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Impact of climate change on the potential distribution of Mediterranean pines

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Abstract—The impact of climate change on the potential distribution of four Mediterranean pine species – *Pinus brutia* Ten., *Pinus halepensis* Mill., *Pinus pinaster* Aiton, and *Pinus pinea* L. – was studied by the Climate Envelope Model (CEM) to examine whether these species are suitable for the use as ornamental plants without frost protection in the Carpathian Basin. The model was supported by EUFORGEN digital area database (distribution maps), ESRI ArcGIS 10 software's Spatial Analyst module (modeling environment), PAST (calibration of the model with statistical method), and REMO regional climate model (climatic data). The climate data were available in a 25 km resolution grid for the reference period (1961–1990) and two future periods (2011–2040, 2041–2070). The regional climate model was based on the IPCC SRES A1B scenario. While the potential distribution of *P. brutia* was not predicted to expand remarkably, an explicit shift of the distribution of the other three species was shown. Northwestern African distribution segments seem to become abandoned in the future. Current distribution of *P. brutia* may be highly endangered by the climate change. *P. halepensis* in the southern part and *P. pinaster* in the western part of the Carpathian Basin may find suitable climatic conditions in the period of 2041–2070.

Key-words: Mediterranean pines, climate envelope model, CEM, potential distribution, climate change, distribution modeling, *Pinus brutia*, *Pinus halepensis*, *Pinus pinaster*, *Pinus pinea*

1. Introduction

According to the predictions for the period of 2011–2040, spatially analogue territories of Hungary – the territories with present climate similar to the future climate of Hungary – can be found in Southern Romania, Northern Bulgaria, Serbia, Macedonia, and Northern Greece (*Horváth*, 2008). Therefore, the ornamental plant assortment of Hungary – as the assortment of other central and eastern European countries – should be reconsidered (*Szabó* and *Bede-Fazekas*, 2012; *Schmidt*, 2006). This realization inspired some previous studies (*Bede-Fazekas*, 2012a,b) on whether some warm-demanding ligneous plants are able to be adapted in Hungary in the future.

By this time, regional climate models have good horizontal and temporal resolution and are reliable enough for creating some climate envelope models (CEMs) based on the current distribution of tree species. Our previous works of research were about modeling the future area of introduction of several Mediterranean ligneous plant species that can have significance in the future ornamental plant usage. Based on these former studies, it was aimed to run a new and more accurate model on four of the previously studied species. The improvement of the modeling method was achieved by statistical calibration based on an iterative error evaluation. Hence, the improved model is able to study not the future area of introduction but the future potential distribution.

We aimed to create multi-layered distribution maps with a GIS (Geographic Information System) software, displaying the predicted shift of the potential distributions. These maps can have importance not only in forestry, landscape architecture, and botany, but in visualization of the effects of climate change also for non-professionals (*Czinkóczky* and *Bede-Fazekas*, 2012). The studied species were Brutia pine (*Pinus brutia* Ten. syn. *Pinus halepensis* var. *brutia* (Ten.) A. Henry), Aleppo pine (*Pinus halepensis* Mill.), maritime pine (*Pinus pinaster* Aiton syn. *Pinus maritima* Lam.), and Italian stone pine (*Pinus pinea* L.), which are very close relatives (classified in section *Pinus*, subsection *Pinaster*) according to phylogenetic studies (*Wang et al.*, 1999; *Gernandt et al.*, 2005; *Eckert* and *Hall*, 2006).

2. Materials and methods

2.1. Climate data and distribution maps

The current (latest update was achieved in 2008) continuous distribution map of the species was derived from the EUFORGEN digital area database (*Euforgen*, 2008), while the discrete (fragmented) observations were ignored. Therefore 28 (*P. brutia*), 233 (*P. halepensis*), 23 (*P. pinaster*), and 109 (*P. pinea*) observed data were disregarded by the model. The distributions from 2008 were bound to the reference period. This difference may not cause any problem since the pines have long life cycle and can slowly adapt to the changing climate.

