potential of competing vegetation [11].

Likely environmental changes and potential Ecosystem responses. Most models agree that the warming will be greatest over eastern Europe in winter and over western and southern Europe in summer. In northern Europe the increase in temperature is similar in all seasons. The temperature changes are coupled with increases in mean annual precipitation in northern Europe and decreases further south.

According to the results of Christensen et al. [12] the temperature changes are coupled with an increase in mean annual precipitation in northern Europe and a decrease further south. Regarding extreme events, the yearly maximum temperature is expected to increase more in south and central Europe than in northern Europe. In central, southern and eastern Europe, the summer warming will be more closely connected with higher temperatures on warm days than with a general warming while much of the warming in winter is connected with higher temperatures on cold days [13].

Under many climate change scenarios, increased temperature and increased frequency of summer drought may result in more stressful forest environments owing to, among other reasons, an increased evaporative demand combined with limited soil moisture [14]. But intensity and serious consequences depend on the site! Namely the more the site is continental the more serious the consequences are.

The predicted environmental changes will meet established forest ecosystems. Under some predictive scenarios, changes in climate may occur that will exceed the capacity of existing forest tree populations to adjust physiologically and developmentally. Actual impacts will depend upon the physiological adaptability of trees.

A) Direct ecosystem responses: vitality of tree species and outcome of interspecific competition

The range of European forests is limited primarily by climate, either through moisture availability or through temperature (both, absolute amounts and seasonal distributions) [15]. Each tree species has a more or less specific geographical distribution that is related to its range of adaptation to the forest site. Thus, the climate factors predefines where and how forests grow and determines resp. limited tree species composition. Likely affects of increased moisture stress include reduced growth and productivity and decreased economic value of forest stands.

But our forests are likely to be widely more impacted by the predicted changes in climate. The pace of these changes could overcharge trees and stands in their adaptability. The effects will be a complex of biophysical factors. The potential ecosystem responses to climate change affects physiology, phenology, range and distribution, and abundance of species [16].

Trees of the same species adapted to gradual climate change have an advantage. There will be a selection within the gene pool already existing. Less flexible individuals will die off.

Changes in climate exceeding the tolerance range will cause readapting interspecific competition. Fig. 3 exemplifies this phenomenon for common tree species in Germany: The wet Alnus-dominated sites (its natural range) will almost wither, the very wet sites get adaptable for Beech, and Pedunculate oak will be displaced. On the other hand Common beech will likely become less important on semi-dry sites (for the benefit of Pedunculate oak).

In addition to the already existing site spectrum we will probably identify sites specifics never found before. Beyond the oak range there will be extreme dry conditions (especially in continental areas and on soils with low water retention) eligible for *Robinia pseudacacia.*

This change of tree species is combined with an alteration of vitality parameters (like increase of growth, susceptibility, etc.). Decreasing vitality of a tree species may compensate lacking growth of another. With respect to soil humidity we will notice a differing sequence of the considered tree species. Fig. 4 points out the response of tree species when environmental factors are changing. Tree species close to their biological limits (in terms of temperature and moisture) will be more sensitive to climate change than tree species near the middle of its ecological optimum. In consequence of dry spell there will be no decrease in dominance of Locust but an adverse balance for Beech (and its regeneration).

The Beech response to temperature regime and water availability seems to be significantly affected by intraspecific competition as Cescatti & Piutti highlighted [17]. When competition is strong, trees show a high sensitivity to water balance whereas, at low competition level, trees react positively to high temperatures.

