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Investigation of the interactions between pine and beech in two-layer mixed stands using methods of tree-ring research

W. Beck

Institute for Forest Ecology and Forest Assessment Eberswalde, Federal Research Centre for Forestry and Forest Products, Germany;

email: wbeck@bfh-inst7.fh-eberswalde.de

Introduction

The conversion of pure even-aged coniferous forests existing at large areas, for instance in the north eastern German lowlands, is an avowed will of forestry and society in Germany and in many other European countries. Objectives of forest conversion are to overcome uniformity of forest structures, to get a higher degree of naturalness of tree species distribution, to get a higher degree of structural and biological diversity and to enlarge stability and robustness of forests against biotic and abiotic threads. An additional objective of forest conversion pronounced and investigated by the Institute for Forest Ecology and Forest Assessment is the hydro-ecological importance of forests for drinking water supply.

Model region: North- eastern German lowlands

The water budget of the north-eastern German lowlands is limited by the amount of precipitation of about 600 mm/yr. Sandy soils with low water holding capacity are the predominating substrate. The increase in summer temperature during the last 100 years in the region near river Oder is about 3,5°K. Typically drought periods occur during mid-summer. High loads of nitrogen depositions during the last 50 years emitted by industry, traffic and agriculture have changed site conditions considerably (ANDERS et al., 2002). The north-eastern German lowlands represent a border region of the natural distribution of the tree species beech (*Fagus sylvatica*), pine (*Pinus sylvestris*) and oak (*Quercus petraea* and *Q. robur*). Actually the share of pines in the forests is about 80%, however the natural portion is about 11%. Of the existing forests 74% are pure coniferous, 14% pure broadleaved and 11% mixed stands. That´s why silvicultural policy aims to the enlargement of the broadleaved forest types to about 3% and of mixed forests to about 30%, according to 287.000 ha in total. This situation at large led to the wording of the scientific question: What are the ecological conditions and effects of forest conversion from pure even-aged pine stands towards pure beech stands via consecutive stages of mixed pine-beech stands (ANDERS et al., 2004) ?

Experimental design and methods

A series of sample plots was installed as a chronosequence of consecutive stages within the forest conversion process, starting with

- a pure pine stand (age: 84 years),

- a two-layer mixed stand (pine 51 years, beech 11 years),
- a two-layer mixed stand (pine 76 years, beech 33 years),
- a two-layer mixed stand (pine 114 years, beech 53 years) and
- a pure beech stand coming from a pine-beech-mixed stand (age 101 years)

at equal soil types with similar soil properties and inside the same forest district with equal climatic conditions. The research project comprised the following assessments:

- physical and chemical soil properties including humus layer,
- water fluxes in structural differentiable stand ranges (pine dominated; beech dominated; pine and beech in intensive mixture),
- soil biology and root ecology in pure and mixed stands of pine and beech,
- stand structure, net primary production and growth analysis of pure and mixed stands.

Within the forest growth assessment methods of tree-ring research were applied. The following investigations were carried out to acquire data and results on pure and mixed stands of pine and beech:

- stand-structural parameters and net primary production,
- recording of intra-annual diameter increment courses by high resolution measurements,
- taking increment cores of pine and beech sample trees to reconstruct growth development, actual growth behaviour, dependence on neighbourhood relations and climatic sensitivity,
- modelling climate impact on tree growth.

From the results obtained by the investigations mentioned above two examples were chosen to present the value of methods of tree-ring research within a framework of multi-disciplinary forest ecological research.

Results

Course of intra-annual diameter growth

The tracking of the seasonal course of diameter growth by high resolution circumferential measuring tapes is a suitable method to find out how weather influences growth activity. The secondary diameter growth of trees comprises the processes of cell division, cell enlargement and cell wall thickening which are running mainly simultaneously. Only the process of cell enlargement is measurable by macroscopic methods. The values obtained from high resolution diameter increment measurements are overlaid by fluctuations of moisture content inside stem and bark. Despite of these constraints the method of tracking the seasonal course of diameter growth by high resolution circumferential measuring tapes is suitable and useful to improve our knowledge on short-term reactions of different tree species to heat and drought or to precipitation events. Additionally a comparison can be made between the growth courses recorded in pure and in mixed stands. Figure 1 displays such a comparison between a pure pine stand, a mixed pine-beech stand and a pure beech stand.

