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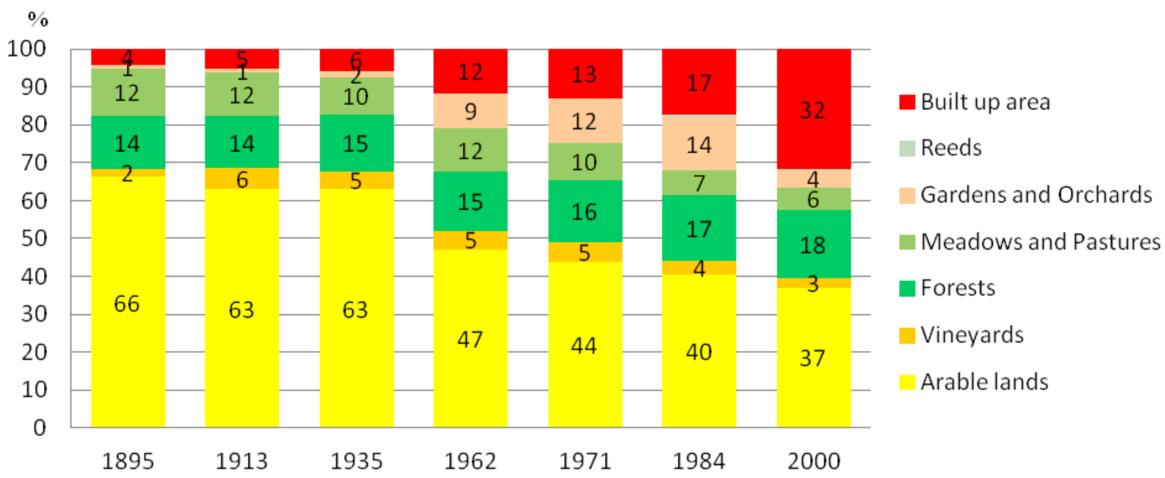

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REGIONAL CLIMATE CHANGE IMPACTS ON WILD ANIMALS' LIVING TERRITORY IN CENTRAL EUROPE

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Abstract. In this paper the projected future impact of climate change has been analyzed for the quality of living conditions of the European terrestrial vertebrates (amphibians, reptiles, birds, mammals) in the Carpathian Basin. According to the climate scenarios, warmer and drier climatic conditions are likely to occur in the Carpathian Basin by end of this century. Simultaneous analysis of climate parameters, climate simulations and animal range datasets enables us to evaluate the vulnerability of different European species to regional warming and climate change. The spatial climate analogy technique is used to analyze the estimated rapid change of the wild animals' habitats and their northward migration. For the reference climate data of Debrecen is considered, and three spatial analogue regions are compared. The results suggest that generally a significant decline in habitats is very likely for most of the analyzed animal groups by the end of the 21st century. The largest rate of decline is estimated for birds. However, living conditions for reptiles may improve in the future due to the warmer and drier climatic conditions, which are favourable for these species.
Keywords: *spatial analogy, climate change, vertebrates species, ecology, area dynamics*

Introduction

Global climate change does not affect only humans and the urban environment, but also, the living conditions of wild animals. The analysis of phenological, geographical and genetic impacts of climate change to wildlife is an increasingly popular research topic (e.g., Thomas et al., 2004; Rosenzweig et al., 2008; Moritz et al., 2008; Diós et al., 2009; Drégelyi-Kiss and Hufnagel, 2009; Eppich et al., 2009; Sipkay et al., 2008, 2009; Chen et al., 2011), however, the projections of future conditions are rarely investigated due to the lack of methodology. The results suggest that the relationship between global warming and the response of the wildlife is clearly strong.

Climate is one of the abiotic factors, which controls primarily the range areas of the wildlife. According to the Niche theory (Jackson and Overpeck, 2000) in a particular region, multivariate changes in climate imply shifts in species' range areas because each species reacts individually (Williams et al., 2007).

If the climate significantly changes in a particular region, it may disturb the ecosystem, and increase the risk of extinction. Based on previous studies (e.g., Williams

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et al., 2007) accomplished in case of the A2 scenario (Nakicenovic and Swart, 2000), 12-39% of the Earth's terrestrial surface is very likely to experience significantly different climate conditions from the current climate in the future.