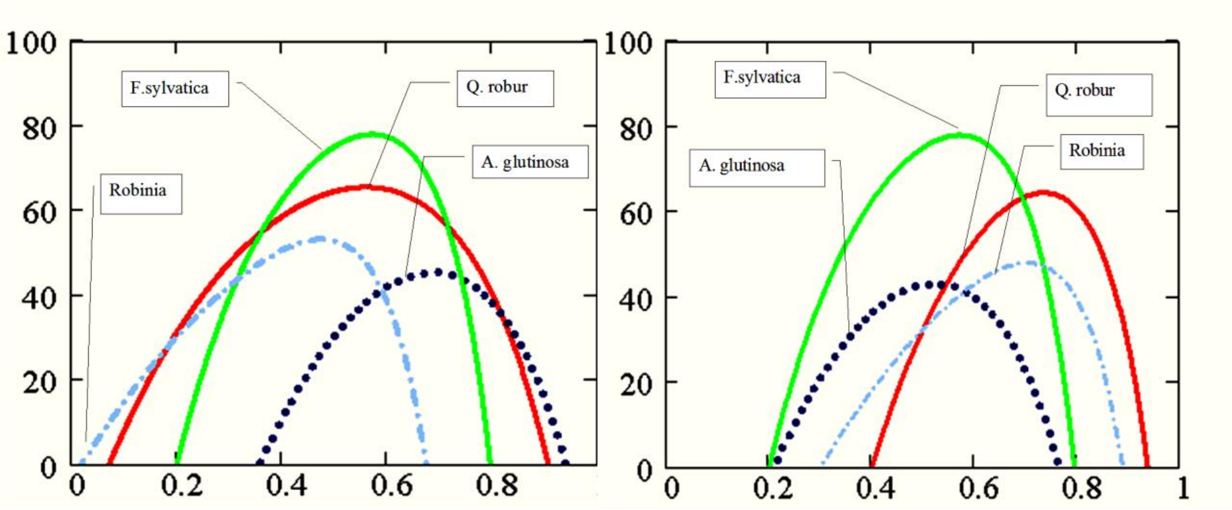

Fig. 3 and 4. Vegetative vitality (e.g. growth) of different tree species plotted against site humidity (left) and against temperature within growing season of the site (right). The axes are standardized

In general, tree species with high climate amplitude probably will be more robust (such as Common oak and Birch trees). Norway spruce will turn out to be a problematical tree species, especially on sites with potential risk for dry spell (sites with small thickness in upper soil, warm and south inclination sites with high radiation, compressed soils with stannic properties or temporarily anoxia (for details see *(D) Vitality of single trees and stands*). An alternative to Norway spruce management is the mixture with/or the establishment of pure Douglas fir of adapted provenance. In case of decreasing vitality of spruce Douglas fir might compensate growth deficit. Douglas fir is known as a tree species comparably tolerant to dry spell (fig. 5).

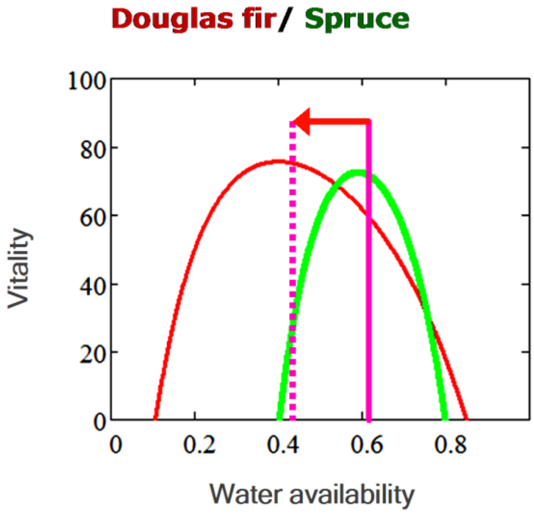

Fig. 5. Vitality of Douglas fir (Pseudotsuga menziesii) and Norway spruce (Picea abies) with respect to soil water availability 5. Vitality of Douglas fir (Pseudotsuga menziesii) and Norway spruce (Picea abies) with respect to soil water availability

Silvicultural management in a changing environment is a crucial research task which needs investigation objectives and techniques convenient for new arising problems. Exempli gratia the ability to natural regeneration! It is evident that we have to look more in detail to the tree specific demand on climate and soil. It would be not enough to focus on growth and vitality of the old stand. Already existing mature stands may be good adapted to climate change and may abound in vitality. But tree species communities, single plant species or genotypes may be poorly adapted to future climate conditions if you go more in detail in single steps of their life cycles, for example resulting in lacking safe sites for natural regeneration, increased risk of regeneration failures, altered trajectories of forest growth, development, and productivity. A long run adaptation of trees should consider all parts of the life cycles: pollination, flowering, fructification, seed/fruit dispersal, and germination in specific safe sites, establishment of seedling and growth of the young tree [18, 19]. We have to ask if the new localities ensure well-balanced factors and resources for the young tree or whether we have to postulate high resilience against stress-induced or competition-induced mortality.

