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MODELING THE IMPACTS OF CLIMATE CHANGE ON PHYTOGEOGRAPHICAL UNITS. A CASE STUDY OF THE MOESZ LINE

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Abstract

Regional climate models (RCMs) provide reliable climatic predictions for the next 90 years with high horizontal and temporal resolution. In the 21st century northward latitudinal and upward altitudinal shift of the distribution of plant species and phytogeographical units is expected. It is discussed how the modeling of phytogeographical unit can be reduced to modeling plant distributions. Predicted shift of the Moesz line is studied as case study (with three different modeling approaches) using 36 parameters of REMO regional climate dataset, ArcGIS geographic information software, and periods of 1961-1990 (reference period), 2011-2040, and 2041-2070. The disadvantages of this relatively simple climate envelope modeling (CEM) approach are then discussed and several ways of model improvement are suggested. Some statistical and artificial intelligence (AI) methods (logistic regression, cluster analysis and other clustering methods, decision tree, evolutionary algorithm, artificial neural network) are able to provide development of the model. Among them artificial neural networks (ANN) seems to be the most suitable algorithm for this purpose, which provides a black box method for distribution modeling.

Keywords: climate change, REMO, Climate envelope model, phytogeography, Moesz line, model improvement

INTRODUCTION

The latest regional climate models (RCMs) have high horizontal resolution and good reliability. They provide projections for the Carpathian Basin that are related to botany (Czúcz, 2010), landscape architecture (Bede-Fazekas, 2012a), and forestry (Mátyás et al., 2010; Führer et al., 2010; Czúcz et al., 2011). Our future climate, which is likely to be warmer, dryer in summer, and have more extreme precipitations in the colder half-year term (Bartholy et al., 2007; Bartholy and Pongrácz, 2008), will enforce changes in the composition of the natural and the planted vegetation. The landscape architecture can have a significant role on the mitigation. We should note, however, the importance of adaptation, since climate change cannot be compensated by the intensive garden maintenance (Bede-Fazekas, 2011). One of the most important tools from the adaptation toolkit of landscapes architecture is the reconsideration of the ornamental plant assortment. There are some papers dealing with this issue (Schmidt, 2006; Szabó and Bede-Fazekas, 2012).

Geographical visualization can be produced with GIS (Geographic Information System) software based on the large amount of tabulated data of the different climate models, which might be interpretable not only by experts. They are able to visualize the direction and the volume of climate change also for non-professionals (Czinkócky and Bede-Fazekas, 2012). This is true in case of different modeling themes, such as the distribution area of the Mediterranean plant species; the distribution area of the plant species migrating northwards from the Carpathian Basin; and the phytogeographical units and borders that may shift from or shift to the Carpathian Basin. Phytogeography, a branch of biogeography, is concerned with the distribution area of plant species, communities and floras. This paper summarizes the experiences gained by the model run on the Moesz line as a case study and highlights the possible improvements of the model, including the application of Artificial Intelligence (AI) algorithms.

There are really few models that have studied the assortment of plants able to spread through or be introduced in the Carpathian Basin in the 21st century. There are, however, numerous researches that have connection with these modeling approaches. The research of Horváth (2008a) about finding the territories having similar climate nowadays to the future climate of Hungary has high importance. He has found that these spatially analogue territories are, for the next 60 years, the following: South Rumania, North Bulgaria, Serbia, and North Greece (Horváth, 2008b). By studying the vegetation and ornamental plant assortment of the analogue territories we can estimate the future vegetation and the possibilities of ornamental plant usage in the future in Hungary.

Among forestry species the distribution of beech (*Fagus sylvatica* L.) has been modeled (Führer, 2008). The impacts of climate change on the natural vegetation and habitats were studied by Kovács-Láng et al. (2008) and Czúcz (2010). Artificial neural network, is one of the artificial intelligence methods described further as a recommended improvement of the model, was used for modeling the inland excess water by Van Leeuwen and Tobak (2008).