Because of the warming, some species colonize new regions, others move towards presently yet colder climatic zones. However, in case of some other wildlife species, it may be especially difficult to adapt to the accelerating warming. For instance, Beever et al. (2011) concluded that the wild mountain-dwelling pikas of North America migrated upward at an average of 13 m per decade throughout the 20th century, and this rate increased up to 145 m per decade in the last 12 years. According to Chen et al. (2011) the range of species of North America and Europe shifted poleward 17 km per decade, and to higher elevation at a rate of 11 m per decade in the recent decades. As species move from their previous ranges, they meet other species, sometimes unprecedently, which affects the whole ecosystem of the region.

Mountain ecosystems have very diverse wildlife, thus, they are major areas of biodiversity (Balogh et al., 2008). Increasing temperature is estimated to cause significant loss of appropriate environment of all regionally endemic animals. These possible losses may increase if the warming compared to present climate is larger than 2°C. According to estimation of Williams et al. (2003), even with an optimistic temperature increase of 1°C, one endemic species will entirely lose its habitat and almost all other endemic species will suffer severe decreases in their range areas of the Australian Wet Tropics bioregion. Moreover, in the case of a large warming (exceeding 7°C), all of the endemic species will lose their previous habitats.

The species that are affected the most negatively by climate change are the habitat specialists, and the species being less mobile. Species that live in fragmented landscapes may also struggle with the negative impacts of climate change because they are not able to colonize the area (Chen et al., 2011).

Each species has its own climatic and environmental needs and tolerances. If these conditions change (e.g., by climate change) they may shift their ranges, or regulate their morphology, shifting the timing of life-cycle events or in the worst case, they may suffer extinction (Rosenzweig et al., 2007). Because of the large number of endangered species, several analyses focus on extinctions due to climate change recently (e.g., Burrowes et al., 2004; Sekercioglu et al., 2004; Pounds et al., 2006; McLaughlin et al., 2002). Specifically, 75 endemic frog species in the American tropics are extinct because of a pathogenic fungus (*Batrachochytrium dendrobatidis*) infection due to recent warming (Pounds et al., 2006). Furthermore, a native butterfly, *Euphydryas editha bayensis* in the San Francisco Bay area in California is another victim of global warming because its total habitat loss and thus, extinction in the region were due to the increasing variability in precipitation (McLaughlin et al., 2002). Based on the study of Sekercioglu et al. (2004) 21% of 9916 historic bird species of the world are threatened by extinction, and 6.5% of the analyzed IUCN Red List avian species are functionally extinct. According to the estimations, 6-14% of all historic bird species will be extinct, 7-25% will be functionally extinct, and 13-52% will be functionally deficient by the end of the 21st century (Sekercioglu et al., 2004).

Besides vertebrates, even insects show a very sensitive reaction to the change of abiotic factors of the environment (Ladányi and Hufnagel, 2006; Ferenczy et al., 2010). Therefore, they can be considered as a good indicator species of climate change (Gergócs and Hufnagel, 2009; Gergócs et al., 2010). For instance, a recent paper by Kocsis and Hufnagel (2011) of the impacts of climate change on the fourth largest order of insects in Europe discussed remarkable changes in abundance, distribution range and phenology of Lepidoptera.

The above mentioned studies all highlight the importance of this global issue and the need of further research to understand the mechanisms of climate stress to ecosystems. Such detailed analysis may help to minimize these negative impacts of global warming to the wildife and ecosystems before it would be irreversible.

The research presented in this paper aims to evaluate the regional impacts of climate change on the habitats of wild European vertebrates (amphibians, reptiles, birds, mammals). The method of spatial climate analogy (Horváth, 2008b) has been used to analyze the possible future climatic conditions in Eastern Hungary by the late 21st century. Global warming implies increasing temperature, dryer summers and wetter winters in the region (Bartholy et al., 2008), which is similar to the current Mediterranean climate, therefore, the climate analogy sites are located south, southeast to Hungary. Comprehensive habitat and climate analysis enables us to evaluate the sensitivity of the European vertebrate species to regional warming and climate change.