Another monitoring with regard to Germans most important broadleaf tree species arouses our suspicion that combination of environment factors will probably change in future. Schmidt [20], (fig. 6) could support an increasing frequency of masting during the last 20 years in beech. We do not have any final explanation for this phenomenon. It is expected, that global change (periodical higher temperature in the early summer before the mast) could be responsible for this generative beech potential. Perhaps there are additional influences by the atmospheric deposition of nitrogen promoting the generative capacity of beech stands.

Another important facet affects the biomass distribution of trees under the terms of global warming: An interesting long term study in Russia [21] highlights shifting allometries in tree compartments in changing environment. In areas where summer temperatures and precipitation have both increased, a general increase in biomass is primarily a result of increased greenery, rather than roots and stem. In areas that have experienced warming and drying trends, greenery has decreased, and both roots and stems have increased. It is most likely that this is a tree specific feature and that we have to assume specific capacities for the adaptation to changing environment.

Of course, addressing questions of root and rhizosphere function in the field is difficult and vexed with problems and uncertainties. Thus, this study once again stresses the importance not to disregard the subsurface reaction of tree vitality and to have a look more in detail into the fine roots of stand development. Ecosystem-level observations of root and soil processes as influenced by global change are beginning to emerge [22]. Unquestionable a deeper understanding of root dynamics is critical to describe the integrated response of forest ecosystems to global change.

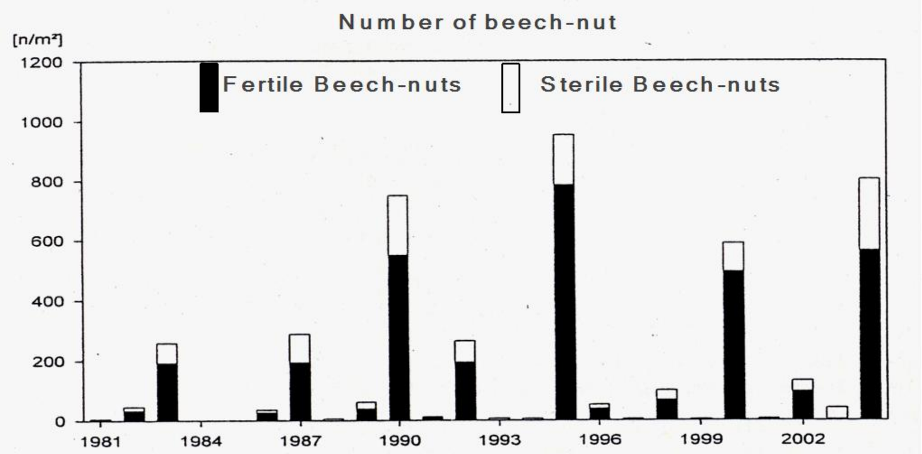

Fig. 6. Masting of Beech (nuts/m² at Göttinger Wald site from 1981 to 2004 (1984 no data available. Schmidt, 2006)

B) Indirect ecosystem responses

Climate change affects the temporal and spatial dynamics of pest species, influencing the frequency, intensity and consequences of outbreaks as well as their spatial patterns, size and geographical range. Warmer temperatures will make mountain forests in middle and South Germany more susceptible to disturbances and large-scale pest attacks from bark beetles (*Ips typographus* and *Pityogenes calcographus*) [23].

Coevolved relationships between hosts and their pests probably will be disturbed, hosts will come in contact with novel pathogens and herbivores, and changes of species composition of communities are to be expected. With climate change, non-native species from adjacent areas may cross frontiers and become new elements of the biota. Examples include thermopile species that have recently appeared in South Germany. E.G. the expansion of highly thermopile, Mediterranean pathogen species is expected, as well as an increase of pathogenicity of fungal endophytes in drought-stressed trees. In the southern part of Germany there are already pests of Mediterranean fungi on a variety of tree species like *Acer pseudoplatanus* (*Cryptostroma corticale* [24]) and *Aesculus hippocastanum* never present before.

Case study 'Brandenburg'. Most of the studies emphasise regional variability of climate change. A focus on landscape level in Germany shows that climate change will vary between the different federal states. The driest region in Germany is the north eastern state of Germany (federal state 'Brandenburg'. In this region low precipitation condition (areas lower than 500 mm per year) is aggravated by the predominance of sandy soils with low water-holding capacities and by the lack of substantial amount of water inflows to the region. Currently, forestry in Brandenburg relies mainly on Scots pine stands; simulation results show that there is little chance for improved conditions at current sites even under optimistic projections of climates [25].

