CLIMATIC EXPOSURE OF FORESTS IN THE CARPATHIANS: EXPOSURE MAPS AND ANTICIPATED DEVELOPMENT

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Abstract – The Carpathians represent the largest European mountain range with diverse ecosystems and landuse. Recent recognition of climate change related threats to mountain ecosystems initiated an array of researches on this topic. This study investigates the anticipated development of selected bioclimatic variables in the Carpathians using an ensemble of climate change scenarios; and it presents the analysis of European beech climatic exposure as a part of integrated forest vulnerability assessment. Bioclimatic variables used are Holdridge`s annual biotemperature and Ellenberg climatic quotient. Climate data were developed within the frame of the ENSEMBLES FP6 project, and further processed and made accessible through the FORESEE database.
We identified a remarkable large-scale trend in the future development of addressed bioclimatic variables indicating more intensive drying and warming of climate in the Eastern and Serbian Carpathians as compared with the Western Carpathians. Exeedance of climatic limit for European beech persistence in terms of Ellenberg climatic quotient was found in all beech stands in the Hungarian and Serbian part of the Carpathians, and in large areas of beech stands in Romania.

Keywords: climate models, Ellenberg Climatic Quotient, Holdridge`s annual biotemperature, European beech

1. INTRODUCTION

Carpathians represent the largest European mountain range passing through Austria, Czech Republic, Slovakia, Poland, Hungary, Ukraine, Romania and Serbia (RUFFINI et al. 2006). Diverse climate is driven by elevational, latitudinal and continentality gradients; such climate along with diverse landuse support exceptional biodiversity reachness (GURUNG et al. 2009). Mountain areas, however, are vulnerable to climate change (DULLINGER et al. 2012), mainly because of the presence of an array of zonal communities in relatively limited space, and limited options for species migration to follow the shifting climate (MALCOLM et al. 2001). For these reasons, some transboundary initiatives addressing the vulnerability of Carpathian ecosystems and societies, and evaluating and implementing the adaptation options have appeared, such as Carpathian Convention, Carpathian Ecoregion Initiative, Carpathians Environmental Outlook, etc.; or EU funded projects such as CarpatClim, Carpivia or CarpathCC.
Regional climate projections imply that future climate in Central and Eastern Europe is likely to include temperature increase by as much as 3-5°C (CHRISTENSEN et al. 2007), while changes in precipitation distribution remain uncertain. In addition, future climate is likely to feature an increased frequency and severity of extreme droughts and hot spells (STERL et al. 2008). As survival of woody species is constrained by water availability, prolonged drought during vegetation season may induce episodes of large-scale tree decline (BRÉDA et al. 2006).

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In contrast, mountain ecosystems may benefit from prolonged vegetation season or increased nutrient input initiated by accelerated decomposition rates (FRIEDLINGSTEIN – PRENTICE 2010). The trade-off between such processes can shape the future of Carpathian forests.
In this paper, we investigate the anticipated development of selected bioclimatic variables in the Carpathians to assess the future climatic exposure of forests in this region. We focused on spatial variability of the climatic exposure of European beech (*Fagus sylvatica* L.) associated to the use of an ensemble of climate change scenarios. Two time period have been addressed – reference period (1961-1990) and distant future (2071-2100).

2. DATA AND METHODS

2.1. Study area

Carpathian border used in this study was designated as the union of borders specified by the Carpathian Ecoregion Initiative (www.carpates.org) and Carpathians Environment Outlook (KEO 2007) (*Figure 1*). The region covers parts of Austria (0.3%), Czech Republic (3.3%), Slovakia (15.9%), Poland (8.6%), Hungary (5.1%), Ukraine (11.9%), Romania (50.8%) and Serbia (4.1%). Size of the region is 229,966 km^2. Elevation range is 27-2,604 m a.s.l. Forests cover 48% of the region, with 19% of coniferous, 59% percent of broadleaved and 22% of mixed forests (Corine LandCover 2000, European Environmental Agency).

