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Modelling the Potential Distribution of Three Climate Zonal Tree Species for Present and Future Climate in Hungary

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Abstract – The potential distribution and composition rate of beech, sessile oak and Turkey oak were investigated for present and future climates (2036–2065 and 2071–2100) in Hungary. Membership functions were defined using the current composition rate (percentage of cover in forest compartments) of the tree species and the long-term climate expressed by the Ellenberg quotient to model the present and future tree species distribution and composition rate. The simulation results using the regional climate model REMO showed significant decline of beech and sessile oak in Hungary during the 21st century. By the middle of the century only about 35% of the present beech and 75% of the sessile oak stands will remain above their current potential distribution limit. By the end of the century beech forests may almost disappear from Hungary and sessile oak will also be found only along the Southwest border and in higher mountain regions. On the contrary the present occurrences of Turkey oak will be almost entirely preserved during the century however its distribution area will shift to the current sessile oak habitats.

potential tree species distribution / composition rate / beech / sessile oak / Turkey oak

Kivonat – Három klímazonális fafaj hazai potenciális elterjedésének modellezése jelenlegi és jövőbeni klímában. A bükk, a kocsánytalan tölgy és a csertölgy potenciális elterjedését és elegyarányát vizsgáltuk Magyarországon a jelenlegi és a jövőben (2036–2065 és 2071–2100) várható klimatikus körülmények között. A vizsgált fafajok jelenlegi elegyarányának (az erdőrészletben elfoglalt terület aránya, %) és a klímának (az Ellenberg index-el kifejezve) az összefüggését használtuk a fafajok elterjedésének modellezéséhez. A REMO regionális klímamodellel történt szimuláció a bükk és a kocsánytalan tölgy elterjedési területének és elegyarányának jelentős csökkenését mutatta a 21. század folyamán. A század közepére a jelenlegi bükk állományok 35%-a, a kocsánytalan tölgy állományok 75%-a maradna a jelenlegi alsó elterjedési határuk felett. A század végére a bükk szinte teljesen eltűnhet Magyarország területéről és a kocsánytalan tölgy is a magasabb hegyvidékekre és a délnyugati határ menti területre húzódhat vissza. Ellenben a csertölgy jelenlegi állományait várhatóan nem érinti számottevően a klímaváltozás, viszont az elterjedési területe a jelenlegi kocsánytalan tölgyes állományok helyét foglalhatja el.

potenciális fafaj elterjedés / elegyarány / bükk / kocsánytalan tölgy / csertölgy

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1 INTRODUCTION

The present distribution of tree species is influenced by several factors such as historic and current ecological and climatic conditions, natural disturbance regimes and forest management activities. However, climate is generally considered to be one of the most important factor of the potential natural distribution of tree species.

For Central Europe, climate models project about 2–5°C annual mean air temperature rise in the 21st century (IPCC 2007). Climate change is likely to increase the frequency of summer drought in this region (Schär et al. 2004, Bartholy et al. 2007, Beniston et al. 2007, Gálos et al. 2007).

Climate change is considered to unfavourably affect forest ecosystems through the impact on forest growth and regeneration. Numerous studies suggest a decline in forest regeneration (Rennenberg et al. 2004, Penuelas et al. 2007) or extensive forest dieback in mid european latitudes (Berki et al. 2009, Czúcz et al. 2010, Kramer et al. 2010, Lindner et al. 2010) during dryer and warmer climatic conditions as it is already observed in several locations (Allen et al. 2010, Mátyás 2010).

In general the xeric (or rear, trailing) limits of the tree species is difficult to follow due to the more complex ecology and human disturbance. The occurrence of the species is determined here mainly by climatic aridity (Mátyás et al. 2009), contributing to the loss of competitive ability (Loehle 1998, Hogg et al. 2005). However, the change in climatic aridity is more difficult to predict than alone air temperature due to e.g. the high variability of soil water holding capacity. Biotic interactions (e.g. pests and disease), persistence and plasticity of species may also play a major role at xeric range limits (Mátyás et al. 2008, Lakatos and Molnár 2009).