Reduced water availability would result in substantially reduced yields and has profound effects on populations of invertebrate pests (mainly insects like pine moth, pine looper). An increase in the frequency and severity of summer droughts would be expected to lead to an increase in the number of fires and pine stands affected in those years.

The actual tree species dominance with Scots pine in vast areas effects another problem in connection with water balance in the soil. Degree and persistence of soil water repellency depend on content and distribution of soil organic matter, foremost thickness and morphology of humus layer [26]. In general, the effect is stronger for dry soils and decreases with increasing moisture content. Beyond soilspecific 'critical' water content, water repellency vanishes and soils become wettable. Under Scots pine stands (extenuate under Norway spruce) we usually find typical vertical humus disintegration with an accumulation in the humus layer and a loss in the upper mineral soil. The result is raw humus or raw humus like moder. This condition intensifies the hydrophobic structure and the infiltration behaviour of the soil. In case of extreme precipitation most of the water will be a surface run of [27]. This phenomenon will likely be different in mixed stands where we usually find better humus forms [28, 29].

Uncertainty vs. authority to act. Scientists agree that natural disturbances are likely to increase in frequency and intensity in response to climate change during this century [6]. Even though we cannot be certain about the specifics of change: forestry should not wait until absolute certainty arises, which will likely never be the case anyway! Even though there is uncertainty there are already changes; it is incidental that future environments will be different from present (achieved in chapter 2).

Because novel ecological conditions can cause severe and long-lasting environmental damage even with large economic costs, ecologists must identify possible environmental climate and ecosystem shifts and must develop a pro-actively forest ecosystem management [30].

Millar et al. [31] postulate an integration of adaptation strategies (actions that help ecosystems accommodate changes adaptively) and mitigation strategies (actions that enables ecosystems to reduce anthropogenic influences on climate). This makes sense for overall plans. In our paper we only focus on the adaptation strategies. It includes resistance options to protect highly valued functions of forest ecosystems, sustainability and resilience respectively response options by transforming the condition of already weaken ecosystems.

Strategies for coping with uncertainty. *Initial condition of forest stands.*

Mainly beginning in the 19th century Scots pine (*Pinus sylvestris*) or Norway spruce (*Picea abies*) plantations were established in most of the German states which had originally been dominated by deciduous trees. At present, forest management in all German states is changing. Changing demands of society, an enhanced level of ecological understanding and the conviction that climate change demands specific stand structure and tree species composition have given an impetus to a lively discussion and intensified research regarding the improvement of these secondary Norway spruce and Scots pine stands [32]. In the sense of a sustainable forest management in Germany these vast areas covering pure coniferous stands are currently converted to semi-natural and structured deciduous and mixed forests.

Besides the ecological aspects [33], mixed stands are widely believed to be potentially more productive than monospecific stands [34], which may be due to *complementarity* (tree species may differ in their crown morphology, shade-tolerance, in height and diameter dynamics, rooting depth and/or phenology) and/or to *facilitation* (positive interactions and feedbacks such as synergism and symbiosis). Ecosystems and societies are not static, but both are continually changing. This change may be slow and gradual, but it may also be dramatic and swift. For the purpose of this paper the strategies to cope with uncertainty can be grouped under three major headings:

I. Management strategies in order to assure specific services in the next century

II. Management strategies in order to absorb uncertainty

III. Management strategies to cope with the trend of dynamics

I. Management strategies in order to assure specific services in the next century. In times of site and climate change with constant and unchanging consideration of current forest services in the future (e.g. harvest profit[2]) forest conversion is needed. It is the sum of silvicultural strategies to improve horizontal structure by introducing other tree species (e.g beech or oak) in more or less pure coniferous stands (fig. 9).

