PROJECTED CHANGES OF THE FORESTRY ARIDITY INDEX INDICATING REGIONAL CLIMATIC CHANGE IN CENTRAL/EASTERN EUROPE

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1. INTRODUCTION

Climate change affects several sectors, i.e., agriculture, energy supply, tourism, transportation, healthcare. In addition, it also affects the natural vegetation, as the changing climatic conditions may induce the shifting or shrinking of the area where certain species can be found – or in the worst case even extinction. In order to be prepared for the projected changes, and preferably – if possible – to build adaptation strategies in time, special investigations are needed. For this purpose, the present study analyzes the so-called simplified Forestry Aridity Index (FAI; Führer et al., 2011) representing the climate marker for forest species over an Eastern/Central European country, Hungary (located in 45.7-48.6°N; 16-23°E, as shown in Fig. 1), and compares the results for a historical period (1971–2020) and the future (2021–2100).

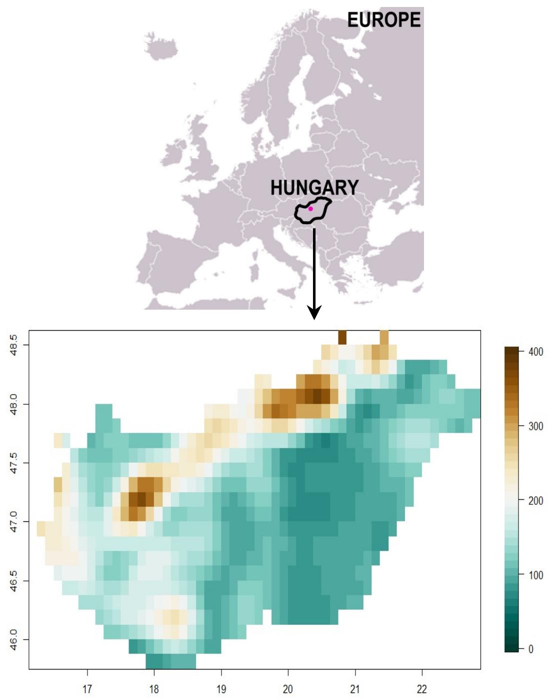

Fig. 1: Topography [m] of the target domain of the analysis

2. DATA AND METHODOLOGY

The observation-based, homogenized and interpolated HuClim data sets (created by Hungaro-Met, the Hungarian Meteorological Service, thus ensuring high-quality reliability) are used to analyze the last three decades of the 20th century and the first two decades of the 21st century, i.e., 1971-2020. Furthermore, these data serve as reference when bias-correcting the simulation data.

For the analysis of the future decades until the end of the 21st century, six regional climate model (RCM) simulations with 0.11° horizontal resolution driven by four global climate models (GCM) are used from the EURO-CORDEX (Jacob et al., 2014) data portal (Table 1), taking into account the RCP4.5 and the RCP8.5 scenarios as well. The RCP4.5 assumes that the global anthropogenic emission of greenhouse gases (GHG) will start to decrease in the 2040s, while the RCP8.5 can be considered as a business-as-usual scenario, with increasing GHG emission and no mitigation until 2100, more details can be found in van Vuuren et al. (2011).

GCM ↓ / RCM →	RCA4	RACMO22E
EC-EARTH	✓	✓
CNRM-CM5	✓	✓
IPSL-CM5A-MR	✓	
NorESM1-M	✓	

Table 1: Climate model simulations used in this study

The FAI is calculated from monthly temperature and precipitation data using the following formula (Führer et al., 2011):

$$FAI = 100 \cdot \frac{T_{VII\text{-}VIII}}{P_{V\text{-}VII} + P_{VII\text{-}VIII}}$$

where
$T_{VII\text{-}VIII}$ is the average temperature in July and August,
$P_{V\text{-}VII}$ is the precipitation total from May to July,
$P_{VII\text{-}VIII}$ is the precipitation total from July to August.

Then, five different FAI categories can be distinguished, which are favorable for certain vegetation species based on the index (Table 2).

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Ecosystem types	Interval
beech:	FAI < 4.75
hornbeam-oak:	4.75 ≤ FAI < 6
sessile oak and Turkey oak:	6 ≤ FAI < 7.25
forest-steppe:	7.25 ≤ FAI < 8.5
steppe:	8.5 ≤ FAI

Table 2: Classification of FAI values on the basis of Führer et al. (2011)

In order to eliminate the errors emerging from the RCM simulations, a simple bias-correction method was applied to the FAI values based on raw model outputs using the relative delta-method for each grid cell within the domain, and for each RCM simulation separately, as follows:

$$FAI_f(RCM_{bc}) = \frac{FAI_{p,20yr}\,(OBS)}{FAI_{p,20yr}\,(RCM)} \cdot FAI_f(RCM)$$

where

$FAI_f(RCM_{bc})$ is the bias-corrected simulated FAI for the future,

$FAI_f(RCM)$ is the raw simulated FAI for the future,

$FAI_{p,20yr}\,(RCM)$ is the 20-year mean value of the raw simulated FAI for the reference period (i.e. 2001–2020),

$FAI_{p,20yr}\,(OBS)$ is the 20-year mean value of the FAI using the HuClim reference data (i.e. observations in 2001-2020).

The validation results are discussed in detail by Kis et al. (2023).

3. DETECTED CHANGES

The ecosystem distribution of the past reflects the topography of the country, which determines both temperature and precipitation conditions to some extent. The spatial correlation coefficient value between the FAI and sea level height fields is -0.8 indicating higher FAI value in the plain regions, and lower FAI values in the hilly areas.