Here we will deal with bioclimatic envelope models (niche models) to examine effects of climate change to a set of the main tree species in Hungary. Niche models rely on statistical correlations between existing species distribution and environmental variables to define a species' tolerance (Pearson & Dawson, 2003). These kind of models are often used to predict the impacts of climate change on species distribution (Rehfeldt et al. 2003, Araujo et al. 2004; Thuiller et al. 2005, Czúcz et al. 2010, Rasztovits et al. 2012). Although the distribution limits are defined through statistical models with considerable uncertainty (Kramer et al. 2010), the predictions of general distribution changes have high ecological and economic significance (Koskela et al. 2007).

Statistical distribution models (SDMs) apply statistical relationship between observed presence/absence or abundance of a given species to a relevant set of limiting environmental factors controlling the distribution of the species (Guisan and Zimmermann 2000).

Numerous studies have focused on particularly important group of major forest tree species, such as beech and oak species predicting potential shifts of forest cover (Rehfeldt et al. 2003, Thuiller et al. 2005, Ohlemüller et al. 2006, Rickebusch et al. 2007, Kramer 2010). But due to the difficulties of modelling at the xeric limits, such distribution studies are scarce (Hogg et al. 2005, Czúcz et al. 2010, Rasztovits et al. 2012).

In this paper we investigate the potential distribution and composition rate of beech (*Fagus sylvatica* L.), sessile oak (*Quercus petrea*) and Turkey oak (*Quercus cerris*) for present (1961–1990) and future climate (2036–2065 and 2071–2100) applying fuzzy membership functions using the relationship between the composition rate of the tree species and long-term climate in Hungary. Although the presence of tree species in Hungary is influenced by human (and will also in the future), the composition rate (%) was used as a kind of probability of occurrence instead of using only the presence/absence information of the species.

All three investigated tree species form extensive forest stands throughout Central Europe and from the forest steppe limit upward, according to their moisture requirement. Turkey oak, sessile oak and beech dominate as climate indicators of the zonal forests.

So far, distribution changes of beech and sessile oak were modeled since they are the most important tree species in forest management in Hungary. Only a few studies are dealing with the distribution change of turkey oak (e.g. Führer et al. 2011). The resistance of turkey oak against droughts may increase the importance of this species in the forest sector considering climate change.

In our study the following research questions are addressed:

1. What is the relation between the tree species composition and climate aridity?
2. How would the current potential distribution and tree species composition change under projected climate conditions?
3. Are the modeled present and future potential distribution of the tree species agree with the results of previous studies?

To answer the research questions (1) we created the Ellenberg climate surfaces for the present (1961–1990) and future (2036–2065 and 2071–2100), (2) coupled the composition information of beech, common oak and turkey oak with EQ to define membership functions, (3) modeled the current and future distribution of the species and (4) compared the present and future distributions with other potential distribution maps.

2 MATERIALS AND METHODS

2.1 Climate data

For modeling the potential vegetation the Ellenberg quotient (*EQ*, Ellenberg 1988) has been used. EQ has been shown as one of the best indicator for tree species distribution (Czúcz et al. 2010, Rasztovits et al. 2012, Stojanovic et al. 2013) defined as the mean temperature of the warmest month (July) divided by the annual precipitation:

$$EQ = 1000 T_{07} P_{ann}^{-1}$$

The precipitation data (approx. 80 stations) was interpolated by Kriging with 50km search radius and 500m resolution. The interpolation was checked with cross-validation namely by leaving out stations with measured data from interpolation and afterwards comparing it to the interpolated value. This has shown that the average deviation was only about 10.2% of the annual precipitation sum.

Air temperature for July (31 stations) was also interpolated using kriging with 500m resolution. The effect of elevation was considered by the SRTM digital elevation model using constant monthly gradients (Peczely 1979).

For the future climate (2036–2065 and 2071–2100) results of the regional climate model simulations by REMO (Jacob et al. 2001, Jacob et al. 2007) were analyzed for the A1B IPCC-SRES emission scenario (*Table 1*).