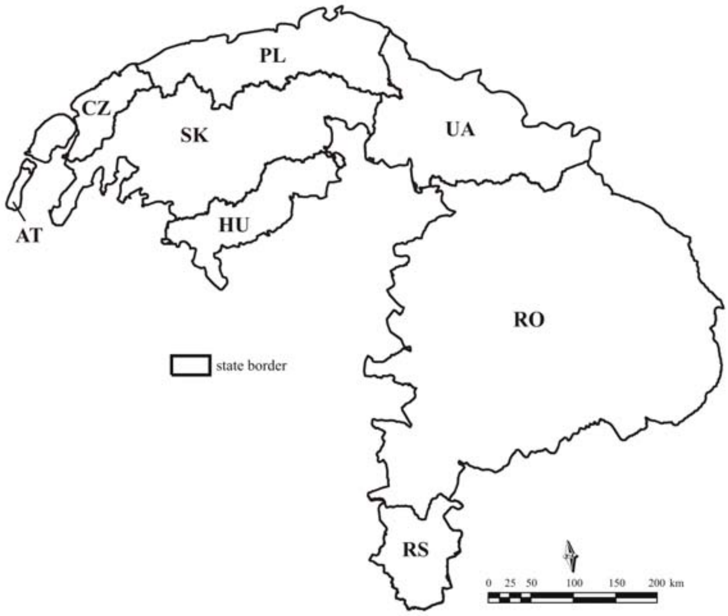

Figure 1. Study region position with state borders

2.2. Forest distribution data

Forest tree species distribution data were taken from statistical mapping of tree species over Europe based on the data of national forest inventories, predictive mapping and national forest statistics (BRUS et al. 2011). The result is a raster map with a resolution of 1×1 km, with information about species proportion in a cell. We corrected this data using the Corine Landcover data to remove forests identified in the statistical mapping which are distributed outside the border of forests in Corine LandCover data (see example of European beech in Annex 1b).

2.3. Climate data

Used climate data was taken from the FORESEE database (DOBOR et al. 2012), which contains the modified results of regional climate simulations performed within the frame of the ENSEMBLES project (VAN DER LINDEN et al. 2009). Four Regional Climate Models (RCMs) were used for the decription of future climate – RegCM (The Abdus Salam International Centre for Theoretical Physics), HIRHAM5 (Danish Meteorological Institute), RACMO (Royal Netherlands Meteorological Institute) and REMO (Max-Planck-Institute for Meteorology). The Global Regional Model ECHAM5 and emission scenario A1B (NAKICENOVIC – SWART 2000) were used to drive the regional climate simulations. The modified and interpolated E-OBS dataset (HAYLOCK et al. 2008), which is a part of the FORESEE database as well, was used to describe the reference climate. Two time periods have been addressed in this study – 1961-1990 (reference climate) and 2071-2100 (distant future climate).

We investigated the future variability of Holdridge`s annual biotemperature (HOLDRIDGE 1947) and Ellenberg climatic quotient (ELLENBERG 1988) in relation to the distribution of European beech (*Fagus sylvatica*) in the Carpathians; these bioclimatic variables were derived from the described climate data. External drift kriging based interpolation was used to produce the maps of variables thereof, using elevation as supportive variable (HUDSON – WACKERNAGEL 1994, VIZI et al. 2011).