Apart from Hungary, there can several researches be found using similar methods to that ones I suggest in the Discussion. One of the most significant is the work of Arundel (2005), which is about finding the climate envelope of five warm-demanding species of North America by significance analysis. Modeling was, however, not carried out by him. Berry et al. (2002) modeled the distribution of 54 species and the composition of 15 habitats of Ireland and Great Britain. Harrison et al. (2010) studied the potential composition change of the vegetation of Oregon. The distribution of 134 North American tree species was modeled by Iverson et al. (2008) with the use of regression trees. Stankowski and Parker (2010) found that regardless of distributional and environmental data, there is not any algorithm which could maximize model performance for all species; thus different species demand different models. Guisan and Zimmermann (2000) give full review of the methods that can be used for ecological modeling.

METHODS OF MODELING

The approach of modeling the shift of phytogeographical units can be reduced to modeling the potential distribution area of fictive or real species bound to the phytogeographical unit. The inputs of the model are the current distribution of the plant species, the climate date for the reference period, and the climate data for the future period(s). There are three main steps: 1) querying the climate demands/tolerance of the species; 2) validating the model (modeling the reference period); 3) predicting (modeling for the future period). The climate requirements of the species can be filtered based on the distribution and the climate data of the reference period, since the extremes of a certain climate parameter indicate the tolerance boundaries of the species. The selection of climate parameters, however, is subjective. Note that the model can fail if not enough or too much

