Negative impact of climate change on the distribution of some conifers

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Abstract

A climate envelope model was run on the distribution of four coniferous species (European silver fir, European larch, Norway spruce, and Swiss pine). The model was supported by EUFORGEN area database, ArcGIS 10 and PAST software, and REMO climate model. Prediction periods were 2011-40 and 2041-70.

Keywords: *climate envelope model, future distribution, climate change, European silver fir, European larch, Norway spruce, Swiss pine*

Tartalmi kivonat

Éghajlatburkológörbe-modellt futtattunk négy fenyőfaj (közönséges jegenyefenyő, európai vörösfenyő, közönséges luc és havasi cirbolya) elterjedési területére ArcGIS 10 és PAST szoftverek segítségével, EUFORGEN area-adatbázis és REMO klímamodell felhasználásával a 2011-40 és 2041-70-es időszakokra.

Kulcsszavak: *klímamodellezés, jövőbeli eloszlás, éghajlatváltozás, európai vörösfenyő, lucfenyő, svájci fenyő*

Introduction

Regional climate models have good temporal and horizontal resolution and are reliable enough for creating climate envelope model (CEM; also known as niche-based model or correlative model) based on the current distribution of tree species. 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[1,2]. We aimed to create multi-layered distribution maps with GIS[3] software to display the predicted retraction and shift of the potential distribution of four coniferous European species live in highlands. These maps can have importance not only in botany, forestry, and landscape architecture, but in visualization of the effects of climate change also for non-professionals[4]. The studied species were European silver fir (*Abies alba* Mill.), European larch (*Larix decidua* Mill.), Norway spruce (*Picea abies* (L.) H. Karst.), and Swiss pine (*Pinus cembra* L.).

Materials and methods

Climatic data

The climatic data were obtained from the REMO regional climate model (RCM); which has a grid had with 25 km horizontal resolution. The model REMO is based on the ECHAM5 global climate model and the IPCC SRES A1B scenario. This scenario assumes a future world with a very rapid economic growth, a global population that peaks in the mid-century and quick introduction of efficient technologies[5]. The reference period was 1961-90, the two future periods of modeling were 2011-40 and 2041-70. Although entire Europe is within the domain of REMO, only a part of the grid (25724 of the 32300 points; *Fig. 1*) was used in this research. 36 climatic variables were gained from the climate model: monthly mean temperatures (T, °C), monthly minimum temperatures (M, °C), and monthly precipitation sums (P, mm). All the climatic data were averaged in the three periods.

Opinions differ if climatic variables are by themselves sufficient or even the most important factors for explaining the real distribution of species[6]. In case of determining the potential distribution of plant species edaphic characteristics found

[1] Ibáñez, I., Clark, J.S., Dietze, M.C., Feeley, K., Hersh, M., Ladeau, S., Mcbride, A., Welch, N.E., Wolosin, M.S., 2006: Predicting Biodiversity Change: Outside the Climate Envelope, beyond the Species-Area Curve. Ecology. 87(8), 1896-1906.
[2] Hijmans, R.J., Graham, C.H., 2006: The ability of climate envelope models to predict the effect of climate change on species distributions. Global Change Biology. 12, 2272-2281.
[3] Geographic Information System
[4] Czinkóczky, A., Bede-Fazekas, Á., 2012: Visualization of the climate change with the shift of the so called Moesz-line. In: Buhmann, E., Ervin, S., Pietsch, M. (eds.): Peer Reviewed Proceedings of Digital Landscape Architecture 2012 at Anhalt University of Applied Sciences. Herbert Wichmann Verlag, Berlin, Germany.
[5] Nakicenovic, N., Swart, R. (eds.), 2000: Emissions Scenarios. Cambridge University Press, Cambridge, UK.
[6] Dormann, C.F., 2007: Promising the future? Global change projections of species distributions. Basic and Applied Ecology 8, 387-397.

within their current distribution area seem to be the only parameters that may be as important as climatic factors are.