Table 2. Simulation results of REMO for the future related to the base period 1961–1990 (values are representing country means for Hungary)

Climate variable	1961–1990	2036–2061	2071–2100
July temperature mean	19.6°C	+1.6°C	+3.7°C
Annual precipitation sum	583 mm	+2.59%	–2.2%

For country means, climate change signals for July temperature mean and annual precipitation sum was calculated as the difference of the simulated future and past periods (e.g. 2036–2060 vs. 1961–1990). To avoid the model bias, delta change approach has been applied: the simulated change signals were added to the observed climate in the past. Based on the resulting temperature and precipitation maps**,** EQs have been computed for the future in the same way as for the present climate.

Applying climatic means are not fully appropriate for describing species distribution change driven by climatic change, since the decline of the species is related mostly to prolonged extreme events and subsequent biotic damages (Berki – Rasztovits 2009, Rasztovits et al. 2012). However, lacking reliable projections on extreme events, climatic means were used as surrogates (Mátyás et al. 2008).

2.2 Forest data

As mentioned above the distributions of three tree species were investigated beech, sessile oak and Turkey oak in Hungary for potential distribution modeling. The occurrence and composition data was derived from the Hungarian Forest Inventory database provided by the Central Agricultural Office, gathered in 2012. The database included all the forest compartments containing any of the three tree species. We have used the geometrical centre of the forest compartment polygons as reference point to extract climate parameters from digital climate surfaces.

The Forest Inventory database contained details on site and stand conditions, which allow excluding sites located at microclimatic, edaphic and hydrological extremes, from further analysis. Accordingly, all compartments have been omitted with shallow soil, surplus water effect and steep slopes above 20°.

The composition rate (%) of tree species was defined as the species percentage cover of each forest compartment which reflects the favour of the environmental conditions for the tree species occurrences. The natural equilibrium in the mixture ratio is strongly altered by the forest management even in semi-natural forests but towards the distribution limit of the tree species this selection has no significant effect on the mixture ratio as the ecological conditions overwrite biotic interactions.

2.3 Defining the relation between EQ and the composition rate

We defined the relationship between the EQ and mixture rate to model the current and future potential distribution of the three tree species.

First, the value of the present aridity index (1961–1990) was added to each compartment using zonal statistics. The relations between the composition rates of the species and EQ were then plotted on compartment level. We aggregated the data to equal interval classes of EQ and calculated the average composition rate of each class with the corresponding 95% confidence intervals. Polynomial regressions in the order of four were applied to describe the relationships.

2.4 The fuzzy membership approach

To model the current and future potential distribution of tree species the fuzzy membership has been applied. This approach was selected as it allows to better consider the continuous variation of forest stand composition of tree species due to location characteristics, species competition and forest management.

The approach uses membership functions to classify features of arbitrary range into fuzzy values, between zero and one to indicate the degree of membership. In our case the membership functions were based on the relation between EQ and composition rate of the tree species.

We have used the eCognition software (Definiens 2005). eCognition is usually applied for remote sensing classifications by merging the information of the spectral “bands” of images like orthophotos or satellite images. Here the three tree composition fractions were stored in separate grid layers treated as 3 bands of an image raster. So finally spatial objects of similar tree composition could be delineated through a statistical segmentation process. The extracted objects correspond to certain homogeneity criteria based on a scaling parameter.

The membership functions for the three tree species are evaluated for each object during the classification. The result of the classification is twofold, a fuzzy classification with mixture values of tree species and a discrete classification where each image objects are assigned to of the one tree species with the highest fuzzy share.

3 RESULTS AND DISCUSSIONS

3.1 Relationship of EQ and composition rate

The computed Ellenberg quotient maps show that the aridity will increase in Hungary during the century (*Figure 1*).