The climatic data were gained from the REMO regional climate model (RCM); the grid had a 25 km horizontal resolution. The model REMO is based on the ECHAM5 global climate model (*Roeckner et al.*, 2003, 2004) and uses the IPCC SRES scenario called A1B. This scenario supposes a future world characterized by a very rapid economic growth, a global population that peaks in the mid-century, and rapid introduction of new and more efficient technologies (*Nakicenovic* and *Swart*, 2000). The reference period was 1961–1990, the two future periods of modeling were 2011–2040 and 2041–2070. The entire European continent is within the domain of REMO, we used, however, only a part of the grid (25724 of the 32300 points; *Fig. 1*).

36 climatic variables were used for the distribution modeling: monthly mean temperature (*T*, °C), monthly minimum temperature (*M*, °C), and monthly precipitation (*P*, mm). All climatic data were averaged in the three periods.

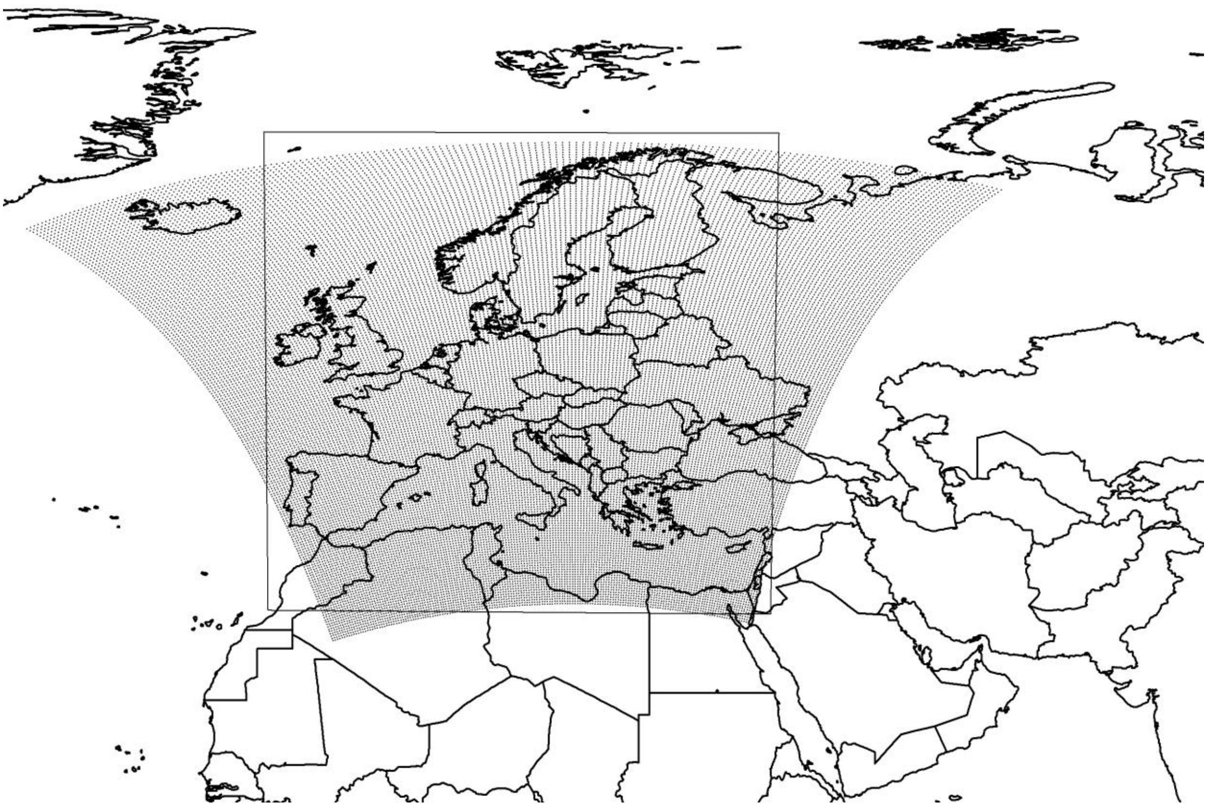

Fig. 1. The domain of climate model REMO and its part used in the study.