2.3.1. Holdridge`s annual biotemperature

Holdridge`s annual biotemperature (ABT) is frequently used proxy of growing season warmth, which influences vegetation distribution, growth and survival (HOLDRIDGE 1947; KIRA 1991). ABT was originally defined as the mean positive unit-period temperature (T), with the substitution of 0 °C for all unit-period values below 0 °C. To account for differences in seasonal variations between the equatorial and sub-tropical regions, HOLDRIDGE et al. (1971) revised the calculation of mean biotemperature by assigning a value of 0 °C both for unit-period temperatures above 30 °C and those below 0 °C:

$ABT = sum(T)/12$ if $0°C < T < 30°C$; where T is monthly mean air temperature

2.3.2. Ellenberg climatic quotient

Ellenberg's climate quotient (EQ) expresses the coupled effect of temperature and precipitation, and it has been frequently used to describe the climate humidity (MÁTYÁS et al. 2010). ELLENBERG (1988) defined EQ as the quotient of the mean air temperature of the long-term hottest month per year (MTWM) and the annual precipitation sum (AP):

$$EQ = MTWM / AP \times 1000$$

This quotient has been applied for example to separate areas dominated by beech from areas of boreal or thermophilic species (e.g. JENSEN et al., 2004, MÁTYÁS et al. 2010, FANG – LECHOVICZ 2006).

3. RESULTS

3.1. Spatial variability of future climate development

ABT in the reference period (Annex 1a) varies between 4.0 and 11.5, and spatial distribution of these values is apperarenly driven by Carpathian`s orography. South of the Hungarian parts of the Carpathians and the Serbian Carpathians show the highest values. ABT increase exhibits a similar large-scale pattern in case of all RCMs used (Annex 1 c,d,e,f), while differences can be observed at a medium-scale. The highest increase can be seen in the Transylvannian Plateau, spatial pattern and magnitude of such increase however differs between the models.

EQ covers the range 10 – 85 across the Carpathians, most of the Carapthians is however covered by values up to 50 (Annex 2b). Lower values in the range of 35 – 50, indicating drier climate, are distributed mostly in the Hungarian part of the Carpathians and in the Outer Eastern Carpathians in Romania. Projected change in EQ shows similar large scale pattern in all RCMs used, regional differences are however more distinct as compared with ABT (Annex 2 c,d,e,f). There is a remarkable trend in EQ difference between the distant and reference climate, increasing from the Western Carpathians towards the Eastern and Serbian Carpathians.

3.2. Climatic exposure of European beech as an example

EQ and ABT have been found to influence the distribution of European beech, and critical values for beech occurrence and decline were suggested for example by FANG – LECHOVICZ (2006) and MÁTYAS et al. (2010) We analyse here the effect of changing climate on critical value of the EQ 40, the exceedance of which may induce beech mortality (MÁTYAS et al. 2010), and 30, which may indicate the limit of the loss of beech competitive vigour (JAHN 1991).

Under the reference climate, values between 30 – 40 occured mainly the Hungarian part of the Carpathians, and the Outer Eastern Carpathians in Romania (Annex 3a). Critical value of EQ 40 was exceeded in sparse spots in Hungary, and in beech stands in the Transylvannian Plateau, where beech occurs marginaly. Climatic conditions for beech persistence were projected to worsen substantially in the distant future (Annex 3b), and limit of 40 may be exceeded in all beech stands in the Hungarian and Serbian part of the Carpathians, and in large areas of beech stands in Romania.

The use of multiple RCMs allows for investigating the match of zones exeeding the critical values of EQ as have been derived from the four RCMs used (Annex 3 c,d). The uncertainty of exceedance of the critical value of 30 is low, and all four models imply the same position of the above-value regions with minor uncertainty in the Western Carpathians. Uncertainty of the exceedance of value 40 is larger, and regions where only 2 or 3 models are matching are distributed across the all Carpathians.

4. DISCUSSION AND CONCLUSIONS

We explored the possibility to asses the future climate development in the Carpathians using an ensemble of climate change scenarios drawn from the recently developed FORESEE database (DOBOR et al. 2012). Instead of investigating essential climate elements, we focused on the development of two bioclimatic variables to enable us exploring more complex spatial patterns in future climate development, which have not yet been studied in detail.

We identified a remarkable trend in future development of investigated variables, increasing from the Western Carpathians towards the Eastern and Serbian Carpathians. All four regional climate models used indicated the same large-scale pattern, though different medium-scale patterns in differences between future and reference climate can be seen. This indicates higher climatic exposure of forests in the latter geomorphologic units.