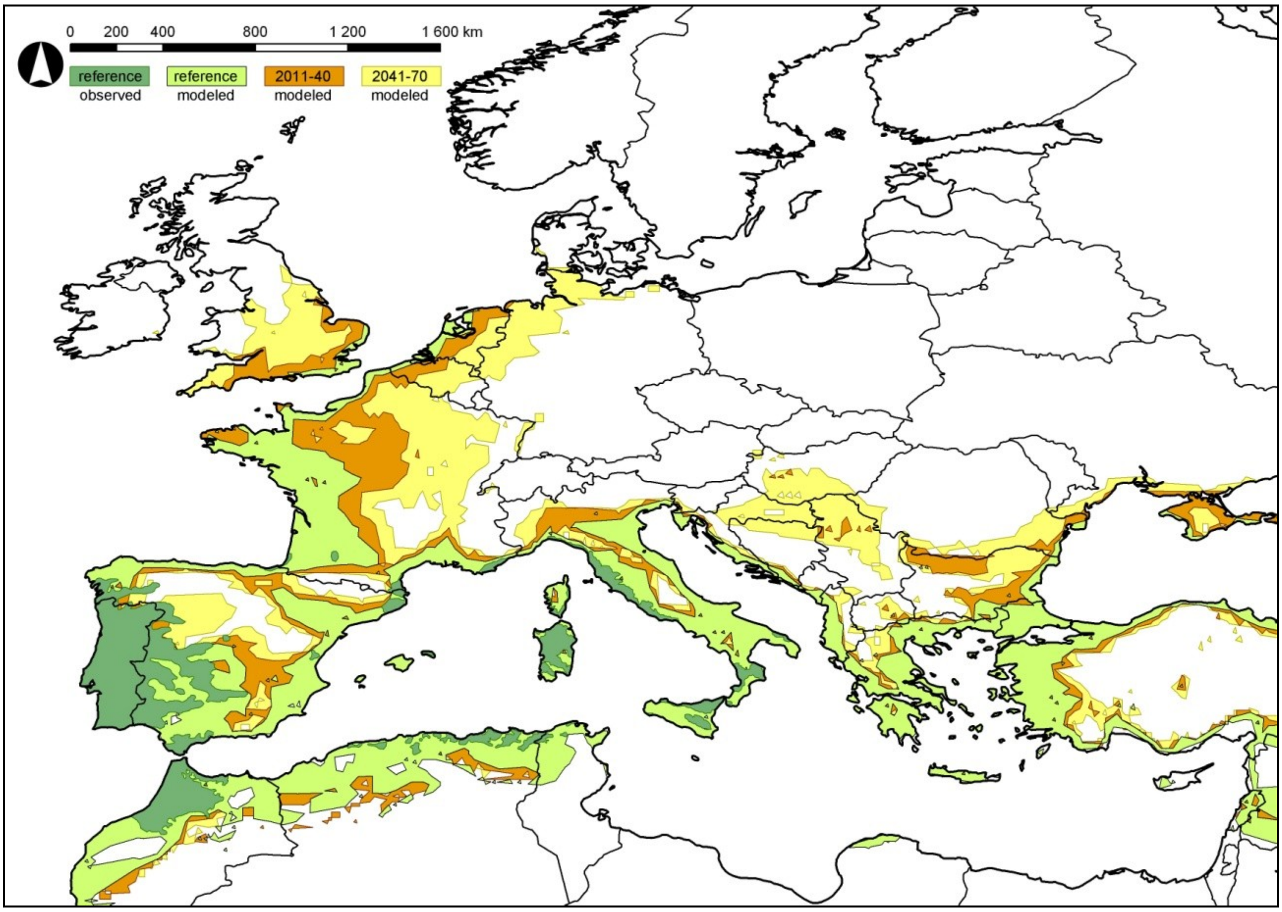

Fig. 1 Observed distribution, modeled potential distribution for the reference period, and predicted potential distribution for the future periods of cork oak (*Quercus suber*)

climate parameters are selected (Bede-Fazekas, 2012a). The result of this phase is a list of climatic limits (a zero-order logical formula in mathematical terms) per species, therefore the climate requirements of the species are written as equations. This is the mathematical basis of the prediction that used in the next phase.

Based on the knowledge of the climate requirements, the territories providing suitable climatic environment for the plant can be filtered according to the climate data of the reference period. The sum of these territories is the potential distribution area. Modeling the potential distribution for the reference period is seemingly unnecessary and negligible, and it does not influence the result. This medial phase of modeling is, however, not to be omitted, since the result of this phase provides for the possibility of validating. The reliability of the future predictions (model results) can be concluded by comparing the observed distribution to the modeled potential distribution. In case of much greater area of distribution the model results are not to be reckoned as reliable results, irrespective from the known influence of anthropogenic, edaphic and competitive effects on the real distribution. Therefore, the similarity of the observed and modeled distribution can guarantee that the model is reliable enough.

Based on the climate demands of a certain plant species and the climate data, the suitable territories can be filtered not just for the reference period but also for the future periods. This third phase is the modeling/prediction approach in the strictest sense; this is about finding the future potential distribution (*Fig. 1*).

The method of modeling the future shift of Moesz line (also called as grape line) is going to be reviewed, which is appropriate example of modeling a phytogeographical unit based on modeling the distribution of separate species. Moesz (1911) observed that the northern borders of 12 plant species are highly correlated with each other, and this line is also the northern border of the vine cultivation area. This phytogeographical line, which is situated near the southern foot of the Western Carpathians, was later named after Moesz. There is hardly any international literature about the Moesz line, since it is of local importance. Note, that elongation of the grape line to the west and to the east results in an extended phytogeographical line which still correlate with the northern border of some species originally bound to the Moesz line (eg. *Muscari botryoides* – Somlyay, 2003). The extended line characterizes not only the flora and ornamental plant assortment of the Carpathian Basin, therefore modeling the Moesz line can have importance for entire continent.

There are several approaches of modeling a phytogeographical line. Three different methods (called line modeling, distribution modeling, and isotherm modeling) are going to be discussed. The models were run by the Spatial Analyst module of the GIS software ESRI ArcGIS. All of them were based on the regional climate model REMO, which has a grid resolution of 25 km. Although the entire European Continent is within the domain of REMO, we used only a part (25724 of the 32300 points; *Fig. 2*) of the grid. The reference period was 1961-1990, while the future predictions were applied for the periods 2011–2040 and 2041–2070 based on the IPCC SPES scenario called A1B.