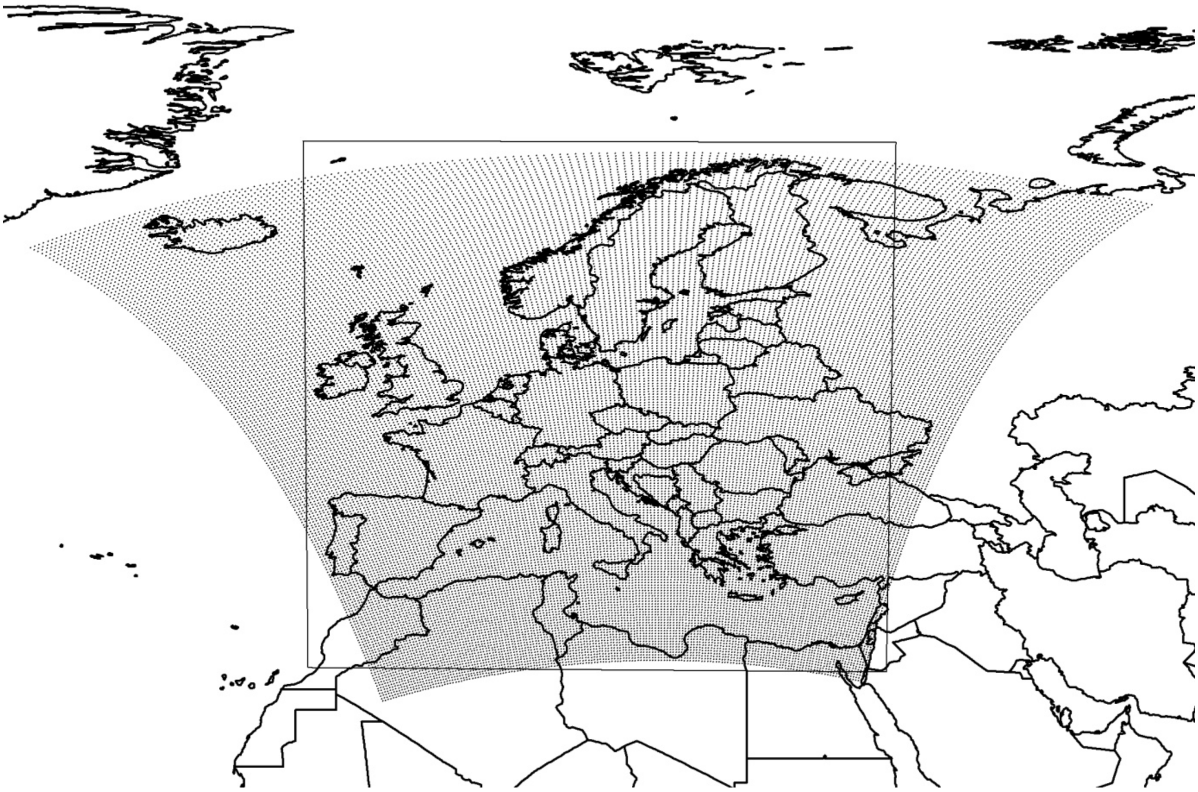

Figure 1.: The domain of climate model REMO and its part used in the study. The map was created with ESRI ArcGIS 10 by the author.

Distribution maps

The current continuous distribution map of the species was derived from the EUFORGEN digital distribution database[7], while the discrete (fragmented) observations were ignored. The distributions from 2008 were bound to the reference period. This difference may not cause any problem since the studied conifers have long life cycle and can slowly adapt to the changing climate.

Modeling method

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

[7] EUFORGEN, 2008: Distribution maps. Bioversity International, Rome, Italy. Online: www.euforgen.org/distribution_maps.html. Last accessed: 2013.01.01.

program. The model calibration was assisted by PAST statistic analyzer software[8] by creating the cumulative distribution function of the climatic parameters, and getting the percentile values of the parameters.