Match of areas where critical values of adressed bioclimatic variables have been exceeded, as produced by four RMCs used, has been evaluated as well. Such spatially explicit information seems usefull for the identification of the critically exposed sites. This information would gain importance when simulations based on various Global Climate Models and/or emission scenarios would have been integrated.

Assessment of forest climatic exposure is – along with the sensitivity and adaptive capacity – part of the integrated forest vulnerability assessment (LINDNER et al. 2010). High climatic exposure of the Eastern and Serbian Carpathians along with the fact that economic performance of Ukraine, Romania and Serbia reaches only 36% of the Western Carpathian countries, in terms of GDP per capita (http://data.worldbank.org), remarkably limits the options for effective adaptation. These facts may generate concern about the future of forests in these regions.

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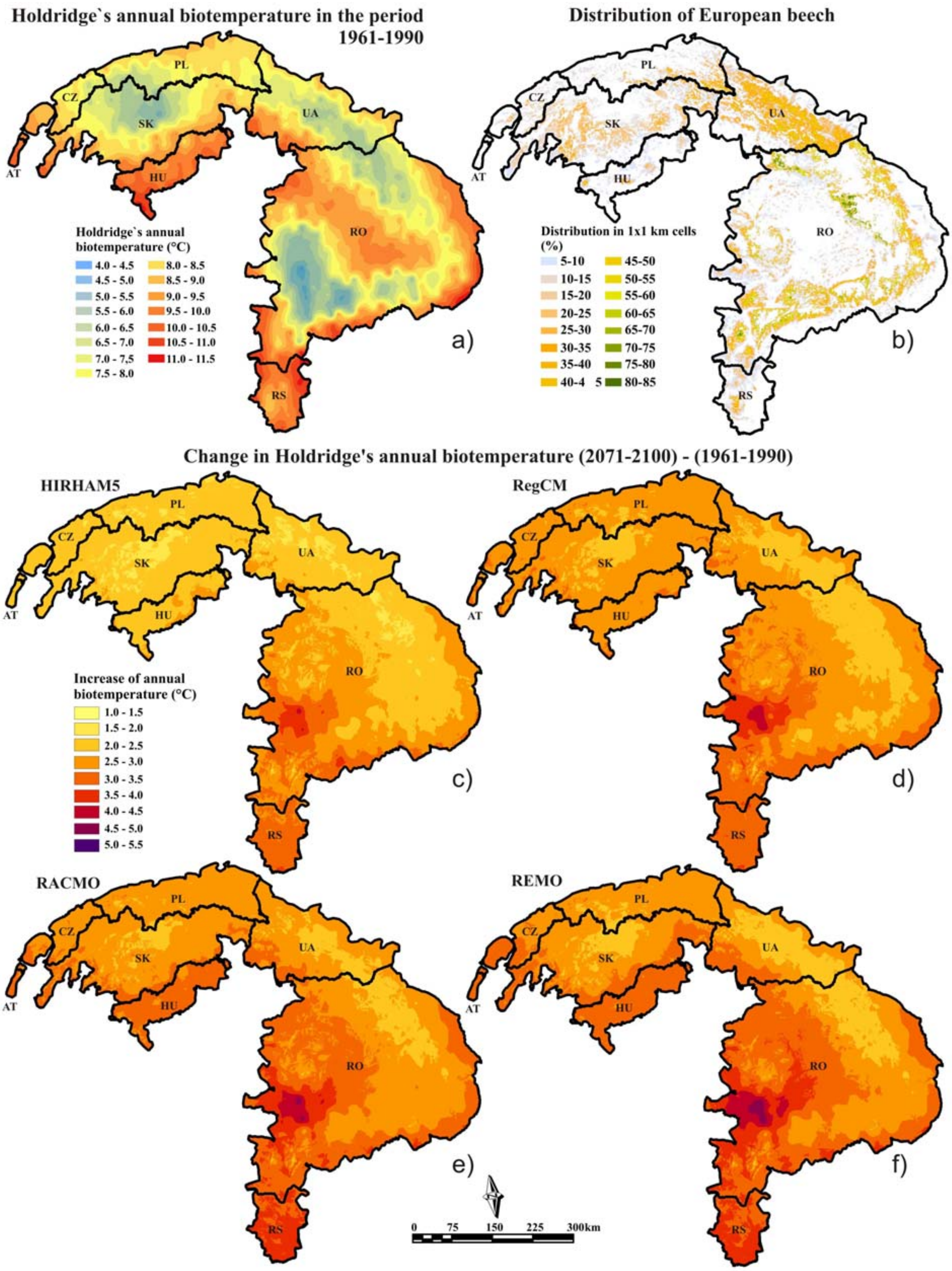
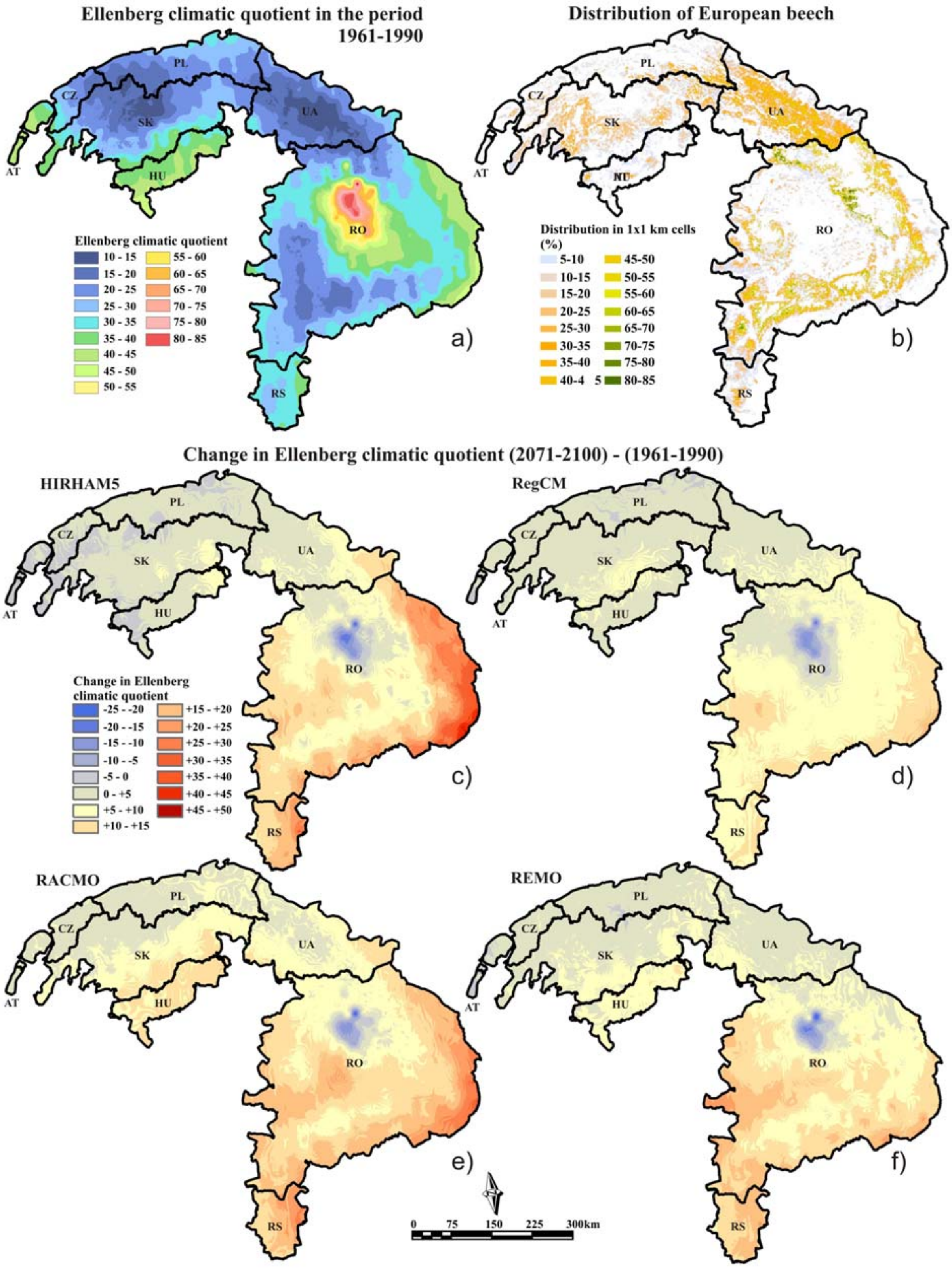
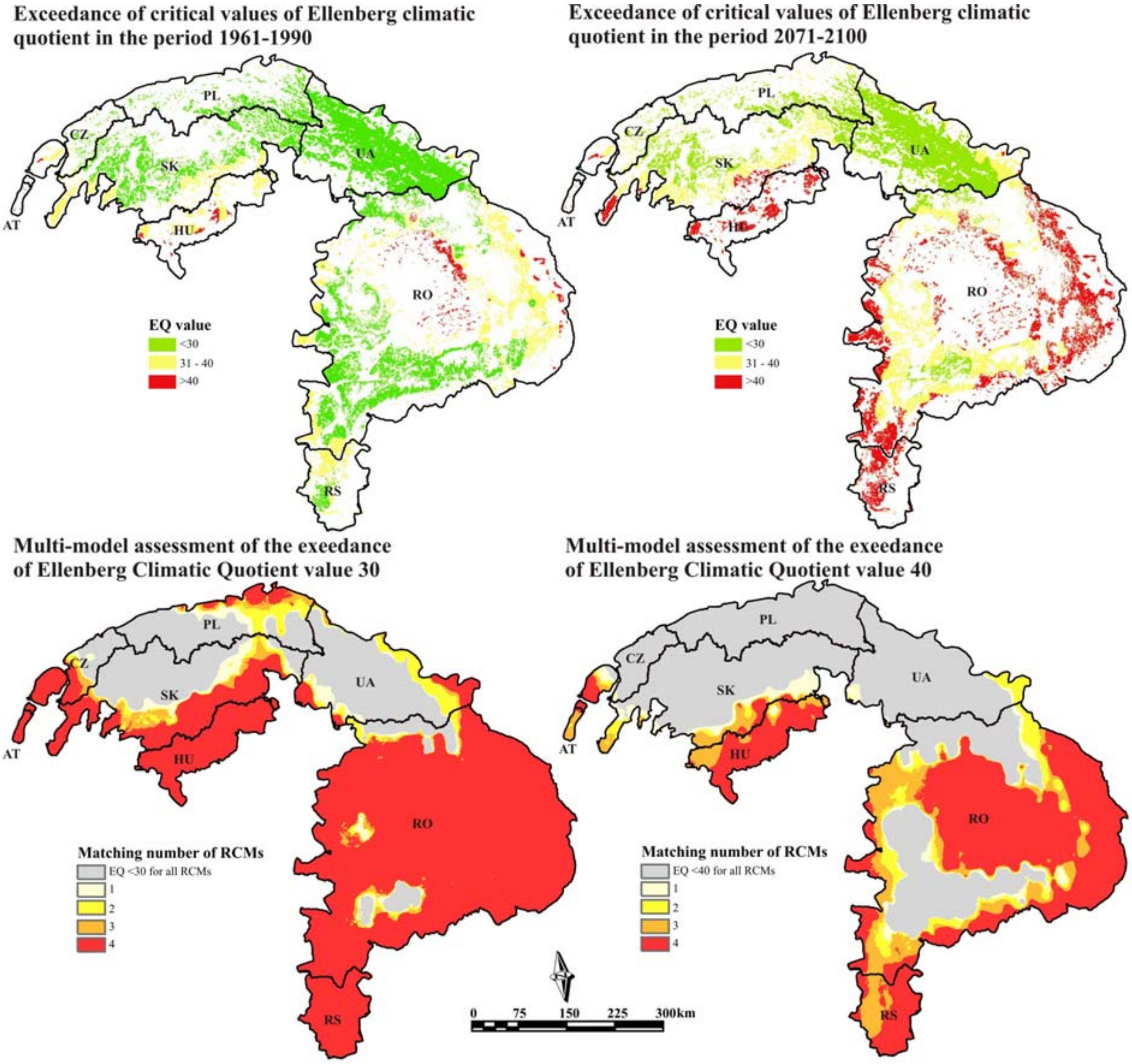
Annex 1


