University of West Hungary
Faculty of Forestry

Theses of doctoral (PhD) dissertation

Beech adaptation to climate change according to provenance trials in Europe

Anikó Kóczán-Horváth

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Doctoral school:	Pál Kitaibel Doctoral School of Environmental Sciences
Leader:	Prof. Dr. Zoltán Kolláth
Program:	Bioenvironmental Sciences
Leader:	Prof. Dr. Levente Albert
Supervisor:	Prof. Dr. Csaba Mátyás

Background and objectives

The dissertation deals with the modeling of adaptive response of one of the dominant tree species in Europe, beech (*Fagus sylvatica* L.). The aim was to construct a prediction of juvenile growth performance across the potential sites within the distribution range, based on the IUFRO provenance trial network. The concept of the analysis was that the growth and vitality of a population at a test site is determined by the inherited adaptation to the site of origin and by the experienced different conditions at the planting site.

The aims of this study were as follows:

- to assess the adaptive variability of beech at the intraspecific level,
- to define ecological variables which are best associated with vitality parameters of beech,
- to create a model which can describe the growth response of trees to environmental changes,
- to provide recommendations for use and transfer of FRM in the future.

The following hypotheses were applied in this study:

- The growth potential of populations from various parts of the distribution area is different, which is the result of long-term adaptation to the past climate at the site of origin.
- Quantitative, adaptive responses measured in common garden experiments can be used to predict the reactions of populations to climate change.
- Survival and growth success of trees in the future depends on how they can cope with the difference between their past, long-term climate and the future environmental conditions.

Materials and methods

In 1995 and 1998 international beech provenance trials were established across Europe, organized by the Institute for Forest Genetics, Grosshandorf, Germany, initiated by H.J. MUHS and G. VON WÜHLISCH. With support of a large number of participants, 42 tests were successively planted across Europe. An important support for international cooperation and creation of a central dataset was initiated by the European COST E52 cooperative action which provided a platform for the participants of the experimental series. One site of the 1998 provenance test series has been planted out in Bucsuta, SW Hungary. Bucsuta is the most extreme site among the trial sites. Almost all provenances which are planted here experience drier and warmer conditions compared to their original site. Transfer function, early survival and detailed phenological analysis have been performed regarding the Hungarian trial.

In order to create a model which best describes the response of provenances to environmental changes triggered by transplantation, height data of the international provenance trials have been used. For the data analysis a mixed-effects model was applied. The great advantage of the mixed-effects method is that random effects can be incorporated in the model. In this study provenance and site were considered as random effects.

For the model construction, the most efficient climate variables had to be selected. The main steps were the followings:

1. Selecting the best climate variables at seed source.
2. Selecting the best climate transfer distance variables.
3. To combine the previous two functions, compare results of full models and select the best one.

Measured mean height of provenances served as dependent variable. To identify the climate variables at the site of origin that best describe the performance of the populations across sites, Spearman's rank correlation was applied. Climate variables with the highest ρ value have been selected.

Climate transfer distance was calculated as the difference between test site climate and seed source climate. For modeling growth response to climate transfer, a quadratic function has been used based on results of previous studies.

After selecting the most relevant and significant climate variables in the first two steps, they have been combined in all possible way. Finally, the full models were compared according to their AIC values.

The model predicts the height growth at 9 years of age of a provenance at a given site as determined by the following variables: the climate at the origin of the provenance, the climatic change (climatic distance) caused by transferring the adapted provenance to the test site and the interaction of the two. The general model form was as follows:

$$y_{ij}=b_0 + b_1x_{1j} + b_2x_{2ij} + b_3x_{2ij}^2 + b_4x_{1j}x_{2ij} + \mathit{site} + \mathit{provenance} + e_{ij}$$

where y_{ij} is the height growth response of j^{th} provenance at the i^{th} site, x_{1j} is climate variable for seed source j, x_{2ij} is climate transfer distance for provenance j at the test site i, x_{2ij}^2 is the quadratic term of transfer distance and $x_{1j}x_{2ij}$ is the interaction; *b'*s are the intercept and regression coefficients and e_{ij} is the residual. Provenance and site were incorporated in the model as random effects.