Database

Three datasets were used for the range of species:

- The Atlas of European Mammals (available from Societas Europaea Mammalogica, http://www.european-mammals.org/php/mapmaker.php). This database was compiled in 1999 (Mitchell-Jones et al., 1999) and has been widely used as reference dataset. It separately contains data for the pre-1970 and post-1970 presence of mammal species in Europe.
- The Atlas of European Breeding Birds (available from the European Bird Census Council, EBCC, http://www.sovon.nl/ebcc/eoa), which contains information on bird species (Hagemeijer and Blair, 1997**.** In case of both mammals and birds, the range of species determined from the datasets may not be precise for the Eastern European regions, i.e., it is possible that several species are only missing due to not detecting them.
- The Atlas of Amphibians and Reptiles (available from the European Societas Europaea Herpetologica, http://www.seh-herpetology.org), which contains spatial distribution information about these species. This database was published in 1997 (Gasc et al., 1997) and was collected on the basis of observations in the 1980s and 1990s.

From the above datasets, altogether 234 mammal species, 58 bird species, 123 reptile species, and 61 amphibian species were analyzed in the present study.

The climate information includes daily temperature and precipitation, which is available from the E-OBS datasets (Haylock et al., 2008). The climatic conditions of Debrecen in 1961-1990 are illustrated in *Fig. 1*. The red curve of the diagram shows the annual distribution of monthly mean temperature values, the blue histograms indicate the average monthly precipitation amounts.

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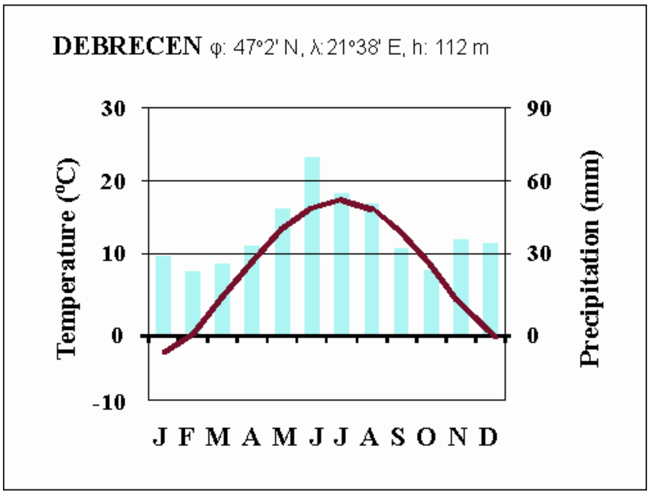

Figure 1. *Climate diagram representing the climate conditions in Debrecen (1961-1990)*

The methodology of spatial analogy

The spatial analogy technique is based on the temperature and precipitation time series. Horváth (2007, 2008a, 2008b) applied the analogy of the search process for the area of Debrecen (Hungary, 47° 2' N, 21° 38' E) using the pessimistic A1FI, and the optimistic B2 scenario (Nakicenovic and Swart, 2000). With the so-called CLIMEX method (*Eq. 1*) (Sutherst and Maywald, 1998; Young et al., 1999), it is possible to determine the spatial climate analogy regions, for which the following formulae can be used:

$$\begin{aligned}
T_{dj} &= \frac{1}{12}\cdot\sum_{i=1}^{12}\left|TEMP_{ji} - T_i\right| \\
P_{dj} &= \frac{1}{12}\cdot\sum_{i=1}^{12}\frac{\left|PREC_{ji} - P_i\right|}{1 + a\cdot\left(PREC_{ji} + P_i\right)} \\
I_{Tj} &= e^{-k_T\cdot T_{dj}} \\
I_{Pj} &= e^{-k_P\cdot P_{dj}} \\
CMI_j &= \sqrt{I_{Tj}\cdot I_{Pj}}
\end{aligned} \qquad \text{(Eq.1)}$$

where,
j: number of the gridpoint (*j*=1,…,31143)
i: number of the month (*i*=1,…,12)
$TEMP_{ji}$: the temperature of the grid *j* in the month *i*
T_i: the temperature of the scenario in month *i*
$PREC_{ji}$: the precipitation of the grid *j* in the month *i*
P_i: the precipitation of the scenario in month *i*
T_{dj}: the absolute differences of temperature
P_{dj}: the differences of precipitation