Isotherm modeling among the three methods is the easiest to apply. It is based on finding that winter minimum temperature isotherm that correlates with the phytogeographical line most of all. The predicted shift of the isotherm probably indicates the shift of the

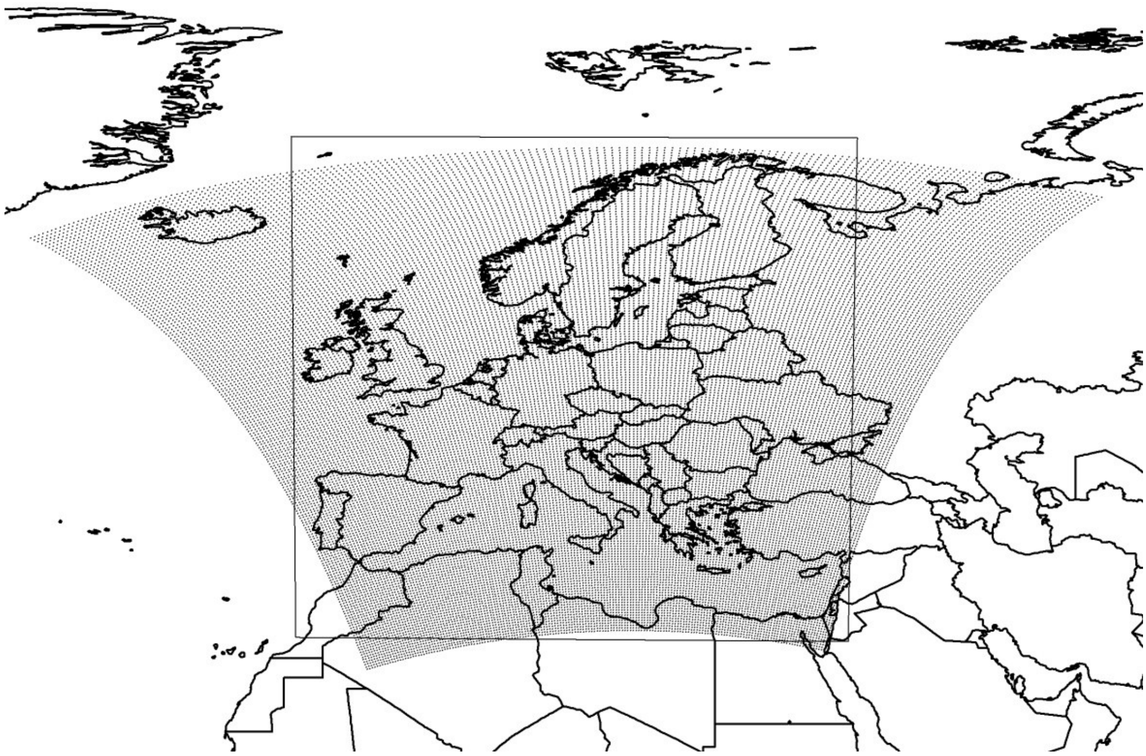

Fig. 2 The domain of regional climate model REMO (grid) and its part used in the study (within the rectangle)