2.2. Climate envelope modeling

2.2.1. Modeling approach and software

ESRI ArcGIS 10 software was used for preparing climatic data, running the model, and displaying the model results. Climatic data were managed and the expressions for modeling were prepared with the assistance of Microsoft Excel 2010 program. PAST statistic analyzer software (*Hammer et al.*, 2001) was used for creating the cumulative distribution function of the climatic parameters, and getting the percentile values of the parameters (model calibration).

The impact of climate change on the distribution of selected species was modeled with climate envelope modeling (CEM; also known as niche-based modeling, correlative modeling) (*Hijmans* and *Graham*, 2006). This method 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 under future scenarios (*Ibáñez et al.*, 2006). It hypothesizes that (both present and future) distributions are dependent mostly on the climatic variables (*Czúcz*, 2010) which is somewhat dubious (*Skov* and *Svenning*, 2004). Compared to mechanistic models, CEM tries to find statistical correlations between climate and distribution of species (*Guisan* and *Zimmermann*, 2000; *Elith* and *Leathwick*, 2009), and models the future temporal correspondence based on the present spatial correspondence between the variables (*Pickett*, 1989).

2.2.2. Calibration by iterative modeling

The calibration of the model has been conducted by iterative error evaluation. The model was run iteratively to determine the optimal amount of percentiles to be left from the climatic values. Cumulative distribution functions were calculated by PAST for all climatic parameters. Then 0 to 14 percentiles have been left from the lower values of a certain type of climate parameters (e.g., 12 monthly precipitations), while the maximum values were fixed and also the other 24 climatic parameters were fixed at the extreme values. In case of a certain species, 90 error evaluations were done. Two types of error values were calculated: internal (the ratio of the current distribution segment not determined by the model), and external (the ratio of area outside the current distribution, determined falsely by the model). Then the errors were summarized. The increasing accumulated error function determined the appropriate number of percentiles to left: the greatest number of percentiles was chosen which produces no more than 100% summarized error. Cohen's kappa values (*Cohen*, 1960) were estimated in two cases: without and with percentile leaving to evaluate the improvement achieved by the model calibration.

This iterative calibration technique shows several similarities with "area under the receiver operating characteristic (ROC) curve" (AUC; *Hanley* and *Mcneil,* 1982). The comments of *Lobo et al.* (2008) on AUC may also refer to the calibration method used in this research. For further error-based model calibration procedures see *Fielding* and *Bell* (1997).

2.2.3. Modeling method

First, climatic data were refined by Inverse Distance Weighted interpolation method. Then the modeling steps were as follows:

1. The grid points within the distribution were queried (a few hundred × 36 data; ArcGIS).
2. The percentile points of the 36 climatic parameters (101×36 data, PAST) were calculated.
3. The appropriate percentiles of the climatic parameters determined by the calibration were selected (2×36 data, Excel).
4. Modeling phrases (3 strings, Excel) were created by string functions for the three modeling periods.
5. Those territories were selected where all the climatic values of the certain period were between the extremes selected in step 3. (ArcGIS – Raster Calculator function).

Positive raster results were transformed to ESRI shapefile format (polygons). The order of the four layers (one observed and three modeled distributions) determines whether the result maps are able to display the northward expansion, not the retreat from the southern parts (trailing edge) of the current distribution. Therefore, two types of layer order were applied and are shown herein.

3. Results

3.1. Result of iterative modeling

Based on the iterative modeling, the optimal number of percentiles to be left was determined in case of the four species, and two extremes of the three types of climate variables (*Table 1*). The improvement of the model can be estimated by comparing the two different Cohen's kappa values. The most significant improvement can be seen in case of *P. pinaster*, while the Cohen's kappa value shows inessential increase in case of *P. pinea*.