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a: we can count only the differences of precipitation, because the differences for small precipitation is more important than for the high ones. For the calculation we used *a*=0,05
I_{Tj}: the similarity of the grid *j* by the temperature to the scenario (value: 0-1, if the temperature is the same, than I_{Tj}=1)
I_{Pj}: the similarity of the grid *j* by the precipitation to the scenario (value: 0-1, if the precipitation is the same, than I_{Pj}=1)
k_T: can be set by the user, if k_T=0.1 than for 1°C differences the similarity is I_{Tj}=0.9, to define the analogue regions, we used the value k_P: can be set by the user, we choose the k_P=0.1
CMI_j: „Composite Match Index", the similarity between the gridpoint and the scenario, for the perfect similarity the value is *CMI*=1

The center of the three regions derived from the method of spatial climate analogies (*Fig. 2*) indicate the possible future climatic conditions for the region of Eastern Hungary (represented by Debrecen as the largest city in the area with reliable observed meteorological time series) in the 21st century. Climate conditions similar to the present conditions of Timisoara and Russe are estimated by the middle of the 21st century, and conditions similar to the present conditions of Thessaloniki by the end of the century. The details of the entire selection process of the spatial climate analogy regions represented by the above mentioned cities are described by Horváth (2007, 2008b).

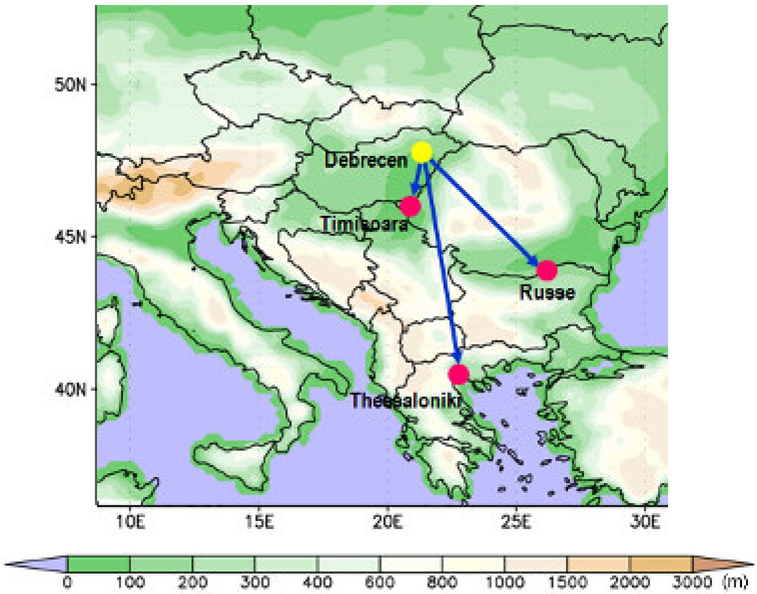

Figure 2. *Location of the climate analogue sites*

The climate diagrams of *Fig. 3* show that warmer climatic conditions and significantly decreasing summer precipitation are projected in the region by the end of the 21st century. Current climatic conditions of the spatial analogue sites are presented in the left column (in similar forms to *Fig. 1*) while the difference between the analogue sites and Debrecen (implying the projected climatic changes) can be seen in the right column. The larger the geographical distance between the spatial analogue site and Debrecen, the warmer the climate and the drier the summer. First, summer climate of Timisoara is only slightly warmer and drier than that of Debrecen: the anomalies of the

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monthly mean temperature do not exceed 2°C, and the monthly precipitation anomalies do not exceed 10 mm. This slight difference can naturally be explained by geographical proximity. In the temperature conditions of Russe the differences in summer can exceed 4°C and the difference of the summer monthly precipitation exceeds 20 mm. The greatest climatic anomalies compared to Debrecen occur in Thessaloniki, located on the southernmost, which is projected to characterize Debrecen by the late 21st century (Bartholy et al., 2008). The summer temperature differences between Thessaloniki and Debrecen are 6-7°C, and monthly precipitation decrease is about 40-50 mm.