phytogeographical line. The main disadvantage of this method is that the existence of this isotherm cannot be guaranteed in case of all phytogeographical borders (in case of the Moesz line the appropriate isotherm was found). Only one or a few climatic parameters are considered by this method, thus it is a rather inaccurate and not so reliable method. Moreover it can yield to a result that is hard to interpret (similar to the case of isotherm modeling of Moesz line). Nevertheless, it is a very fast method and does not require digitizing distribution areas. Line modeling is a somewhat complicated method. It is based on modeling the shift of the distribution area of a fictive species, whose northern distribution borders coincide with the phytogeographical line (the southern border is irrelevant). It is a slow but somewhat more accurate method. The most complicated method is called Distribution modeling, which is also the slowest one. The model is run on the distribution of numerous plant species bound to the phytogeographical line separately. Then the northern borders of the predicted potential distributions are merged. The method provides detailed result, but drawing the final line (the prediction) is still subjective. Detailed comparison of the three aforementioned modeling methods is published by Bede-Fazekas (2012b). Distribution modeling is, in methodical terms, similar to multiple Line modeling.

Line modeling is a kind of Climate Envelope Modeling (CEM) which is about predicting responses of species to climate change by drawing an envelope around the domain of climatic variables where the given species has been recently found and then identifying areas predicted to fall within that domain in the future (Ibáñez et al., 2006, Hijmans and Graham, 2006). It assumes that (present and future) distributions are dependent basically on the climatic variables (Czúcz, 2010) which is somewhat dubious (Skov and Svenning, 2004).

36 climatic variables were used for the modeling: monthly mean temperature (°C), monthly minimum temperature (°C), and monthly summarized precipitation (mm). All the climatic data were averaged in the periods of thirty years.

RESULTS OF LINE MODELING

The results of Line modeling is shown in *Fig. 3.* The method was visually validated (by the correlation of the Moesz line and the modeled line for the reference period). Some measurements are also known for model evaluating, eg. Cohen's kappa (Cohen, 1960) and ROC/AUC (Hanley and Mcneil, 1982), they are, however, based on measuring areas instead of coincidence of curves. The observed precision is good enough despite of the relatively low horizontal resolution of the climate data. The modeled distribution of the