The calibration of the model was achieved 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 has been left from the lower values of a certain type of climate parameters (e.g. 12 monthly minimum temperatures), 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: false negative and false positive errors. Then they were summarized. The increasing accumulated error function determined the appropriate number of percentiles to be left: the greatest number of percentiles was chosen that produces no more than 100% summarized error. This selected limit is subjective and means that the area of the model result is the double of the observed distribution in case of no false negative error.

After the model calibration all the climatic data were refined by Inverse Distance Weighted interpolation method. Then the modeling steps, in case of a certain species, 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);
6. the positive raster results were transformed to ESRI shapefile format (polygons).

[8] Hammer, Ř., Harper, D.A.T., Ryan, P.D., 2001: PAST: Paleontological statistics software package for education and data analysis. Palaeontologia Electronica. 4(1), 9.

The order of the four layers (one observed and three modeled distributions) determines whether the result maps are able to display the northward expansion, or the retreat from the current distribution (trailing edge). The latter was studied in this research.

Results and discussion

Model calibration

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*).

Species	min(T)	max(T)	min(M)	max(M)	min(P)	max(P)
Abies alba	6	4	7	5	3	5
Larix decidua	7	4	8	5	3	5
Picea abies	3	4	4	4	3	5
Pinus cembra	7	5	5	5	4	5

Table 1.: The result of model calibration: the number of percentiles to be left over in case of certain extrema (min: minimum, max: maximum) of a certain climatic parameter set (T: mean temperatures, M: minimum temperatures, P: precipitation sums)

Abies alba

The observed distribution (*Fig. 2*) of *A. alba* is focused on the Alps, the Carpathians, the Pyrenees, and in the Balkan Peninsula. Southern Germany and Southern Poland, and some discrete distribution segments in the Apennines are also included. The modeled potential distribution for the reference period is much larger. The climate of Southern Sweden, Southern Germany, Poland, and western part of Ukraine, Belorussia, Lithuania and Latvia seems to be suitable for the species. Distribution segments in Italy, Switzerland and Austria were, however, not displayed by the model. Retraction of the potential distribution is predicted to occur in Germany, Bohemia, and Poland, while the Pyrenees, the Eastern Alps, and the Carpathians seem to remain suitable in climatic terms.