Table 1. The result of model calibration: the number of percentiles to be left over, the Cohen's kappa value before (Ck 1) and after (Ck 2) percentile omission

Species	**min(*T*)**	**max(*T*)**	**min(*M*)**	**max(*M*)**	**min(*P*)**	**max(*P*)**	**Ck 1**	**Ck 2**
P. brutia	3	2	3	3	5	3	0.1157	0.2056
P. halepensis	9	2	9	3	3	2	0.1103	0.2474
P. pinaster	6	3	6	3	2	4	0.0862	0.2848
P. pinea	6	1	5	2	2	1	0.0805	0.1484

3.2. Modeled potential distributions

3.2.1. Brutia pine (Pinus brutia)

The current distribution of *P. brutia* (*Fig. 2a; Fig. 3a*) is focused on the eastern Mediterranean region (Turkey, Cyprus, and Malta), while the model results in a much larger potential distribution for the reference period that includes southern Portugal, southern Spain, northern Morocco, northern Algeria, Sardinia, southern Italy, and Greece. The Cyprian and Cretan distribution segments were however, not redrawn by the model. Significant northern expansion is not predicted, and Hungary is not affected by the model. Maritime distribution in Turkey seems to become partly viable for the species in the periods of 2011–2040 (near Adana) and 2041–2070 (near Denizli). The Turkish discrete distributions seem to remain climatically viable.

3.2.2. Aleppo pine (Pinus halepensis)

Segments of the observed distribution of *P. halepensis* (*Fig. 2b; Fig. 3b*) can be found in eastern Spain, southern France, Italy, southern Greece, northern Morocco, Algeria, Tunisia, and Libya. The model cannot redraw the Libyan distribution fragment. The potential distribution for the reference period seems to be larger than the observed area: southern Portugal and Spain, Italy, Corsica and Sardinia, the coast of the Aegean Sea, and greater North African territories are modeled to be suitable for the species. Future expansion is predicted in Spain, France, Italy, Croatia, Bosnia and Herzegovina, Serbia, Bulgaria, and the Crimea. The western territories seem to become suitable for living sooner, while the Balkan Peninsula and the Crimea are predicted to be affected only in the far future period. Although most of the discrete distributions in the western Mediterranean were redrawn by the model, discrete observations near Croatia, Lebanon, and Jordan were not. A large part of the distribution in North Africa seems to become abandoned in the period of 2011–2040. Also the Italian and Greek coastline may be negatively affected. Interestingly, some of the Spanish and French distribution segments are predicted to find more suitable climatic environment in the future than in the reference period.