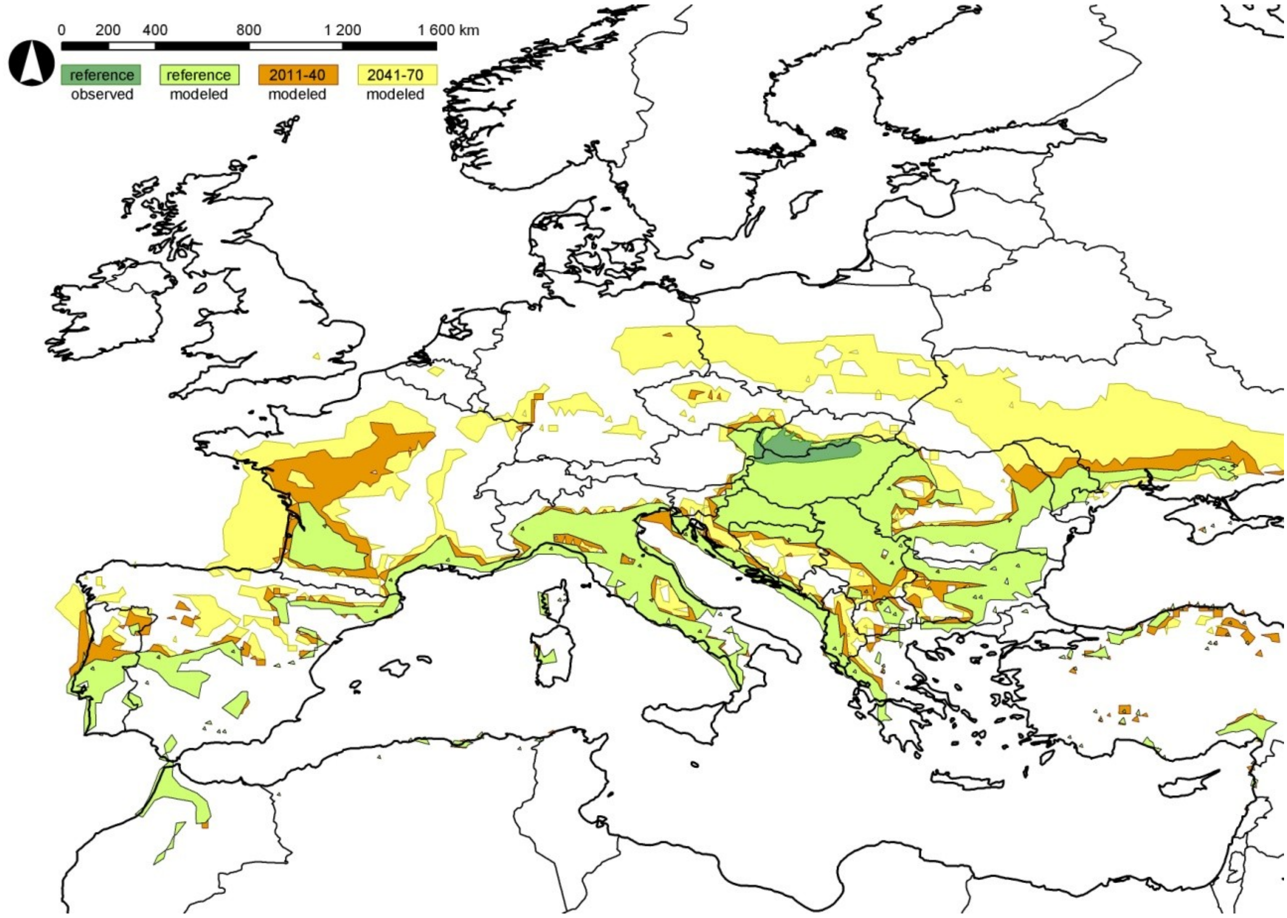

Fig. 3 Observed distribution, modeled potential distribution for the reference period, and predicted potential distribution for the future periods of the fictive plant species bound to the Moesz line in case of the Line modeling method

fictive species shows a northern border from Southern France, through the southern and eastern foot of the Alps, the southern foot of Western Carpathians, the western foot of the Eastern Carpathians, the southern and eastern foot of the Southern Carpathians, to Southern Ukraine. The prediction for the period 2011–2040 shows not such a great shift in the Carpathians as it was expected. Remarkable shift can be seen in France and to the east of the Eastern Carpathians. For the far future period (2041–70) the model provides results that correspond with our preliminary expectations. The predicted line displays in three segments separately: 1) the Moesz line may shift upwards (and northwards) to the Carpathians; 2) in Poland, a new Moesz line may appear, which indicates the northern border of the distribution of species that can be established in Poland; 3) and a southern border of the Polish territories of optimal climate (so called 'anti-Moesz-line') may appear in the northern side of the Carpathians. Besides the expansion in France, discrete territories in England, Belgium, Germany and Bohemia are also predicted for the far future period. *Fig. 3.* also points out that the Carpathians (and subordinately the Alps) will obstruct (as phytogeographical barrier) the expansion of the plant species bound to the Moesz line.

DISCUSSION OF THE IMPROVEMENT OF MODEL WITH ARTIFICIAL INTELLIGENCE ALGORITHMS

As the model results show, two of the three aforementioned modeling methods provide maps good enough (in terms of comparison of the observed and modeled distributions in the reference period) to display the impact of the climate change. Since only a few climatic parameters were applied, the accuracy and reliability of the model can be improved by using some other climatic parameters (eg. sum of heat, length of vegetation period, length of the period endangered by frost) and edaphic parameters (eg. alkalinity, quantity of lime). Although, more detailed and accurate inputs (eg. distribution maps, climate grid) could strengthen the model, it should also be noted, that the real improvement of the model can be reached only by the development of the modeling method.

The cumulative distribution function should be calculated by statistical software to leave some percentiles from the minimum and maximum values of a certain climatic parameter. Hence, only the climatic values that are bound exactly to the studied distribution area will be considered, since climatic extremes are mainly found near the distribution border will be left.