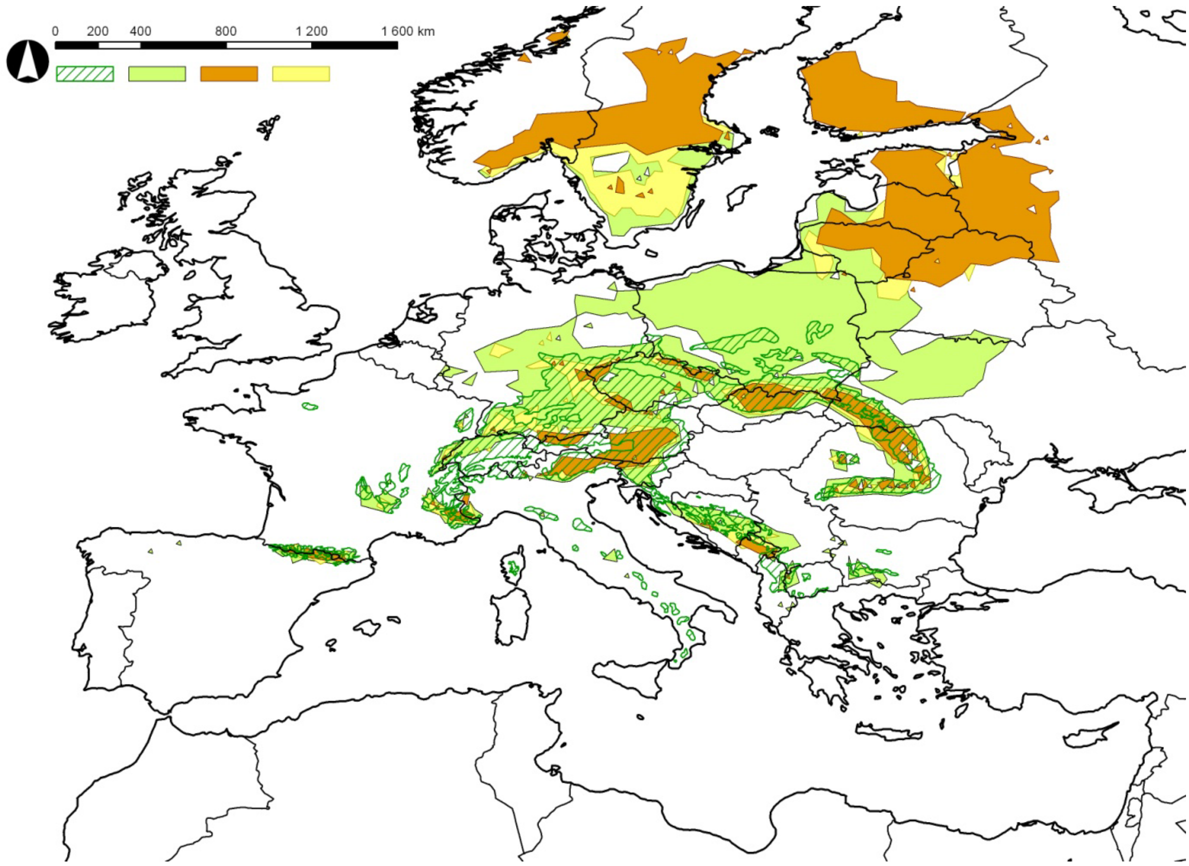

Figure 2.: Current distribution (dark green hatch), modeled potential distribution in the reference period (light green), and modeled potential distribution in the period of 2011-2040 (orange) and 2041-2070 (yellow) of European silver fir (Abies alba). The map was created with ESRI ArcGIS 10 by the author.

Larix decidua

The observed distribution (*Fig. 3*) of European larch is focused on the Alps and the Carpathians. Almost the entire distribution was proved by the model excluding some Romanian and French distribution segments. The model suggests that the climate of the Pyrenees and some territories in France, Germany, Bohemia, Poland and Sweden is suitable for the studied species. Remarkable retraction is predicted in the Northern Alps and also in the Carpathians. In the Northern Carpathians the modeled retraction shows similarities to the shift of the phytogeographical line of the region (Moesz-line)[9].

[9] Bede-Fazekas, Á., 2012b: Methods of modeling the future shift of the so called Moesz-line. Applied Ecology and Environmental Research 10(2), 141-156.