Forest conversion focuses the objective of *forest services*. The current horizontal stand structure is changed in medium-term by readapting stocking grades and/or adjusting thinning regime. Both strategies e.g. can affect diminishment of water availability. The introduction of tree species is an adaptation of stands by long-term. And it is important to consider every recent and essential information of site investigation when arranging tree species regeneration. In case of decreasing vitality of the old stand the alternative tree species might compensate growth deficit. But decreasing stocking grades could implicate one problem highly visible: Adverse effects can be decreasing stock volume, danger of wind throw and grass competition. And last but not the least the management of mixtures is delicate, time consuming and expensive.

II. Management strategies in order to absorb uncertainty. All discussed uncertainties like climate change in space and time, response of tree species and its antagonists, increasing intensity and frequency of disturbances, and unsure future marketing situation could be weekend by a management strategy focussing on sustainability issues.

In particular this means (A) conservation or regeneration of site productivity, (B) biological diversity (in particular of key-species), (C) long lasting ability to (natural) regeneration of stands, (D) vitality of single trees and stands.

(A) Conservation or regeneration site productivity. Site productivity is secured by choice of site adapted tree species (site investigation on small scale is necessary) in particular with intensive root system in mixed stands as possible, avoidance of soil cultivation and disturbances and no nutrient leaching (harvest without clear cutting systems).

Humus layer. The organic substance can be seen as an integrated indicator for site capability. In order to guarantee nutrient cycles the spacious presence of litter material easy to mineralize is essential. This calls for managing with suitable tree species or convenient mixture. Since more than 100 years we are informed about the effects of tree species litter material on humus ecology. New findings are published referring to changes in humus form and soil organic matter distribution caused by forest conversion [35]. The advanced planted broadleaf trees like Beech, Sessile oak and Lime affect a new steady in carbon stock after during the decades of forest conversion. Especially lime and beech promote a comparably intensive integration of organic material in the mineral soil (fig. 7).

Besides the choice of tree species certainly there are other elements within the forest ecosystem promoting the integration of humus layer. With few exceptions the herbaceous ground vegetation affects the humus ecology in a positive way. The significance of sunlight and (derived) temperature in forests is remarkable. Litter material reacts differently but immediately to changes in light intensity and temperature [36]. In this chain of events there is also the complex, yet important role of man: the

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[2] Although timber harvest is a complex interaction of ecology, forest operations, business, law, taxes, marketing and negotiations. It has both short and long term consequences for the stand and the forest landowner.

radiation situation in stands should not be to dark, we have to choose suitable thinning regimes and cycles (see D).

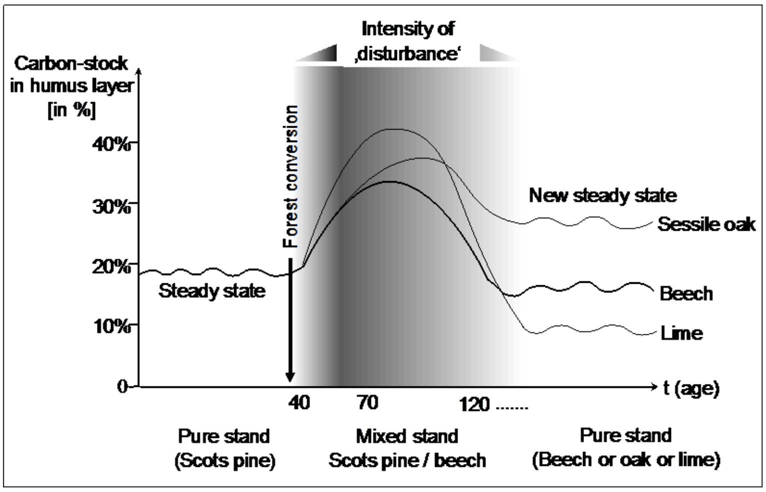

Fig. 7. Carbon-stock in humus layer [in %] during the decades of forest conversion from a pure Scots pine stand to broadleaf stands of sessile oak (Quercus petraea), beech (Fagus sylvatica) and lime (Tilia cordata)

(B) Biological diversity

Spatial structure and forest planning. Small-scale spatial structure and variability are characteristic features of forest soils and are of ecological importance for biological diversity. A few investigations show that predictability of the vegetation and the edaphic environment, at spatial distances relevant for the vegetative and generative fitness of plants, is essential for survival and diversity [37]. Forest planning has to consider these differences in site potential by establishment of different tree species. In addition a variety of harvesting and thinning techniques (single cutting systems up to small clear cuts) are as well indicated.