A B C

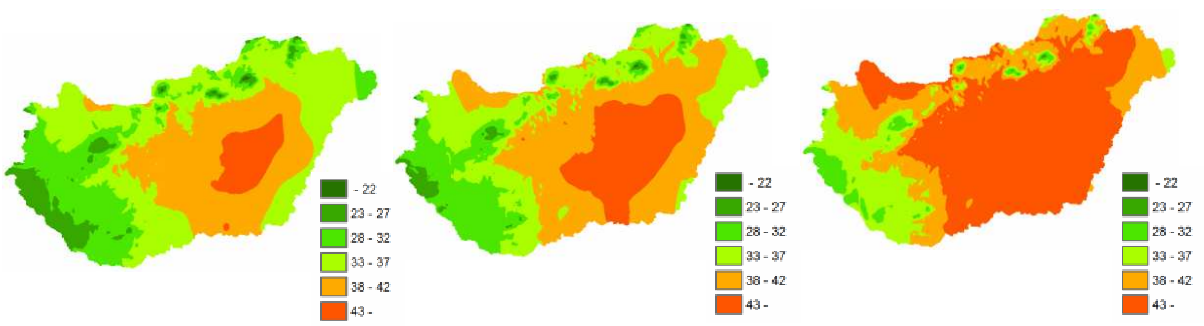

Figure 1. EQ for 1961–1990 (A) for 2036–2065 (B) and for 2071–2100 (C)

For visualization of the dominant spatial occurrences of these species we have used the threshold value of 90% composition rate (*Figure 2*).

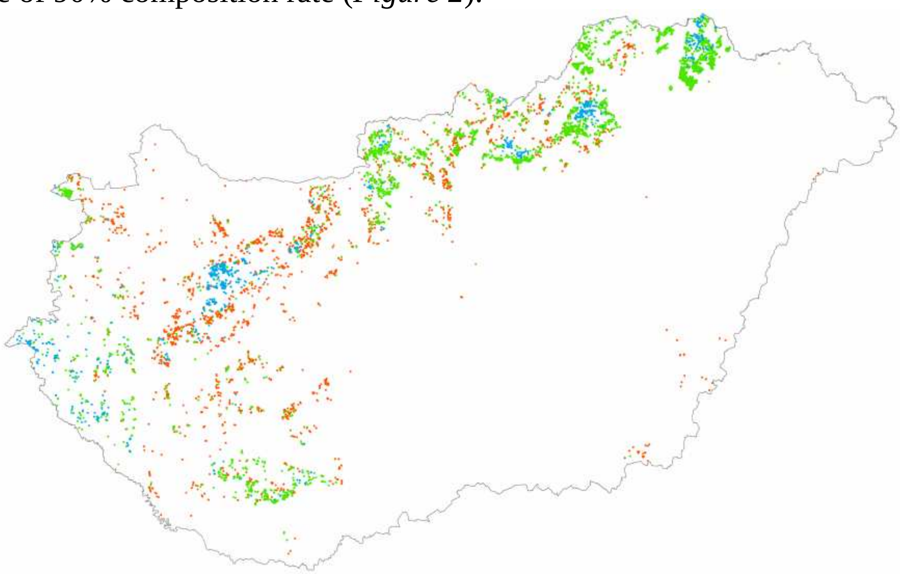

Figure 2. Beech (blue), sessile oak (green) and Turkey oak (red) compartments (with composition rate above 90%) in Hungary

Beech, which is the most climate-dependent among the investigated species, is mainly dominant in the higher mountain areas and in SW-Hungary. The actual distributions of sessile and Turkey oak are disturbed, due to forest management praxis, especially along the xeric limit of the species. Sessile oak is more widespread in the lower parts of the mountains especially in NE-Hungary. Turkey oak occupies the more arid locations along the foothills and lowland regions but it can be also found in more humid conditions as the dominant.

The relationships between EQ and composition rate for each forest compartment have shown no clear correlation in any case of the studied species. Merely, the aggregation of the EQ values to equal classes and the assignment the mean value of the composition rate to the classes have revealed a strong link (*Figure 3*).