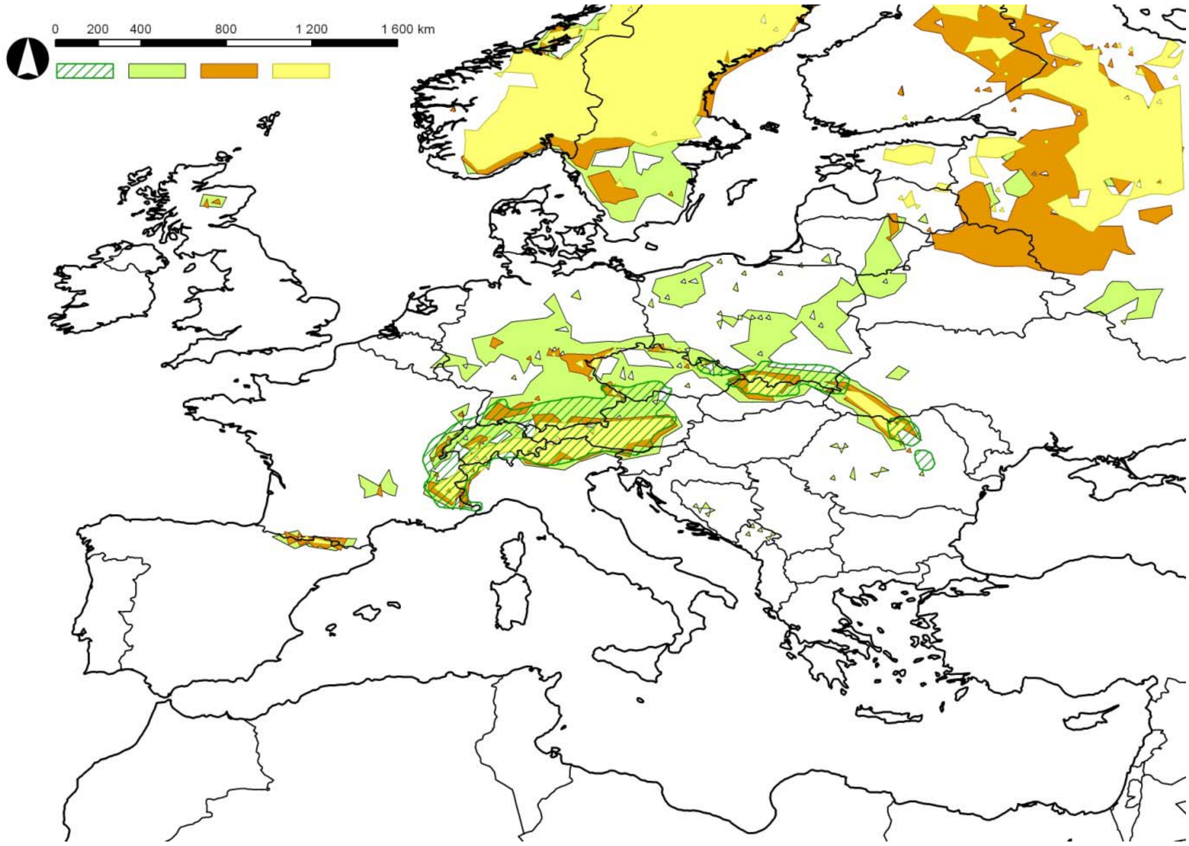

Figure 3.: Current distribution (dark green hatch), modeled potential distribution in the reference period (light green), and modeled potential distribution in the period of 2011-2040 (orange) and 2041-2070 (yellow) of European larch (Larix decidua). The map was created with ESRI ArcGIS 10 by the author.

Picea abies

In contrary to the other three studied species Norway spruce has a large observed distribution that includes both highlands and lowlands. Since the model was calibrated to learn the climatic values bound to the entire distribution, the results are not reliable enough to use them as prediction of the future retraction from the highland distribution segments. Therefore detailed review of the model results (*Fig. 4*) is to be omitted.