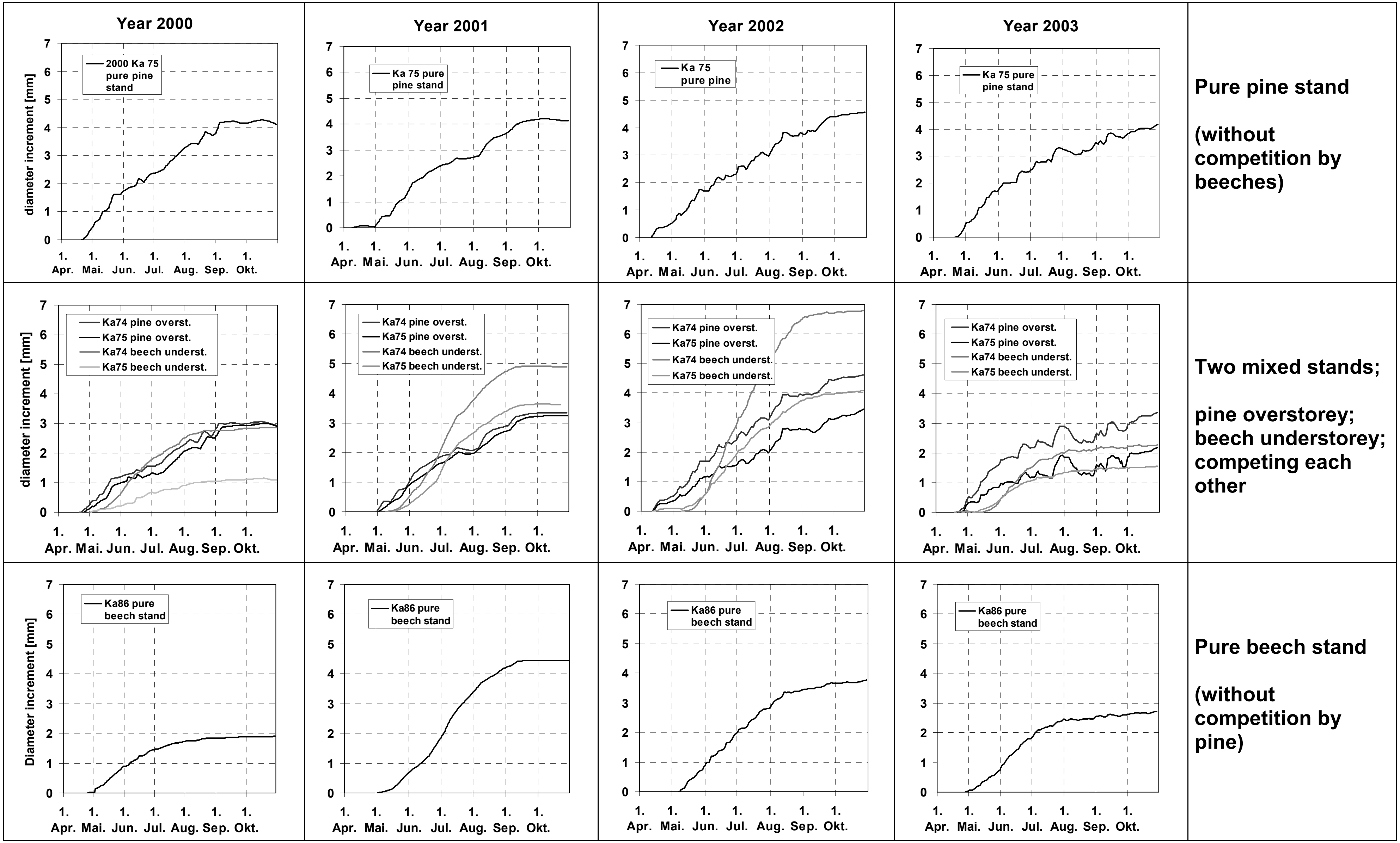


Figure 1: Comparison of intra-annual diameter growth course of pines and beeches in pure stands and in mixed stands