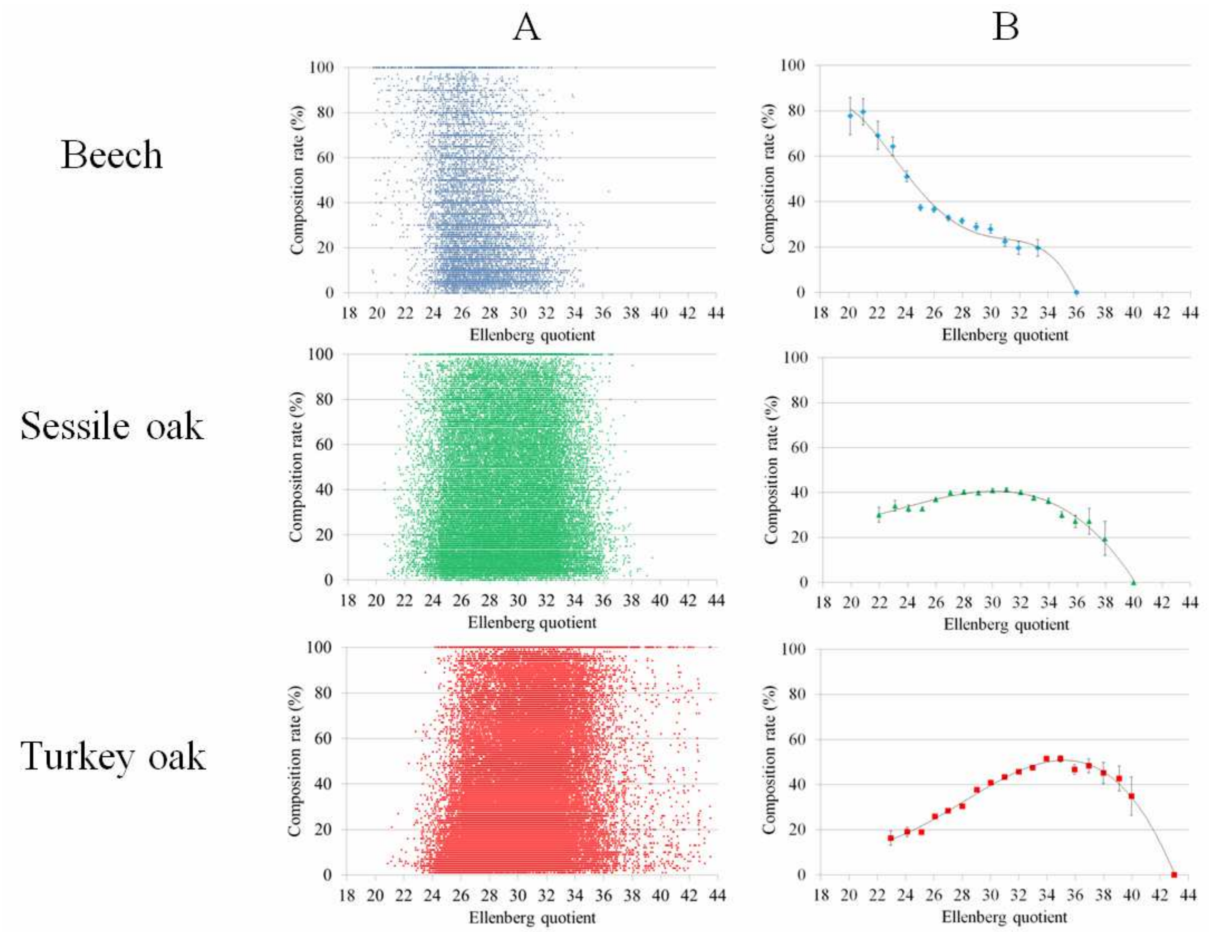

Figure 3. The original (A) and aggregated (B) relationship between the EQ and the composition rate of beech, sessile oak and Turkey oak with corresponding confidence intervals

The membership functions show the degree of suitability of the tree species on a given location using the composition rate as proxy. The lower limit of each tree species was given by the lowest EQ-s of the occurrences. In general the relationships show that the lower limit of each species is approached abruptly, but at different EQ limits. No occurrences of these species were observed above EQ 43. Beech is the dominant tree species at the most humid locations in Hungary, the mixing ratio reaches here up to 80%. The composition rate of sessile oak is surprisingly balanced with around 30–40% in the distribution area, but decreases by approaching its lower limit. The mixing of Turkey oak increases with higher aridity up to 50% until around EQ 35 and then it decreases rapidly as we reach the forest-steppe limit (*Figure 3*).