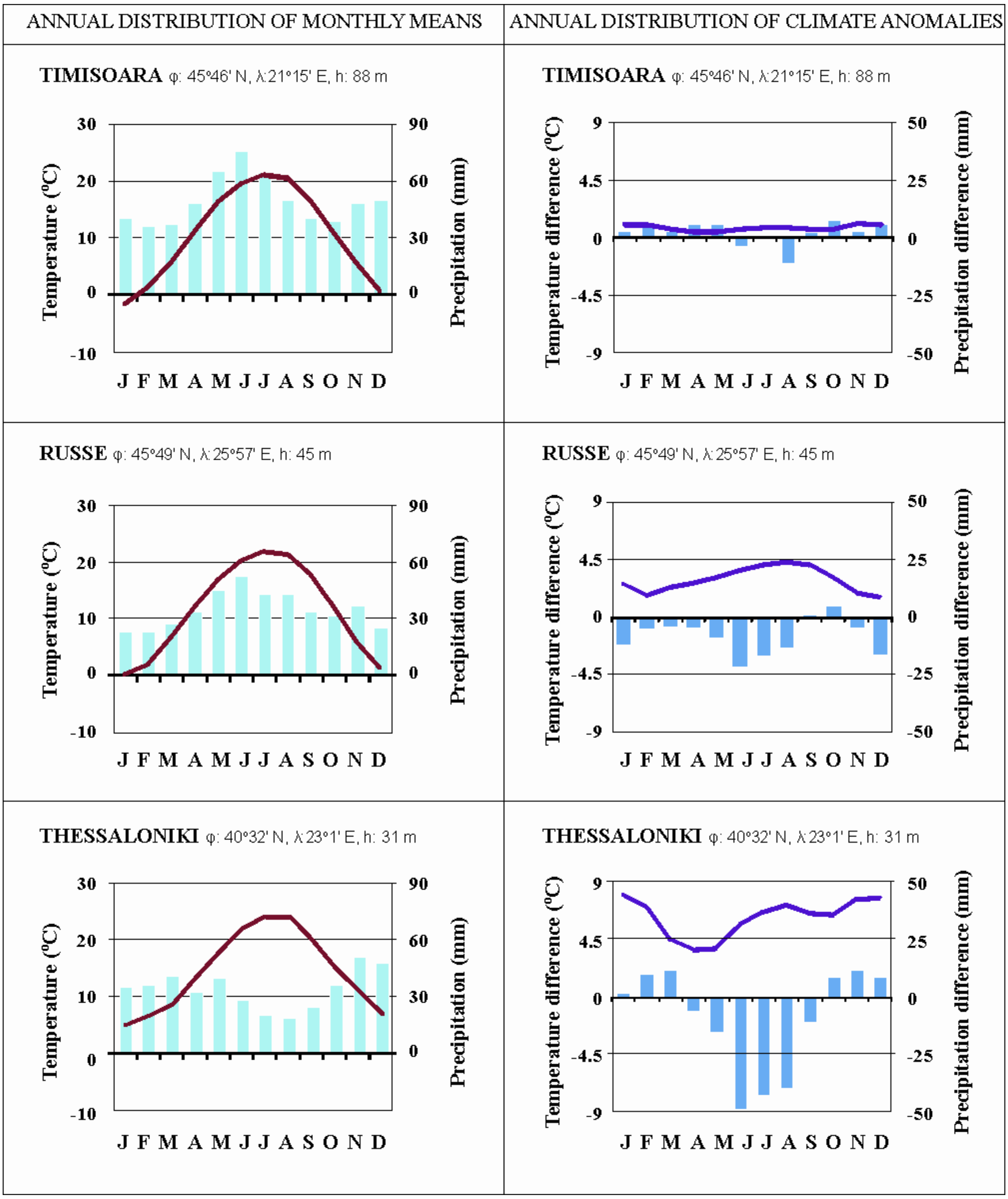

Figure 3. *The climatic conditions of the climate analogue sites (Timisoara, Russe, Thessaloniki).*

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Classification system based on living conditions of species

For the analysis of the change in the range of different vertebrate species, the applied classification system contains four different basic codes: (i) 'Absent', i.e., there are no suitable habitat for the particular animal in the region; (ii) 'Marginal', i.e., the range area is located on the border of the spread area of the particular animal; (iii) 'Sporadic', i.e., the location of the habitats are not a continuous distribution area of the particular animal; (iv) 'Area central' considered to be the best conditions for the particular animal because the range area is centrally located.