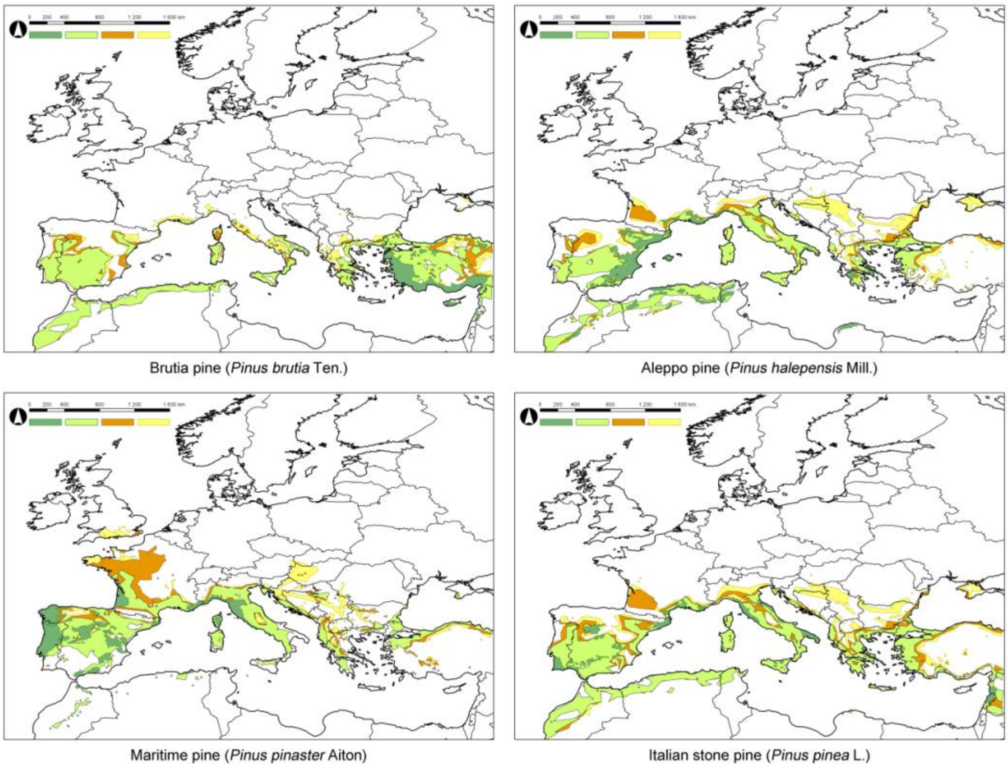

Fig. 2. Expansion: current distribution (dark green), modeled potential distribution in the reference period (light green), and modeled potential distribution in the periods of 2011–2040 (orange) and 2041–2070 (yellow) of the four studied *Pinus* species.

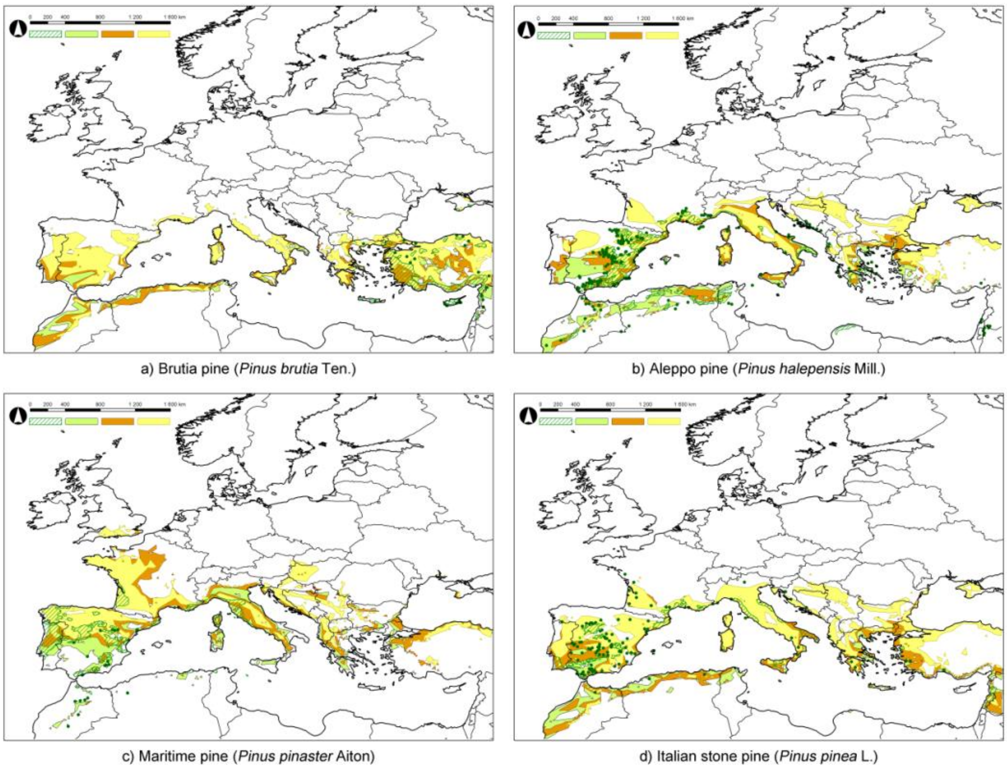

Fig. 3. Retraction: current distribution (dark green hatch and points), modeled potential distribution in the reference period (light green), and modeled potential distribution in the periods of 2011–2040 (orange) and 2041–2070 (yellow) of the four studied *Pinus* species.