The following facts are discoverable:

- Generally the seasonal course of diameter increment of both, pine and beech follows a sigmoid curve.
- Pine reacts to transpiration stress (soil water shortage or high air temperatures) immediately. If the water shortage persists for several days or weeks stem diameter decreases. After a drought period pine can continue its growth immediately with the new supply of water.
- The seasonal growth course of beech is more stable than the one of pines. Beech is able to continue its growth in times of shrinkage of pines, due to water shortage. Apparently beech is able to use the existing soil water content more intensively than pines.
- Though weather conditions in the years 2000 to 2003 were distinctly variable, pine in pure stands shows nearly the same growth rates. Apparently pine is a very stress-tolerant tree species.
- Growth rates of beech in pure stands clearly reflect the actual weather conditions. Growth is enhanced by moist summers and depressed by hot and dry conditions.
- Growth course and growth rates of pine and beech in mixed stands are clearly affected by the increased water demand of two consumers which occupy the whole living space completely, aboveground as well as belowground. Growth rates of understorey-beech are stronger varied by weather conditions than those in pure stands. Growth rates and growth courses of overstorey-pines in mixed stands are also stronger varied compared with those in pure stands.
- When beech starts to grow, pines have taken up water already since 17 days in the average. Water resources for beech in mixed stands are limited already at the beginning of the growing season. Beech ends its growth 27 days earlier than pine. The growing season of beech is 43 days shorter than that of pine (comp. table 1). Seemingly the daily rate of water uptake by beech should be substantial higher than this by pines.

Table 1: Duration of diameter growth activity of pine and beech. Specified are the dates at which 5% and 95% of the total diameter increment of the season is reached. In the time span between "date 5%" and "date 95%" therefore 90% of the total annual diameter increment is produced.

year	**pine**			**Beech**		
	date 5%	**date 95%**	**Duration [no. of days]**	**date 5%**	**date 95%**	**Duration [no. of days]**
1994	08. May	17. Sep	133	23. May	28. Aug	98
1995	06. May	21. Sep	139	09. May	05. Sep	120
1996	05. May	14. Sep	133	24. May	05. Sep	105
1997	04. May	03. Sep	123	22. May	24. Aug	95
1998	27. Apr	15. Sep	142	16. May	15. Aug	92
1999	18. Apr	04. Oct	170	25. May	20. Jul	57
2000	01. May	02. Sep	125	09. May	17. Aug	101
2001	08. May	12. Sep	128	11. May	14. Aug	96
2002	19. Apr	01. Oct	166	21. May	09. Sep	112
2003	28. Apr	05. Oct	161	14. May	30. Aug	109
average	**30. Apr**	**18. Sept**	**142**	**17. May**	**22. Aug**	**99**

- The modified growth behaviour of both, pine and beech in mixed stands clearly reflects the shortage of water resources and the superior role of interspecific competition.

The presented examples in figure 1 demonstrate that by application of high-resolution increment measurements valuable results on both climatic impacts on growth as well as on relations between different tree species in a mixed stand can be obtained.

Analysis of tree-ring series

Besides the analysis of long lasting diameter growth trends the investigations aim at the impact of climate on growth reactions of pines and beeches in pure and in mixed stands. From at least 30 dominant overstorey-pines and understorey-beeches increment cores were taken. After drying and sanding ring widths were measured using a LINTAB-device. Tree ring curves were detrended in two consecutive steps by **i** first order autoregressive process and **ii** smoothing splines. Parallel to the procedure of detrending first order autocorrelation-coefficient and sensitivity of each series was recorded. These two parameters together are appropriate to assess the ability of the two tree species to respond to climatic stress. Calculated values of sensitivity of tree-ring series express the mean size of alterations from year to year expected to be mainly caused by environmental factors. In that sense it has to be understood as a result or effect of climate impact. The autocorrelation coefficient exhibits the opposite. It describes the dependence of ring width at year *t* from that of year *t-1*. This dependence from earlier events is an expression of inertness of tree growth. High degrees of autocorrelation coefficient and significant autocorrelations of higher order represent a far reaching ability of trees to adapt to climatic stress. This ability is surely species specific. Figure 2 presents the distribution of sensitivity and 1st order autocorrelation coefficient of the chronologies of overstorey-pines and understorey-beeches.