3.2 Potential distribution of the investigated tree species for recent and future climate

The result of the discrete classification is a map where each tree composition object is assigned to only one tree species. The current potential distribution map is in good agreement with the current distributions of the tree species (*Figure 4*).

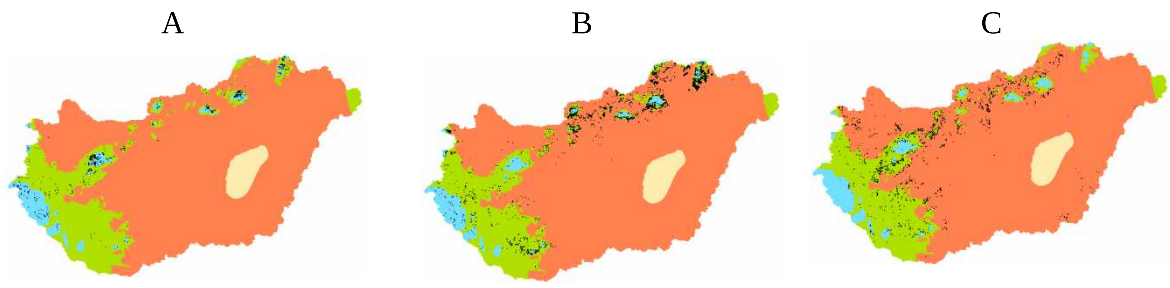

Figure 4. Modeled current tree species distribution maps (A-B-C: beech – blue, sessile oak – green, Turkey oak – red, no forest – white) with the current distribution of beech (A), sessile oak (B) and Turkey oak (C) (with composition rate above 90%)

In case of beech the modeled current tree species distribution pattern covers most of the current pure beech stands. However, some under-prediction can be observed at lower elevations. The lower distribution limit of sessile oak matches well with the forest stands in the Transdanubian region, but there is some substantial difference in the mountains of North-East Hungary. Turkey oak could potentially occupy most of the lowland areas in Hungary except of the most arid places around the center of the Hungarian lowland. Both oak species can be found not only in their dominant area but also in more moist conditions.

The modeled future tree species distribution patterns show large changes due to projected climate change (*Figure 5*).

Figure 5. Modeled future tree species distribution maps for 2036–2065 (A) and 2071–2100 (B), beech – blue, sessile oak – green, Turkey oak – red, no forest – white

The distribution area of beech is expected to decrease substantially till 2050 and will be restricted to the higher mountain areas and along the south-west border. By the end of the century it could disappear totally except of some locations in the highest mountains (e.g in Bükk). Similarly, sessile oak is expected to decline and will be restricted and its occurrence mainly to the south-west of Hungary and in general to higher elevation by 2050 (*Figure 5*). The present occurrences are expected to decrease by about 25%. By the end of the century sessile oak can only be found in higher mountains and probably along the border to Slovenia (*Table 2*).

Table 2. Percentage of occurrences relative to the total occurrences found above the lower limit of potential distribution area presently (1961–1990)

	2036–2061 (%)	2071–2100 (%)
Beech	35.3	1.7
Sessile oak	75.5	13.9
Turkey oak	99.8	96.9

The distribution area of Turkey oak will be about the same by the middle of the century since while it will lose some area in the Hungarian Lowland, it will occupy large tracts of area from sessile oak in the Transdanubian region (*Figure 5*). Finally, by the end of the century the optimum area of this species will also slightly decrease and relocated from the lowland to the hilly and mountainous regions. The area where none of these tree species will find optimal conditions will be significantly greater during the course of the century (*Figure 5*).