3.2.3. *Maritime pine (Pinus pinaster)*

The current distribution of *P. pinaster* (*Fig. 2c; Fig. 3c*) is focused on the western Mediterranean (Portugal, Spain, southern France, Corsica, and northern Italy), which is well expressed by the model. The African (continuous and discrete) distribution segments are, however, not redrawn by the model. Significant northern expansion is predicted to occur in western France, southern England, the Balkans, and the western part of the Carpathian Basin. The latter areas may become suitable for the species in the far future period, while the expansion to western France seems to occur between 2011 and 2040. Maritime and southern Iberian distributions may become abandoned in the period of 2011–2040. By the end of the studied future periods the climate seems to remain suitable for the species in northern Spain and France.

3.2.4. *Italian stone pine (Pinus pinea)*

Apart from central Spain, *P. pinea* (*Fig. 2d; Fig. 3d*) is clearly a coastal pine: its current distribution includes maritime parts of Portugal, Spain, France, Italy, Turkey, Syria, and Lebanon. The potential distribution for the reference period is modeled to include North African coastal territories, southern Portugal and Spain, Italy, and the coastline of the eastern Mediterranean. Future northern expansion can be seen in France, Italy, and the Balkans. Only the Syrian, southern Spanish, and eastern Italian distribution segments are somewhat endangered (the latter one only in the far future period). Most of the distributions in Italy, France, and Spain seem to remain viable by the end of the studied period. Similarly to *P. halepensis*, some continuous and discrete Spanish and French distribution segments are predicted to find more suitable climatic conditions in the future than in the reference period. Discrete distributions in North Africa, Italy, Greece, and Turkey seem to remain viable at least by the period of 2011–2040.

4. Discussion

4.1. Model evaluation

Although the aforementioned predictions are obviously valuable and spectacular, there are some questions and disadvantages concerning the model applied. Opinions differ if climatic variables are by themselves sufficient or even the most important factors for explaining the real distribution of species (*Dormann*, 2007). In case of determining the potential distribution of plant species, edaphic characteristics found within their current distribution area seem to be the only parameters that may be as important as climatic factors are. The studied conifers are, however, tolerant to the alkalinity/lime content of the soil in an extent that they are able to be planted as ornamentals in their predicted future potential distribution area. Nevertheless, it must be noted that the previously presented model results should, in botanical point of view, not to be acknowledged without considering edaphic characteristics. It should also be noted that extremes and absolute climatic values (rather than averages) may better explain the limits of distribution (*Kovács-Láng et al.*, 2008). The input climate data were obtained from RCM, which differ from the observed meteorological data. No bias correction was applied on the modeled climate data, since the bias correction should have been used in the same way in case of the reference and future periods and, therefore, no remarkable difference could have been evolved. The applied model calibration technique seems to result in a realistic and supportable model, since

1. the differences between the potential and observed distributions are not unacceptably large;
2. iterative model calibration resulted in doubled Cohen's kappa values in case of three of the four studied species; and
3. ornamental plantings of these pines in central and western Europe have proven that the predictions are not overestimations.

Various other ways can be found to determine the climate envelope, including simple regression, distance-based methods, genetic algorithms for rule-set prediction, and neural nets (*Ibáñez et al.*, 2006). Our subsequent aim is to develop a program module for ArcGIS that implements the artificial intelligence algorithm artificial neural network (ANN) for modeling the future distribution of Mediterranean tree species.