Deadwood. The importance of deadwood has been identified for biological diversity in particular. Deadwood is typical of a natural forest, in which the reserves of deadwood amount to 50-400 cubic metres per hectare. Managed forests have only a tenth of this quantity of deadwood reserves; the average is 12 cubic metres, and in mountainous areas only 5 cubic metres [38]. Many species of Fauna and Flora depend on decay, so if nature conservation is an aim, which it should be in any sustainable managed forest, leaving deadwood is vital for the survival of these decomposers.

And finally horizontal mixtures are strongly recommended (diverse structure with different small aggregations) to assure buffer action between tree species involved with respect to increment and decrease competition problems between tree species with different ecological requirements.

'Nativeness'. The concept of nativeness or hemeroby which is the evaluation of the dependency of ecosystems on direct human interference was applied to get an objective idea how natural the forests are [39]. It compares present vegetation with a reference vegetation/system, which can be pristine vegetation or present potential natural vegetation (PNV). However, it is nearly impossible to find pristine vegetation on the earth, especially in the developed regions with a long human history. On the other hand, PNV is very hypothetical. In the past the PNV had been very often used as an indicator for close-to-nature-forest-management. We think that the concept has to be modified when adaptability and climate change are discussed.

Warming 'creates' new impulses for the evolution of the forest ecosystems and thus, reorganizes their development. Hence, we hypothesize that the "present state" of forest vegetation or the present vegetation communities under the present site conditions is deviated from its undisturbed state in species composition and functioning of ecosystem in any case.

In fact, species choice may need to be extended. Using a variety of sources of native species in combination with introduced species is appropriate. Valuable but 'non-native' broadleaved tree species currently less considered in some regions may come to play an important role in future forests (like *Castanea sativa*, *Jugland regia*, *Sorbus domestica* and others).

(C) Long lasting ability to (natural) regeneration of stands. As a result of climate change frequency and intensity of storm events are predicted in central Europe which are the most important natural disturbances affecting stand structures of both natural and managed forests. On the cleared areas with intensive soil-surface disturbance (removal of the damaged wood) the species composition changed towards pioneer herb vegetation to pioneer forest species like *Betula pendula*, *pubescens*, *Sorbus aucuparia*, *Populus tremula*, *Larix decidua* [33]. In this situation an extensive participation of these pioneer tree species in every stand development phases is important due to its limited dispersal potential [40]. The comparison between Birch and Beech exemplifies the significant differences between two dispersal strategies in Fig. 8. Paying attention to maximum distances should be secondary important for preservation of genetic transfer between individuals.

(D) Vitality of single trees and stands

Provenances and vitality. Because forest trees are genetically adapted to their local climates, local seed sources are generally recommended for artificial regeneration. However, these recommendations assume that climates are stable over the long-term. Because of local adaptation, the health and productivity of planted and native forests may decline in global warming. Therefore, it is becoming increasingly clear that the foresters must consider future climates when choosing seed sources for their silvicultural strategies. We suggest increasing the diversity of reproductive material at higher levels than currently in order to increase the adaptation capacity of the regeneration. Provenances need to be tested at the limit of their ecological range; it is important to understand the physiological basis for responses [41, 42].

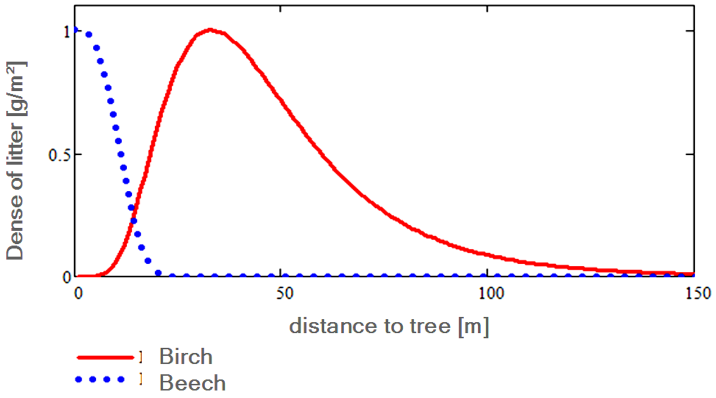

Fig. 8. Density of seeds in dependency to distance value:
Beech = $50/m^2$, Birch = $1500/m^2$)of mother tree (standardized to maximum density

Norway spruce and vitality. Norway spruce is an economically important, but relatively drought-sensitive tree species that might suffer from increasing drought intensities and frequencies. Gaul et al. [43] conclude that even periods of mild drought significantly increase fine root mortality and the associated input of root-derived C to the soil organic matter pool in temperate Norway spruce forests. Additionally an increasing Spruce area does not correspond to predicted wind events as one major cause of natural disturbances in Germany. We have to reflect our experiences with tree species in oceanic distribution (such as Norway spruce).