All statistical analyses were conducted using the R package lme4 (R-3.2.2.) and STATISTICA 12 software.

Results and Discussion

The aim of mixed model analysis was to select the main climate variables which have the most influential effect on height growth of 9 years old beech seedlings and to build up a model which allows to predict how different populations will respond to environmental changes based on common garden experiment data.

Because the role of the climate variables at the different parts of the distribution area is different, using one model for the whole area may increase error variance. In order to improve model prediction, provenances were divided into three groups (Alpine, Atlantic, continental) according to the map of Environmental Stratification of Europe based on climate, ocean influence and geographical data.

The Alpine group, including provenances from high elevation, showed no significant relationship between height growth and any climate parameter. This confirms the results of previous studies which also detected the divergent behavior of beech populations from higher elevations. However, the small number of populations in this group has likely contributed to the weak statistical results.

Winter minimum temperature has been identified as main climate factor to determine the mean performance of the Atlantic provenances. The negative trend of Spearman correlation suggests that provenances adapted to colder winters performed generally better across the sites, their performance was more stable than of others. Almost all significant climate variables related to winter temperature which is the main factor in regulating phenology. Bud burst is a highly heritable trait, it is assumed that within the Atlantic region, provenances close to the continental border are flushing earlier than the coastal provenances thereby prolonging their growing season which is reflected in their performance. In terms of ecological distance of transfer, the difference (change) in Ellenberg drought index (*EQ*) was one of the most significant parameter. According to model prediction Atlantic provenances from milder winters respond to increasing *EQ* value quite negatively. These populations are located close to the coast with typical maritime climate. In contrast, populations from inside the continent adapted to cold winters show a very plastic reaction to the changing *EQ* value. The distribution of the trial sites was, however, unbalanced; most of the sites were established in the continental region (with higher *EQ* values). Consequently, Atlantic provenances close to the continental border experienced less extreme 'climate change' by transplanting than the coastal provenances. This may partly explain the flat response of the function.

In case of the continental group, the climatic moisture deficit showed the strongest relationship with the mean performance of provenances. This quadratic relationship indicates that the ecologically marginal populations (with too low or too high climatic moisture deficit) performed poorer than populations from optimal climate conditions. The effect of climatic transfer was best described with the difference in maximum temperature in April. Based on model prediction, the response of the continental provenances was similar, however, the mean performance of populations was well separated (see intercepts of the functions), particularly the performance of one provenance from Southeast Europe with remarkably high *CMD* value (which refers to dry and warm climate) showed much lower height growth across sites. Presumably, this marginal provenance is under strong stress selection at its original site and its gene pool depleted, therefore, it cannot adapt to rapidly changing environmental conditions. This provenance went extinct in most trial sites.

For both models, the contribution of fixed effects to total variance was larger than the contribution of random effects. It is indicating that the total phenotypic variation of provenance height growth could be well explained by climate. Among random effects, the effect of planting site was much larger than the provenance random effect. It is general for all common garden experiment networks with large extension, due to the strongly varying local ecological conditions of the test sites.

The Hungarian trial site Bucsuta has a great importance. Because of its high temperature and low precipitation conditions it is the most extreme of all trial sites. Here, the local provenance is not the best; another Hungarian provenance, Magyaregregy from South Hungary, adapted to less precipitation amount and lower temperature value performed best. Due to the recent climate change in Bucsuta, which is represented here as climate difference between the past climate (1961-1990) and the weather conditions from outplanting to the date of measurement (1998-2006), the magnitude of changes slightly exceeded the adaptability of the local provenance. However, the flat response of the function underlines the high plasticity of beech.