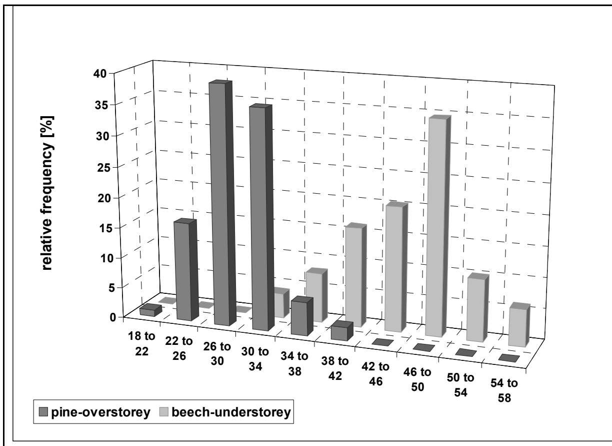


Figure 2a: Pine-beech mixed stand Ka 75; distribution of mean sensitivity coefficients among the tree-ring-series of the pine- and beech-chronology

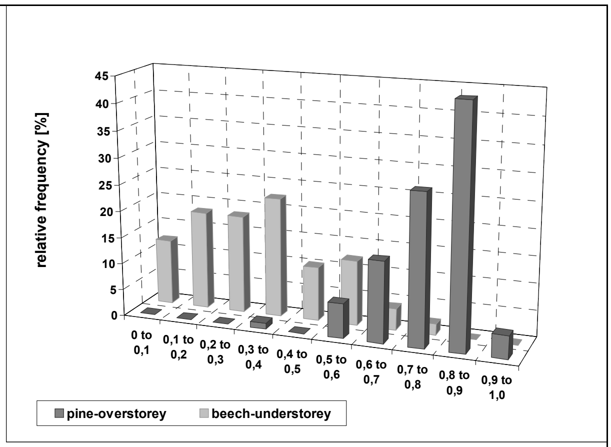


Figure 2b: Pine-beech mixed stand Ka 75; distribution of mean autocorrelation coefficients (1st order, AR(1)) among the tree-ring-series of the pine- and beech-chronology

Obviously pine is less sensitive to climate than beech and has a higher ability to adapt to climate events than beech as denoted by larger first order autocorrelation. Those are clearly more sensitive and show only low degrees of autocorrelation. Evidently beech seems to be more susceptible to climatic stress.

In a next step it is tried to describe annual growth reactions expressed by the time series of tree-ring indices dependent from climatic variables. The main aim is to predict effects of drought on tree and stand vigour. For the modelling approach the following preconditions were fixed:

- the models should be simple, not primitive,
- the number of variables should be limited,
- the models should enable forecasting of effects within reasonable limits of climatic assumptions.

Extreme values of tree-ring-index in time-series were chosen to be an appropriate variable to express the effect of favourable and unfavourable weather conditions during the growing season. Mostly such values of tree-ring-index represent pointer years or event years. This means on the other hand that years with tree-ring index values close to 1,0 have to be excluded, because they only compound the random noise inside the complex relationship of the climate-growth system. Deviations of precipitation und air temperature from normal values of the months from May till September were taken into consideration to form one variable for precipitation and one variable for temperature. Additionally, deviations of late winter temperatures (January to March) from normal values were included. The regression model which was performed is described by

$$y = a_0 + \sum_{p=1}^{4} a_p \cdot x_p$$

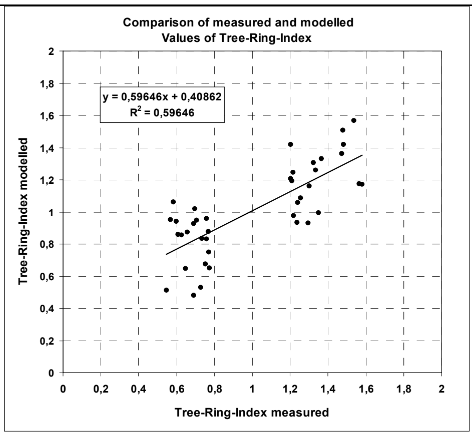
with:

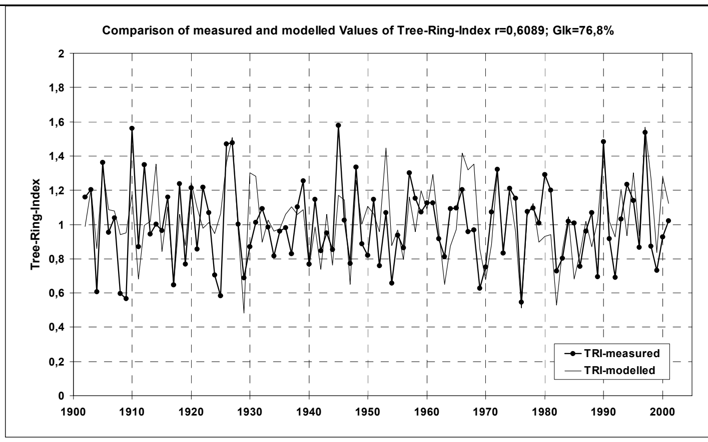
y:	tree-ring index
x_1:	mean daily temperature deviation for the period May till September
x_2:	mean daily precipitation deviation for the period May till September
x_3:	interaction term; $x_3=x_1 \cdot x_2$, because x_1 and x_2 are correlated
x_4:	mean daily deviation of late winter temperature from January to March
$a_0 \ldots a_4$:	parameters of regression

The modelled results of climatic impact on growth reactions of over storey pines and under storey beeches of the mixed stand Kahlenberg 75 are shown in figure 3.

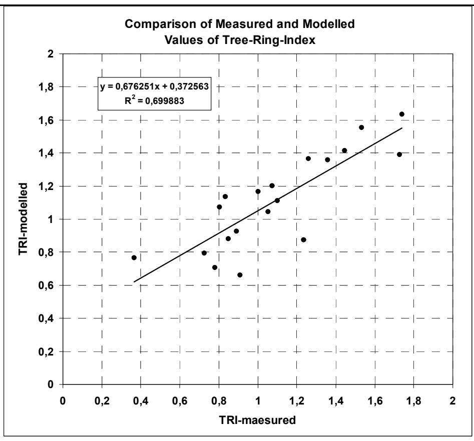
Pine-beech-mixed-stand Kahlenberg 75

Overstorey: Scots pine *(Pinus sylvestris)*





Understorey: Beech *(Fagus sylvatica)*



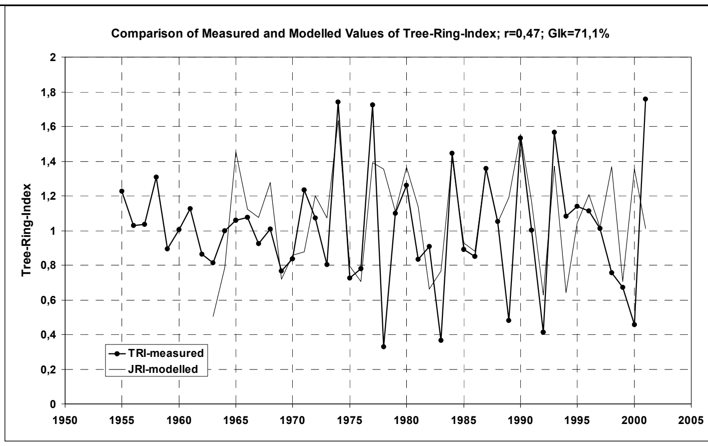


Figure 3: Results of climate-growth modelling for pine-overstorey and beech-understorey; left side, scatter plots: match of measured and modelled values of tree-ring index used in regression procedure; right side: match of measured and modelled values of tree-ring index time series.

These results from regression analysis seem to be quite reasonable. Besides the coefficient of determination the parameter “Gleichläufigkeit” (Glk) is appropriate to evaluate fidelity of mapping growth response by the model. The special meaning of the dependent variable tree-ring index (*TRI*) enables an additional interpretation. Values of *TRI*>1,0 denote wide rings, values of *TRI*<1,0 denote narrow rings. Therefore relative increment changing (*IC*) can be calculated:

$$\Delta IC[\%] = 100 \cdot (TRI - 1) .$$

In that way increment gains or losses arise dependent from the constellations of temperature and precipitation during growth season. So the effects of drought and heat on tree increment and vigour can be displayed inside the existing range of values of the time series (figure 4). Following basic relations are observable: The strongest increment losses of pines are caused by hot and dry conditions. If precipitation is sufficient increment is rising with increasing temperatures. Highest yields are bound to warm and wet conditions.