Further improvement of the abovementioned Line model can be applied by using statistical or artificial intelligence (AI) methods to select the appropriate parameters from the infinite combination of the numerous climate parameters objectively. Various ways can be used to determine the climate envelope, including simple regression, distance-based methods, genetic algorithms for rule-set prediction, and neural nets (Ibáñez et al., 2006). To reduce subjectivity of parameters' choice, logistic regression can be applied, which specifies the linear combination of climate parameters that determines the likelihood of distribution. Another appropriate statistic method is cluster analysis, which explains the vector of climate parameters as points of a multidimensional space, and searches for a lower dimension which separates the distribution apart its surroundings. Other clustering methods can be used, too.

In comparison to statistical methods, applying artificial intelligence algorithms may results in much more improvement of the model. Note, that some of them are black box methods, which can only answer the question what?/where?/when?, but not the question why?/how?. Several artificial intelligence methods can be used for modeling the distribution of plant species or phytogeographical units, such as decision tree, evolutionary algorithm, and artificial neural net (ANN). Hilbert and Ostendorf (2001) studied different forest types with ANN, and the research of Carpenter et al. (1999), Özesmi and Özesmi (1999), Hilbert and Van Den Muyzenberg (1999), Özesmi et al.(2006), Harrison et al. (2010), and Ogawa-Onishi et al. (2010) should be mentioned, since they modeled the distribution of species or communities with ANN. Evolutionary algorithm (which matches the climatic parameters with alleles and provides a process similar to natural selection with finite length) could conclude which parameters (and which extrema of them) are able to express the climate tolerance most of all. The result is therefore similar to the equations used in this research. This does not hold for ANN, since a complicated neural net cannot be reduced to linear mathematical expressions. ANN is similar to a real neural net densely furnished with axons, where the neurons are organized in layers. The algorithm has two main phases. Learning phase is the first, when the program builds up and balances the internal structure of the net in such a way, that it is adjusted to the distribution of the plant. After the learning phase the model could determine the likelihood of presence at all the points of Europe (for the reference period and the future periods, too).

In contrary to ANN, the aforementioned statistical and AI methods are not able to result in a map showing the potential distribution area (which is still the aim of modeling). On the other hand ANN is the only method among them which is not able to separate the filtering of climate demands of species apart from the prediction. The essence of the learning phase is that based on the distribution and climate data the program forms a multi-layered structure and it calculates the so called weights of every axon, iteratively. In the course of the time-consuming, but finite learning phase the weights are continuously changed based on remodeling and error evaluation.

A well parameterized ANN with appropriate topology could model the future potential distribution area in a much more reliable way. The feedforward neural network (with multilayer perceptron model) seems to be the most suitable for distribution modeling. An ANN with Backporpagation training method is now under development in Python programming language for

ArcGIS software. Input layer is connected to the climatic parameters (the number of neurons is determined by the number of parameters). The output layer has only one neuron which is able to predict a presence/absence data (1/0) or the likelihood of the absence (%). The training set is the part of the prediction set; the latter is the grid of the climate model (with more than 20,000 points).

CONCLUSION

The modeling approaches of the distribution of plant species and phytogeographical units were studied and the conspicuous deficiencies of them were discussed. Note, that in absence of AI supported modeling method, the used three simple models could provide spectacular results. Modeling the Moesz line yielded remarkable results, which are not perfectly the same as it was expected. It can be concluded that the Northern Carpathians will provide significant barrier for the plant species bound to the Moesz line. In harmony to the studies of Kovács-Láng et al. (2008) – who stated that the speed of ecological processes is not synchronous with the speed of the climate change and therefore the mountains with latitudinal direction may become natural barriers – we should note that without human aid some of these species will not be able to get as far as Poland. Hence there is a risk that the predicted shift of the Moesz line may be a prediction of the shift of only a virtual line.

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