The temporal changes show slight increasing trends of FAI values (i.e. towards drier conditions) from 1971–1990 to 2001–2020 (Fig. 2) resulting in 46% spatial cover as a dominant ecosystem of sessile oak and Turkey oak (indicated by the yellow color code on the maps) in the western part of the country (i.e. the majority of Transdanubia), and in the eastern transition zone between the northern hills and the Great Hungarian Plain by the first two decades of the 21st century. Furthermore, the second substantial spatial cover within the country is forest-steppe (indicated by light brown) over the Great Hungarian Plain; this FAI category contributes 36% to the country’s total area.

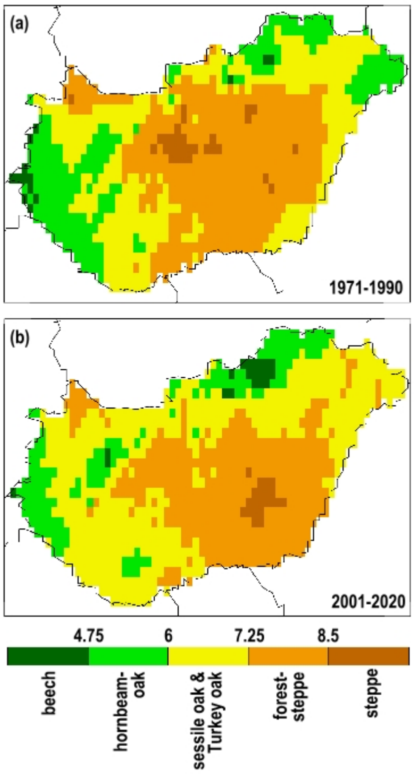

Fig. 2: Spatial distribution of mean FAI values calculated from the HuClim observation-based data for the past 20-year periods of 1971–1990 (a), and 2001–2020 (b)

Finally, 14% of the country was favorable to the hornbeam oak ecosystem in the northern hills, the western part of Transdanubia (which is generally wetter than the other parts of the country).

About 2% of the country is favorable for beech now, which can be located at the higher elevated regions. Almost the same coverage (2%) is suitable only for steppe in the middle of the Great Hungarian Plain (Fig. 2b).

4. PROJECTED CHANGES

For the future, four 20-year periods are analyzed in Fig. 3 throughout the 21st century. The coverage of different FAI categories does not change significantly when the RCP4.5 scenario is taken into account (Fig. 3a-d), and the spatial patterns are very similar to the latest 20 years (Fig. 2b) indicating very little anthropogenic impact if substantial mitigation starts around the mid-century.

On the contrary, if the RCP8.5 is realized, the spatial pattern will change substantially in the second half of the century, i.e., in 2061–2080 and 2081–2100. More specifically, the ideal climate conditions for beech will disappear from the country, and FAI values favorable for hornbeam oak will also shrink substantially to less than 2% of the country area.

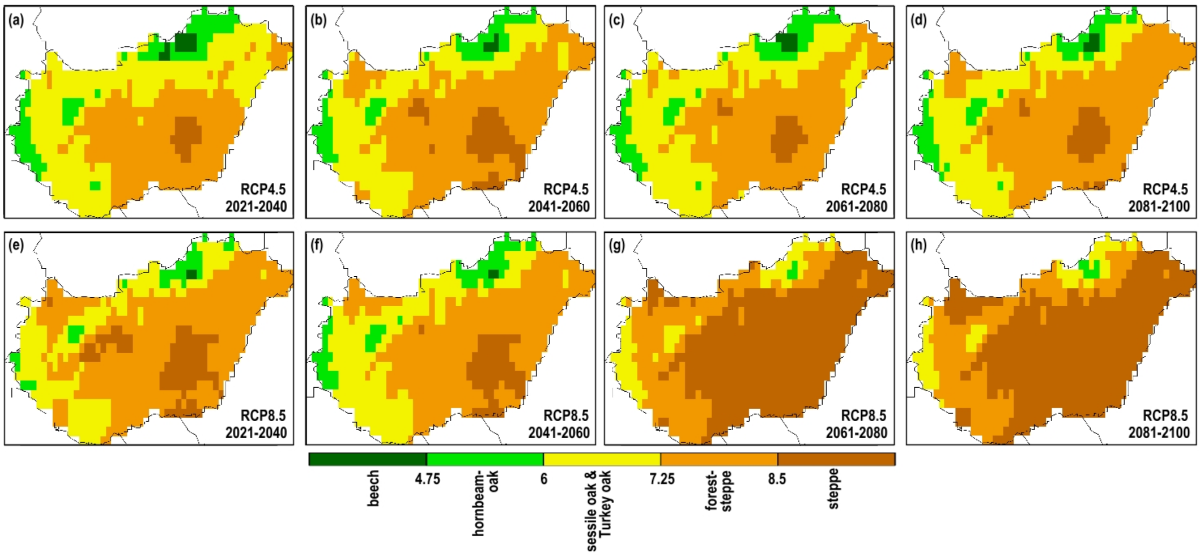

Fig. 3: Spatial distribution of mean FAI values for the four future 20-year periods within 2021–2100 using 6 bias-corrected RCM-simulations assuming RCP4.5 (a-d) and RCP8.5 (e-h) scenarios

12-13% of the country area will remain favorable for sessile oak and Turkey oak, shifting towards the western border of Hungary, and the higher-elevated hilly area (in the north/northeast region and north to the Lake Balaton). The forest-steppe category is also projected to shift westward and northward from the Great Hungarian Plain, forming around 30% of the country area, much less than nowadays. No mitigation will likely turn the steppe into the dominant natural ecosystem of the country exceeding 50% of the total area (covering the entire area of the Great Hungarian Plain as well as the Small Plain in the northwestern part of Hungary) due to the projected year-round warming and drier summers.

The uncertainty of projections represented by the different RCM simulations is discussed in detail by Kis et al. (2023).

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