The quality of living conditions for every terrestrial vertebrate has been determined in the Debrecen region and in the three analogue regions. The resulting sixteen variations of code-pairs can be divided into three classes in terms of changing in their habitat quality. The first six code-pairs (i.e., Absent – Area central, Absent – Sporadic, Marginal – Area central, Absent – Marginal, Sporadic – Area central, Marginal – Sporadic) imply positive changes or improving conditions. Three code-pairs (i.e., Area central – Area central, Sporadic – Sporadic, Marginal – Marginal) imply unchanged situation. The last six code-pairs (i.e., Area centrale – Sporadic, Sporadic – Marginal, Area centrale – Marginal, Marginal – Absent, Sporadic – Absent, Area centrale – Absent) imply negative change or decreasing habitat. Since the 'Absent' – 'Absent' code pair is not relevant in the analysis, it was omitted from the classification system. For the animals, the most negative habitat change is to shift from the 'Area central' to the 'Absent' condition, which means the extinction of the particular species. On the other hand, the most positive change is the change from the 'Absent' status to 'Area central'. This classification unables us to identify the endangered species, the new immigrant species, and a detailed analysis of different species' habitats.

Results

We analyzed the change of habitat quality in case of all four classes of vertebrate animals separately in Debrecen and in the three spatial analogue regions. The results of changing habitats (i.e., the code-pairs) are summarized in *Fig. 4* as a distribution using pie charts for all the four classes of vertebrates. Blue colors indicate decreasing habitat of the animals, while yellow and red colors indicate improved conditions for the species. Grey colors imply unchanged conditions. In case of amphibians no major changes can be projected in living conditions by the mid-century, but a significant decline is expected by the end of the century. The living conditions of reptiles clearly show an improving trend of their conditions, which is due to the fact that the warmer and drier climatic conditions are favorable for these species. The largest portion of decrease is projected for the birds since the conditions become less favorable. The portion of bird species with decreasing habitat conditions can exceed 60% by the end of the 21st century.

In case of mammals, different species react very differently to the changing climatic conditions, thus, some species may benefit from the regional climate change, others will lose their habitats. By the end of the century the living conditions of 48% and 31% of mammal species are projected to decrease and increase, respectively.