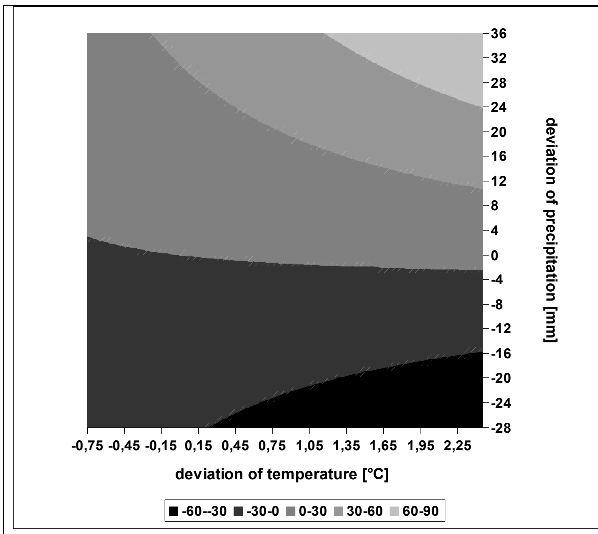


Figure 4a: Pine-overstorey; Increment yields and losses [%] caused by deviations of temperature and precipitation from mean value

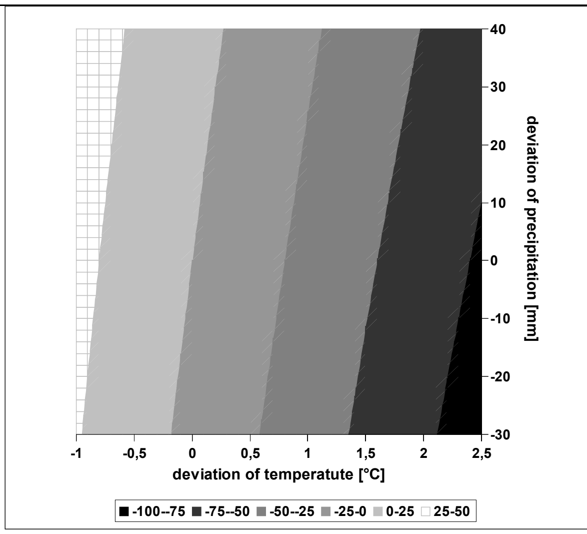


Figure 4b: Beech-understorey; Increment yields and losses [%] caused by deviations of temperature and precipitation from mean value

Beeches react with increment losses to elevations of temperature. Additional rain can compensate effects of high temperatures only in a small extent. This characteristic coincides with the general climatic claims of this tree species, the natural area of distribution of which is clearly stamped by Atlantic conditions. In the north-eastern German lowlands an ecological border situation is reached. The competition of pines and beeches concerning water resources in the mixed stand results in an aggravation of the conditions, especially for the beeches.

Conclusions

Methods of tree-ring research can contribute inside a framework of multi-disciplinary forest ecological research in a striking manner. Since decades methods in the fields of dendrochronology, dendroecology and dendroclimatology are well developed or are still under development. Findings as exemplified here cannot be obtained by other scientific disciplines. That's why it is very urgent to incorporate finally methods of tree-ring research as an integral part of forest ecosystem research. Actually this still seems to be more an exception than the normal case.

The enhancement of our knowledge on effects of climatic impacts on tree and stand vigour is of great importance especially regarding climate change. It is necessary and urgent to elaborate our quantified findings on all important native and foreign tree species. This provides the basis for realistic calculations of a future distribution of tree species, forest structures and decisions concerning the choice of native or foreign species or provenances. Such improved knowledge and reliability for decision making is needed for a reasonable silvicultural policy. It is a duty of forestry to accompany and to design this process of forest conversion which is probably enforced by climate change.

References

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