Thinning regime and vitaliy. Canopy structure, which can be defined as the sum of the vitality, sizes, shapes and relative placements of the tree crowns in a forest stand, is central to all aspects of forest ecology and dynamics. On the one hand, the canopy structure sets the light environment experienced by individual trees, which is known to be a primary determinant of their growth, mortality and fecundity. On the other hand, competition for canopy space drives the growth rates, densities, and size distribution of canopy trees [44]. The ability to be responsive to thinning activity is typal and belongs to tree species. This so called plasticity is acknowledged to be important in forest ecology [45] if one is interested in thinning regime at a particular time.

The key to understand the dynamics of individual tree stability is the process of density-dependent competition for canopy space, and hence light [46, 47]. In these models, complex light-tracing algorithms are used in combination with crown allometries to calculate the degree of shading for different individuals. Growth and vitality are then functions of the level of light incident on each individual. And in forestry it has long been recognized that crown percentages and h/d-ratio are important predictors of the growth and vitality of individual trees.

Forest conversion and forest improvement. Two strategies for increasing the resilience of stands and making them more adaptable to climate change are order of the day within forest administration in Germany (fig. 9):

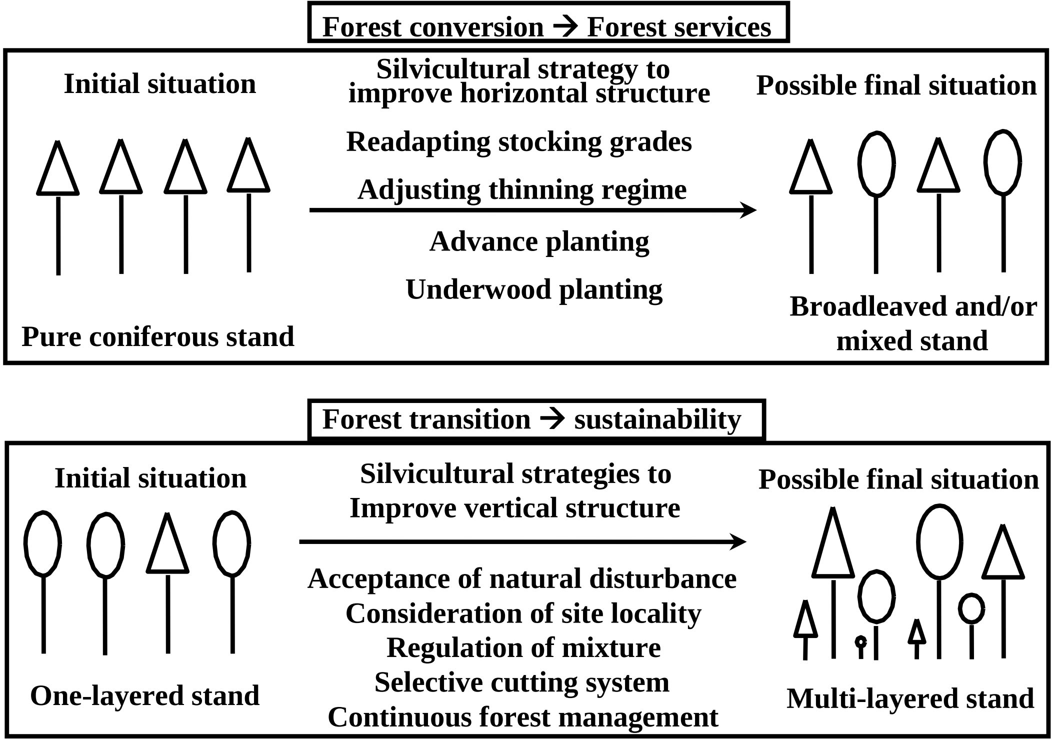

Fig. 9. Silvicultural strategies to improve forest stands that are poor in structure in order to make them more resilient against consequences of climate change