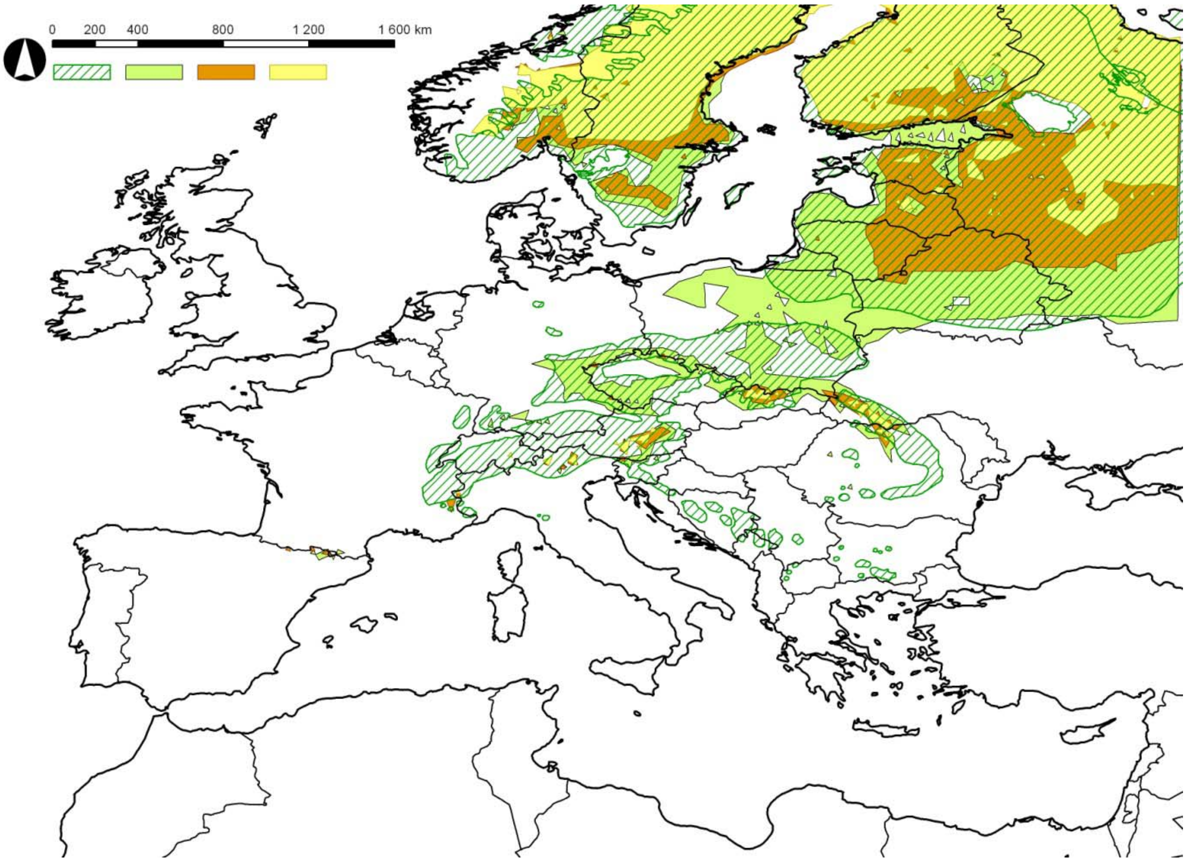

Figure 4.: Current distribution (dark green hatch), modeled potential distribution in the reference period (light green), and modeled potential distribution in the period of 2011-2040 (orange) and 2041-2070 (yellow) of Norway spruce (Picea abies). The map was created with ESRI ArcGIS 10 by the author.

Pinus cembra

The distribution (*Fig. 5*) of Swiss pine is focused on the Alps, and the Eastern and Southern Carpathians. One distribution fragment can be found in the Northern Carpathians. The modeled potential distribution for the reference period is similar to the observed one. Remarkable difference can be seen in the Northern Carpathians and in France. Scandinavian territories were also modeled to be suitable for the species in climatic terms. Retraction is predicted to occur in the Southern Carpathians. We should mention that the impact of climate change on the distribution of Swiss pine can be studied not only for the future but also for the past[10,11].

[10] Höhn, M., Gugerli, F., Abran, P., Bisztray, G., Buonamici, A., Cseke, K., Hufnagel, L., Quintela-Sabaris, C., Sebastiani, F., Vendramin, G.G., 2009: Variation in the chloroplast DNA of Swiss stone pine (Pinus cembra L.) reflects contrasting post-glacial history of populations from the Carpathians and the Alps. Journal of Biogeography 36(9), 1798-1806.

[11] Höhn, M., Hufnagel, L., Cseke, K., Vendramin, G.G., 2010: Current range characteristics of Swiss stone pine (Pinus cembra L.) along the Carpathians revealed by chloroplast SSR markers. Acta Biologica Hungarica 61(Suppl. 7), 61-67.