The potential composition of the tree species evaluated by the fuzzy membership functions for present and future climates show similar changes (*Figure 6*).

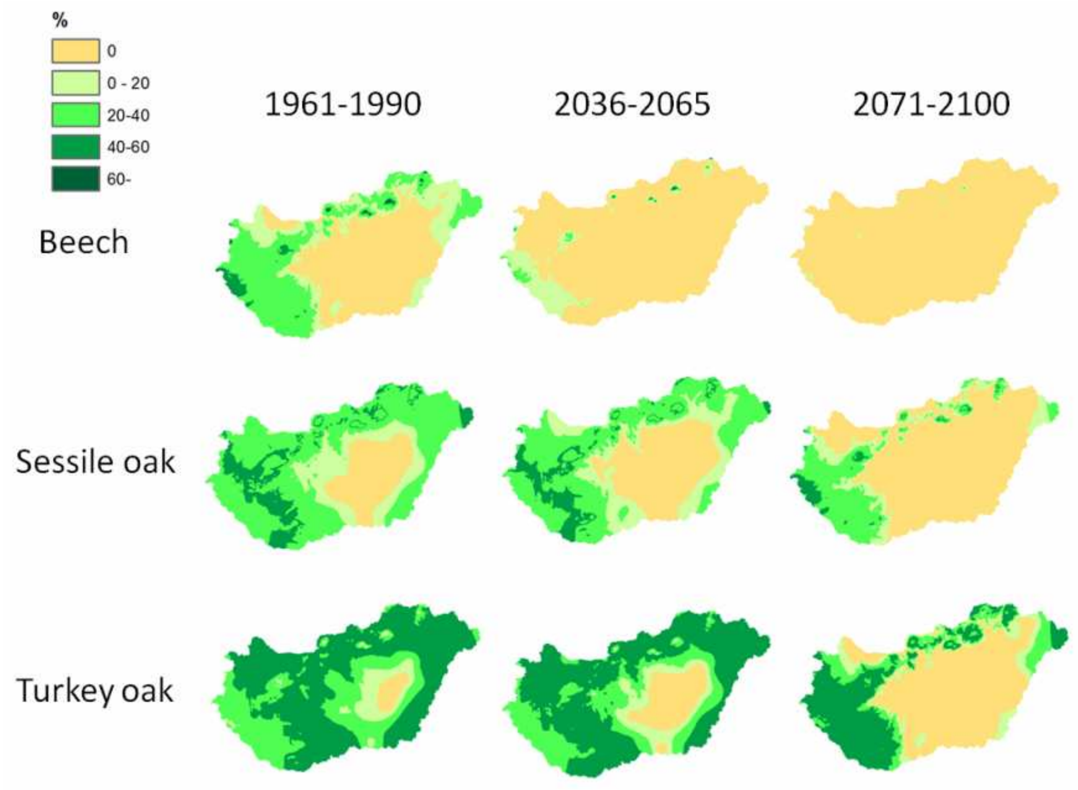

Figure 6. Composition rates of tree species for present (1961–1990) and future climates (2036–2065 and 2071–2100)

Beech is already expected to be a minor tree species for the middle of the century and only some stands may preserve until the end of the century particularly in sites with appropriate microclimatic conditions. The mixture of sessile oak may also decline during the century and the most dominant stands will be concentrated in the mountains (*Figure 6*). The large mixture of Turkey oak in large parts of Hungary will even increase and only by the end of the century it is expected that the mixture may begin to decline especially at lower elevations.

3.3 Comparison with other potential vegetation maps

We have compared our results with similar studies which was not easy due to the wide variety of the applied methods and climate scenarios.

Czúcz et al. (2010) focused on the analysis of climate change impacts at the trailing (xeric) limits of closed forests in Hungary exploring beech and sessile oak forests. Conditional tree regression was applied which have revealed the significance of EQ in distribution modeling. Their results for the HADCM3 A1B scenario showed similar tendencies of decline of the investigated tree species during this century.