Holdridge`s annual biotemperature in the period 1961-1990
Distribution of European beech
PL
CZ
SK
UA
AT
HU
RO
RS
Holdridge`s annual biotemperature (°C)
4.0 - 4.5
4.5 - 5.0
5.0 - 5.5
5.5 - 6.0
6.0 - 6.5
6.5 - 7.0
7.0 - 7,5
7.5 - 8.0
8.0 - 8.5
8.5 - 9.0
9.0 - 9.5
9.5 - 10.0
10.0 - 10.5
10.5 - 11.0
11.0 - 11.5
a)
Distribution in 1x1 km cells (%)
5-10
10-15
15-20
20-25
25-30
30-35
35-40
40-4 5
45-50
50-55
55-60
60-65
65-70
70-75
75-80
80-85
b)
Change in Holdridge's annual biotemperature (2071-2100) - (1961-1990)
HIRHAM5
RegCM
Increase of annual biotemperature (°C)
1.0 - 1.5
1.5 - 2.0
2.0 - 2.5
2.5 - 3.0
3.0 - 3.5
3.5 - 4.0
4.0 - 4.5
4.5 - 5.0
5.0 - 5.5
c)
d)
RACMO
REMO
e)
f)
0 75 150 225 300km

Annex 2


Ellenberg climatic quotient in the period 1961-1990
Distribution of European beech
Ellenberg climatic quotient
10 - 15
15 - 20
20 - 25
25 - 30
30 - 35
35 - 40
40 - 45
45 - 50
50 - 55
55 - 60
60 - 65
65 - 70
70 - 75
75 - 80
80 - 85
Distribution in 1x1 km cells (%)
5-10
10-15
15-20
20-25
25-30
30-35
35-40
40-4 5
45-50
50-55
55-60
60-65
65-70
70-75
75-80
80-85
PL
CZ
SK
UA
AT
HU
RO
RS
a)
b)
Change in Ellenberg climatic quotient (2071-2100) - (1961-1990)
HIRHAM5
RegCM
RACMO
REMO
Change in Ellenberg climatic quotient
-25 - -20
-20 - -15
-15 - -10
-10 - -5
-5 - 0
0 - +5
+5 - +10
+10 - +15
+15 - +20
+20 - +25
+25 - +30
+30 - +35
+35 - +40
+40 - +45
+45 - +50
c)
d)
e)
f)
0 75 150 225 300km


Exceedance of critical values of Ellenberg climatic quotient in the period 1961-1990
Exceedance of critical values of Ellenberg climatic quotient in the period 2071-2100
PL
CZ
SK
UA
AT
HU
RO
RS
EQ value
<30
31 - 40
>40
Multi-model assessment of the exeedance of Ellenberg Climatic Quotient value 30
Multi-model assessment of the exeedance of Ellenberg Climatic Quotient value 40
Matching number of RCMs
EQ <30 for all RCMs
EQ <40 for all RCMs
1
2
3
4
0 75 150 225 300km

Annex 3