The model results for the reference period show the least difference to the observed distribution in case of *P. halepensis* and *P. pinaster*, while the model performed worst in case of *P. pinea* (*Table 2*).

Table 2. The points of grid are within the observed distribution; the ratio of modeled and observed points in the reference period; the expansion from the reference period to the near future period; and the expansion from the reference period to the far future period in case of the four studied species

Species	**Observed points**	**Model/observation (%)**	**Expansion 2011–2040 (%)**	**Expansion 2041–2070 (%)**
P. brutia	236	591.10	14.41	30.04
P. halepensis	326	380.06	22.28	56.98
P. pinaster	352	351.14	31.55	48.95
P. pinea	176	849.43	23.88	53.98

4.2. Shift of distributions

Our former research found that the extent of future shift of area of introduction is much larger. That model was, however, inaccurate. The results of this improved model show clearly and spectacularly the impacts of the predicted climate change on the distribution of Mediterranean pines. The most affected territories may be France and the Balkans. By comparing the model results of the reference period to the results of the future periods (*Table 2*) it can be concluded that the greatest absolute expansion is predicted to occur in case of *P. pinaster*, the greatest relative expansion may occur in case of *P. halepensis* and *P. pinea*, while the distribution of *P. brutia* seems to be nearly unchanged. Although the current distribution of *P. halepensis* and *P. pinea* differs remarkably, the predictions are almost the same, which originates from the similar climatic demand and tolerance of the two species. The northwestern African coastline was predicted to be suitable for *P. brutia*, *P. halepensis*, and *P. pinea*. By 2070, the climate of western and southern Hungary seems to become suitable for *P. pinaster*. In the far future period, *P. halepensis* is predicted to occur in the southern part of the Carpathian Basin, while *P. pinea* and *P. brutia* seem to stay out of the basin. Nevertheless, it must be noted that *P. halepensis* is better adapted to drought but less adapted to cold than *P. brutia* (*Fady et al.*, 2003). Hence, the latter species is able to serve as ornamental plant in the near future period (when frost is limiting factor) and in moist (irrigated) plots in the far future period.

Some plant species originating from a certain part of the Mediterranean Basin and introduced to other parts of it seem to become particularly invasive (*Groves*, 1991), and are better to be treated as potentially invasive species in the territories predicted to become climatically suitable for them. *P. halepensis* is known to be invasive (*Acherar et al.*, 1984; *Trabaud et al.*, 1985; *Lepart* and *Debussche*, 1991). Other species, such as *P. brutia* in southern Anatolia (*Quézel et al.*, 1990), can effectively be established where they had been introduced and even expand in some extent but without becoming really invasive (*Le Floc'h*, 1991). The phenomena of plant invasion is now under revision in ecology, since some of the species treated to be invasive may become important elements of the natural vegetation due to climate change (*Walther et al.*, 2009).

It must be mentioned that the original distribution area of *P. pinea* is obscure, since it was extensively planted around the Mediterranean throughout historical times by Etruscans, Greeks, Romans, and Arabs because of its edible seeds. (*Groves*, 1991; *Barbéro et al.*, 1998; *Fady et al.*, 2004). The differentiation of autochthonous and non-autochthonous stands is, as also in the case of *P. pinaster*, controversial (*Alía* and *Martín*, 2003).

5. Conclusion

Mediterranean pines are potentially able to expand the ornamental plant assortment of the Carpathian Basin. Although some specimens of the four studied conifers can be found in arboreta of Hungary, they are susceptible to frost and, therefore, not widely introduced. In this research we aimed to examine whether these pines will be able to be planted without frost protection in the future by modeling the future potential distributions. The result of CEM shows that *P. halepensis* in the southern part and *P. pinaster* in the western part of the Carpathian Basin may find similar climatic conditions in the period of 2041–2070 than the observed distributions of these species were living within in the reference period. Therefore, landscape architecture, dendrology, forestry, and botany should think of these pines as potential ornamental plants or even as potential plants of natural vegetation in the future in Hungary.

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