The future distribution pattern of the main tree species of the Transdanubian region was modelled by Führer et al. (2011, 2013). For describing the growth of the trees, the forest aridity index was developed, based on phenological patterns of growth. Two future climate scenarios have been applied assuming 1 and 1.7°C increase in summer temperature and decrease of precipitation in summer by 8.2%. The larger temperature change implies that beech may almost entirely disappear from this region. The area of the Turkey oak may remain the same but shifts partly to the area of today's sessile oak. Finally, the area of forest steppe may expand and occupies some of the area from current Turkey oak, similar as projected by our approach.

Rasztovits et al. (2012) has evaluated the habitat suitability of beech forests for three terms in the 21st century in Hungary using different species distribution models. Here a CLM A1B simulation was used. The authors have found that the neural networks (e.g. BP-ANN) and classification tree methods (e.g. CTree) delivered better results than other approaches. BP-ANN predicted a very slight shrinkage of the potential area (8.0%) during 2036–2065. A considerable decrease of the potential area was foreseen only to the end of this century which results that about 45% of the current stands will be out of the potential area. Regionally the most serious decrease was predicted for the sub-Mediterranean region in Southwest Hungary. CTree predicted a more significant shrinkage of beech in all regions of Hungary by losing 67.5% of the area during 2036–2065 and 74.7% during 2071–2100 which was quite in agreement with our results.

3.4 Uncertainties

Our approach is based on the assumption that the potential distribution of beech and common oak are determined by climatic means. The relationship between the potential distribution and the climatic mean may not hold when weather extremes (like droughts) occur with a much higher frequency than nowadays. These act as triggering effect on tree growth decline and pests or diseases that attack populations of weakened vitality and cause mortality (Bréda et al. 2006, McDowell et al. 2007, Lakatos and Molnár 2009). So predictions based on climatic means alone could overestimate the potential distribution of species.

Predictive ecological modelling is usually based on equilibrium between climate and species tolerance. This biotic uncertainty originates from the inadequate understanding of the mainly ecological factors influencing the equilibrium of the species distribution. The genetically set tolerance limits of species are wider than realized ones and this is especially valid for populations near their distribution limits. Climate change may affect also consumes and pathogens that cannot be predicted. The persistence of forest ecosystems is one of the main sources of uncertainty of distribution modelling, which is supported by the wide phenotypic plasticity of trees proven by comparative field tests (Mátyás 2007). The persistence of forests is further reinforced by planned forest management and changing species preferences, which may assist to maintain forests in the future (Mátyás et al. 2009).

Soil conditions (e.g. soil texture, water holding capacity, groundwater depth) were not considered, since fine-scale information for forests compartments was not available, which could lead to over or underestimation of the potential distribution areas of tree species, compared to the pure climatic based assessment of this study.

A substantial proportion of forest stands are situated on non-zonal sites, which were not accounted by our modelling, but these sites may assist to preserve optimal conditions for the investigated species even if the climate will not be suitable for zonal occurrences.

4 CONCLUSIONS

The composition rate was used for describing the probability of occurrence instead of the presence/absence information of the species. We have defined functions using the recent composition rate and the Ellenberg quotient, both applied to model the present and future tree species distribution and composition rate. We have only considered stands located at zonal positions.

The projections based on the simulation results of the regional climate model REMO have shown a significant decline of beech and sessile oak in Hungary during the century which is in accordance with other study results near the xeric limit of these species. By the middle of the century only about 35% of the present beech and 75% of the sessile oak stands will remain above their current potential distribution limit. By the end of the century beech forest may almost disappear from Hungary and sessile oak will also be found only along the Southwest border and in higher mountain regions. On the contrary the present occurrences of Turkey oak will be almost entirely preserved during the century however its distribution area will be shifted to the Transdanubian region hence occupying large areas of current sessile oak habitat.

This study also underlines the importance of future forest management and conversion strategies from the perspective of the species selection, regeneration and financial issues. The results of the study will be in more detail investigated in an upcoming national project TAMOP dealing with the preparation of a decision support system for forest management in Hungary.

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