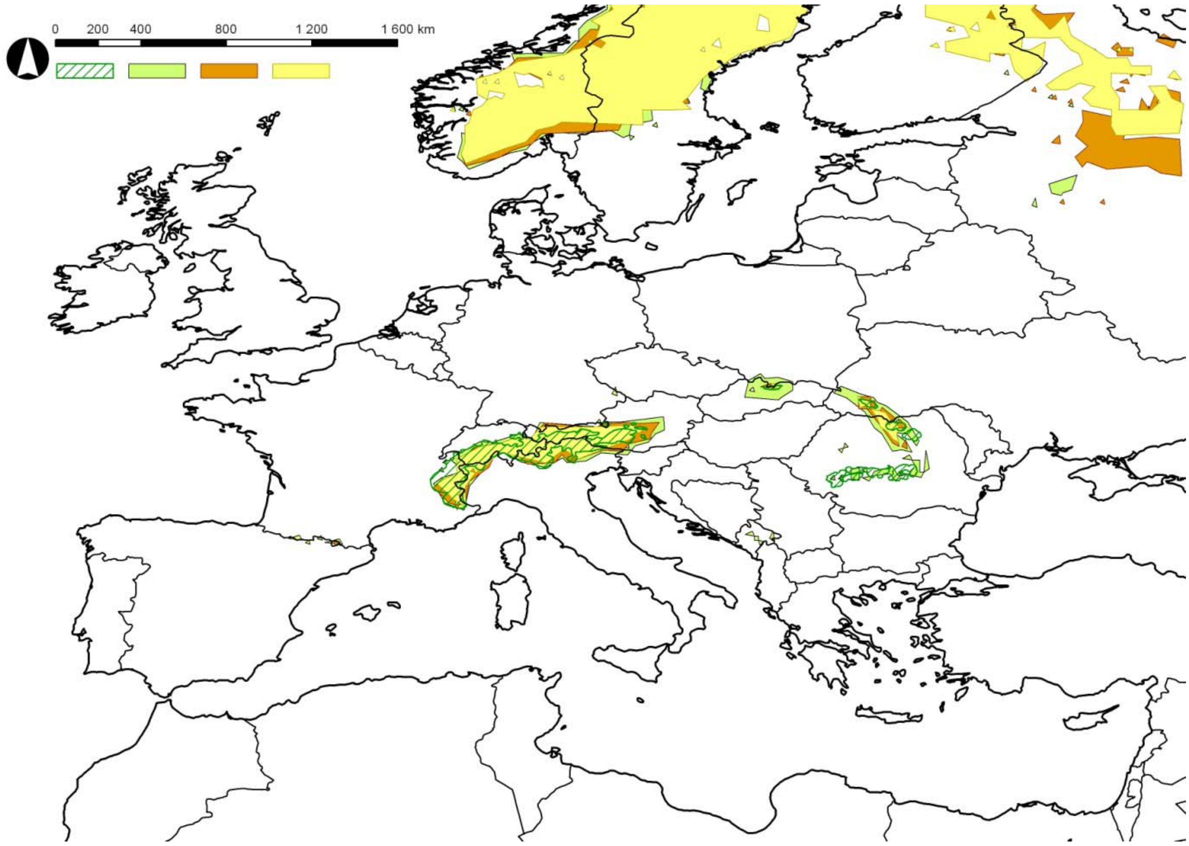

Figure 5.: Current distribution (dark green hatch), modeled potential distribution in the reference period (light green), and modeled potential distribution in the period of 2011-2040 (orange) and 2041-2070 (yellow) of Swiss pine (Pinus cembra). The map was created with ESRI ArcGIS 10 by the author.

Conclusion

For the far future period the model results show that the Carpathian distribution segment of *Abies alba* may remain suitable. Also the Pyrenees may provide suitable climatic environment. In the Western Alps significant retraction is, however, predicted. In case of *Larix decidua* the northern part of the current distribution is predicted to retreat. The model of *Picea abies* is not evaluated since the input data were misleading. *Pinus cembra* is predicted to remain in the Alps but the distribution segments in the Southern Carpathians seems to become abandoned.

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