Based on the early survival (measured in 2001) and height data (measured in 2008), the group of the best performing provenances was determined. High survival rate (above 70%) and significantly better than average growth (above 440 cm) were observed for five continental, one Atlantic and one Alpine provenances.

A detailed phenology assessment was conducted in five different years in Bucsuta. Variance between provenances and between years were significant, however the effect of year was much stronger. Winter temperature had a dominant role on bud burst date. The character of winter of the different years was compared based on the number of days below 5°C between November 1 and March 1 and on the number of days between 0 and 10°C between November 1 and March 1. In summary, warmer winters (high number of days with temperature between 0 and 10°C) delayed the bud burst of trees due to insufficient chilling. The correlation between the continentality of provenances and the accumulation of degree days verify the findings of previous studies that bud burst of beech shows a west-east cline, from late to early flushing. Based on heat requirement for bud burst, three groups of provenances (early, middle and late flushing) were distinguishable at the trial site Bucsuta.

Theses

1. Beech populations from the different part of the distribution area showed different phenotypic response to the environmental changes. This response can be characterised with a growth response model based on long-term climate, i.e. climate at seed source and current climate i.e. weather at the test site from the outplanting to the date of measurement and their interaction.

2. The selective role of climatic factors in the different parts of the distribution area are different, therefore separating provenances based on climatic zone may improve future predictions. It is recommended to separate, at least, the Atlantic, continental and Alpine regions.

3. Genetic variability in bud burst has been detected between provenances at the trial site Bucsuta. The high variability in this trait refers to an adaptation to the climate of provenance origin. Genetic variability in bud burst date showed a west-east cline, from late to early flushing.

4. Winter temperature had a dominant role on bud burst date of provenances. Warmer winters delayed the bud burst of trees due to insufficient chilling.

5. Winter temperature, which is important for phenology, can be characterized both by the number of days below 5°C between November 1 and March 1 and the number of days between 0 and 10°C between November 1 and March 1.

Publications

Articles in reviewed journals

Horváth A., Mátyás Cs. (2014): Növedékcsökkenés előrevetítése egy bükk származási kísérlet alapján [Estimation of increment decline caused by climate change, based on data of a beech provenance trial.] In Hungarian with English summary. Erdészettudományi Közlemények 4:(2): 91-99.

Horváth A., Mátyás Cs. (2016): The Decline of Vitality Caused by Increasing Drought in a Beech Provenance Trial Predicted by Juvenile Growth. South-East European Forestry 7(1): early view. DOI: http://dx.doi.org/10.15177/seefor.16-06

Articles in non-referred proceedings, conference abstracts

Horváth A. (2014): Néhány bükk populáció teljesítményének bemutatása származási kísérletek adatai alapján. In: Bidló A., Horváth A., Szűcs P. (szerk.): IV. Kari Tudományos Konferencia. Nyugat-magyarországi Egyetem, Erdőmérnöki Kar, Sopron, 2013. 12. 10. pp. 54-58.

Horváth A. (2014): Growth Decline Response of Beech to Climate Change. In: Polgár A., Bazsó T., Nagy G., Gálos B. (szerk.): Local and Regional Challenges of Climate Change Adaptation and Green Technologies / A klímaváltozás helyi és regionális kihívásai, zöld technológiák. Nyugat-magyarországi Egyetem, Erdőmérnöki Kar, Sopron, 2014.09.18-2014.09.19. pp. 53-59.

Horváth A. (2014): Meteorológiai paraméterek meghatározásának bemutatása egy nemzetközi bükk származási kísérletben. In: Csiszár I., Kőmíves P. M. (szerk.): Tavaszi Szél 2014 / Spring Wind 2014 V. kötet. Doktoranduszok Országos Szövetsége, Debrecen. pp. 216-222.

Presentation

Horváth A. (2015): Applied climate data in ecological research. International summer school: Methods for analysing climate change and its impacts on forest ecosystems. University of West Hungary, Faculty of Forestry, Sopron, September 1 – 4.