Forest Conversion (change in tree species composition) of secondary coniferous stands into pure or mixed broad-leaved forests usually e.g. by advanced artificial regeneration and

Forest Transition (change in vertical structure) of pure structured stands in multilayered stands, e.g. by moving from an even-aged to an uneven-aged forest stand and changing the rotation period (or even to strive to a continuous cover management).In contrast to radical forest conversion (as discussed in *I*) forest transition with the objective of sustainability definitely makes sense. A continuation and extrapolation with special attention to climate change might be a solution of different problems.

III. Management strategies to cope with the trend of dynamics. The dynamics of environmental factors is contradictory to management strategies which are statically determined; but nevertheless, the foresters have to decide on the planning period. Three time horizons for planning may be distinguished (fig. 10); focussing on

A. the beginning of the period (classic idea of constant conditions)

B. the end of the period (‘panic scenario’)

C. the middle of the period

Promising techniques to cope with the trend in dynamics are strategies of uneven aged forests with a mixture of tree species vary in growth rhythms and dynamic:

- pioneer crop (Birch above Oak, Alder above Beech);
- advanced planting (Oak under Pine, Beech under Spruce);

- natural regeneration under old stands (Oak, Rowan berry under Pine);
- temporarily mixtures (Spruce in Beech).

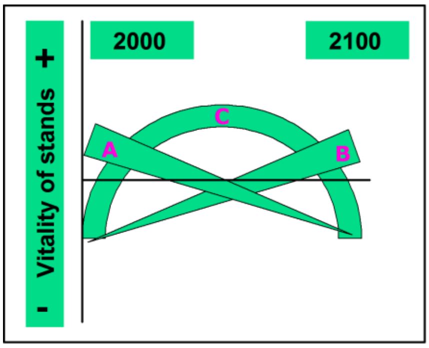

Fig. 10. Three time horizons for forest management planning (adapted from Profft & Frischbier, 2008)

Subsumption and Conclusions.

- Forest conversion with the objective of forest services implies the knowledge to adapt the tree species to climate change. In particular Spruce will not meet the future demands of timber production on each site (decreasing growing potential, lower mean life span of stands). We have to initiate management with productive tree species resilient against climate change (Douglas fir, Oaks).
- Stand management – regulation of mixture, regulation of stock density, promotion of individuals with high growth capacity – is in high demand. We have to modify conventional strategies or we have to develop new management strategies by objective-orientation.
- We can manage in a comparably extensive way when organizing our stands with the objective of sustainability. Forest conversion with the objective of optimising forest services is an intensive interference in the ecosystem. Situation is easier when looking at forest transition with focussing on sustainability.
- Forest transition with the objective of sustainability is a long-needed and practised strategy in many forest districts. Climate change should provoke renunciation of ‚euphoria of forest-conversion‘. It demands a great deal of new ecological knowledge.
- Humus cycles have to be closed and they should be efficient in order to assure biodiversity, the potential of natural regeneration, or vitality of tree species. These are elements of management strategies in case of uncertainty (both, ecological and economical).
- We have to safeguard a variety of tree species with different ecological demands. We need mixed stands with pioneers and tree species resilient against climate change and disaster occurrence.
- More than in the past an improved monitoring systems is needed for identifying future research priorities. In order to reach these goals forest scientists require regional analyses, case studies and compared alternatives instead of a general consensus. The development of management responses to be implemented when new changes occur.

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ПЛАНИРОВАНИЕ ЛЕСОВОДСТВЕННЫХ МЕРОПРИЯТИЙ В УСЛОВИЯХ МЕНЯЮЩЕГОСЯ КЛИМАТА

Прогнозируется, что изменение климата значительно повлияет на структуру лесов и их устойчивость. Изменятся взаимодействие между породами и породный состав лесов. Авторы анализируют существующую информацию о прогнозируемом влиянии меняющегося климата на леса Германии. Рассматриваются вопросы планирования лесоводственных мероприятий на уровне насаждений по их адаптации к меняющимся условиям.

Ключевые слова: *изменение климата, лесоводство, влияние на леса, биомасса, стратегия лесоуправления, защита леса.*

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