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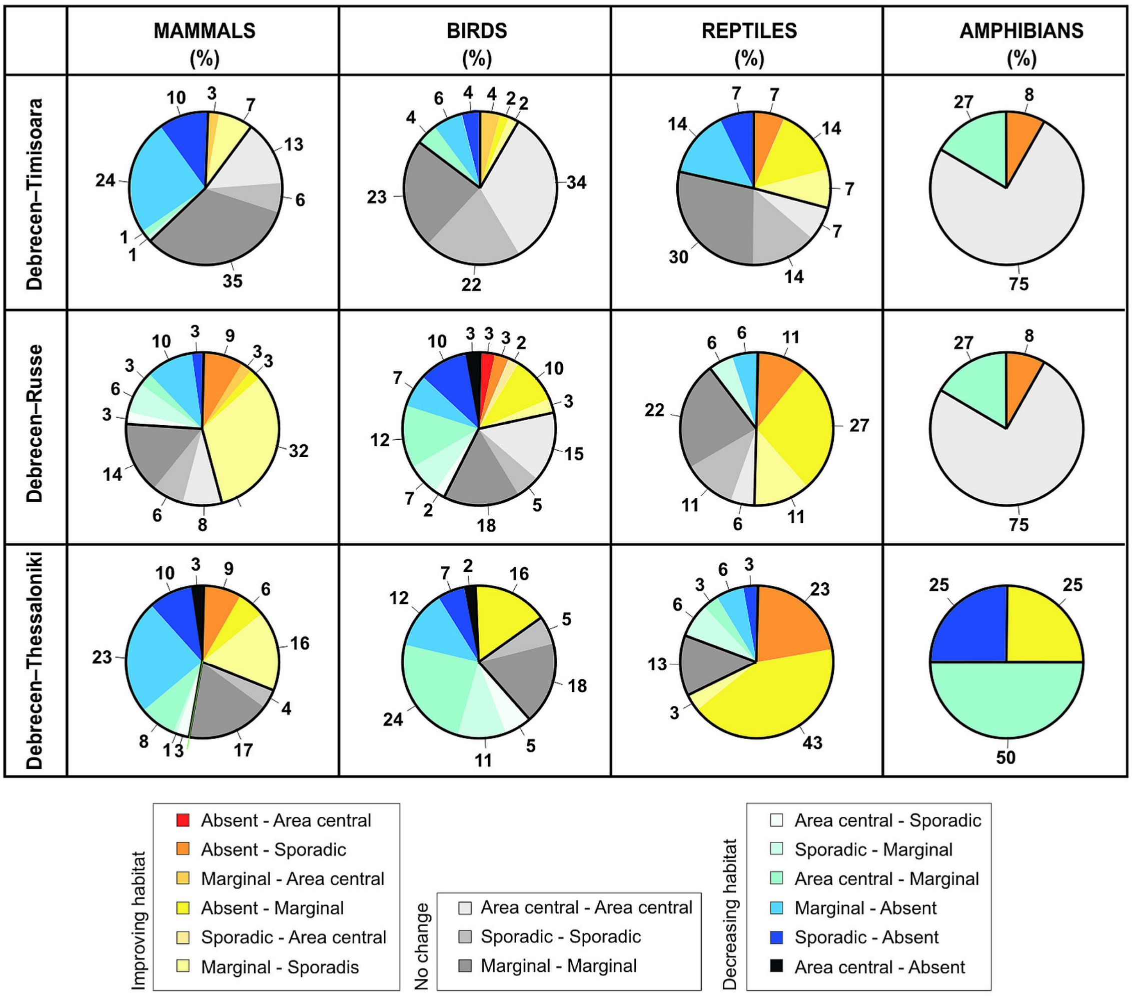

Figure 4. *The distibution of habitat changes of the four groups of animals on the climatic analogue regions*

Results of regional climate change studies suggest that the climate of the Carpathian Basin is expected to be drier and warmer by the end of the 21st century (Bartholy et al., 2008), therefore it is assumed that the migration of animals will shift northward.

The climate change affects the amphibians especially negatively because they are water-bound animals and hence, the estimated drying leads to decrease of the optimal habitats. Among amphibians the following species will probably suffer the strongest habitat decrease by the end of the century: *Bombina bombina* – European fire-bellied toad, *Palobates fuscus* – common spadefoot toad, *Rana esculenta complex* – edible frog, *Rana arvalis* – moor frog.

The reptiles are well-known of their preference of warm areas (due to the lack of an appropriate heat-balancing cardiovascular system), therefore, the projected temperature increase will be generally beneficial for them. However, the living conditions of the following species may be threatened by the effects of climate change: *Zootoca vivipara* – common lizard, *Lacerta agilis* – sand lizard, *Ablepharus kitaibelii* – European copper skink.

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Based on our analysis the following bird species are likely to be the most negatively affected by the climate change: *Acrocephalus paludicola* – aquatic warbler, *Circus pygargus* – Montagu's harrier, *Limosa limosa* – black-tailed godwit, *Numenius arquata* – Eurasian curlew, *Asio flammeus* – short-eared owl, *Otis tarda* – great bustard.

Fig. 5 summarizes the spread of endangered mammal species in Europe and in the Carpathian Basin. Among these mammals the following species are likely to lose partially their habitats in the Carpathian Basin in the future: *Castor fiber* – Eurasian beaver, *Myotis dasycneme* – pond bat, *Barbastella barbastellus* – western barbastelle, *Lynx lynx* – Eurasian lynx, *Mustela erminea* – stoat, *Oryctolagus cuniculus* – European rabbit.

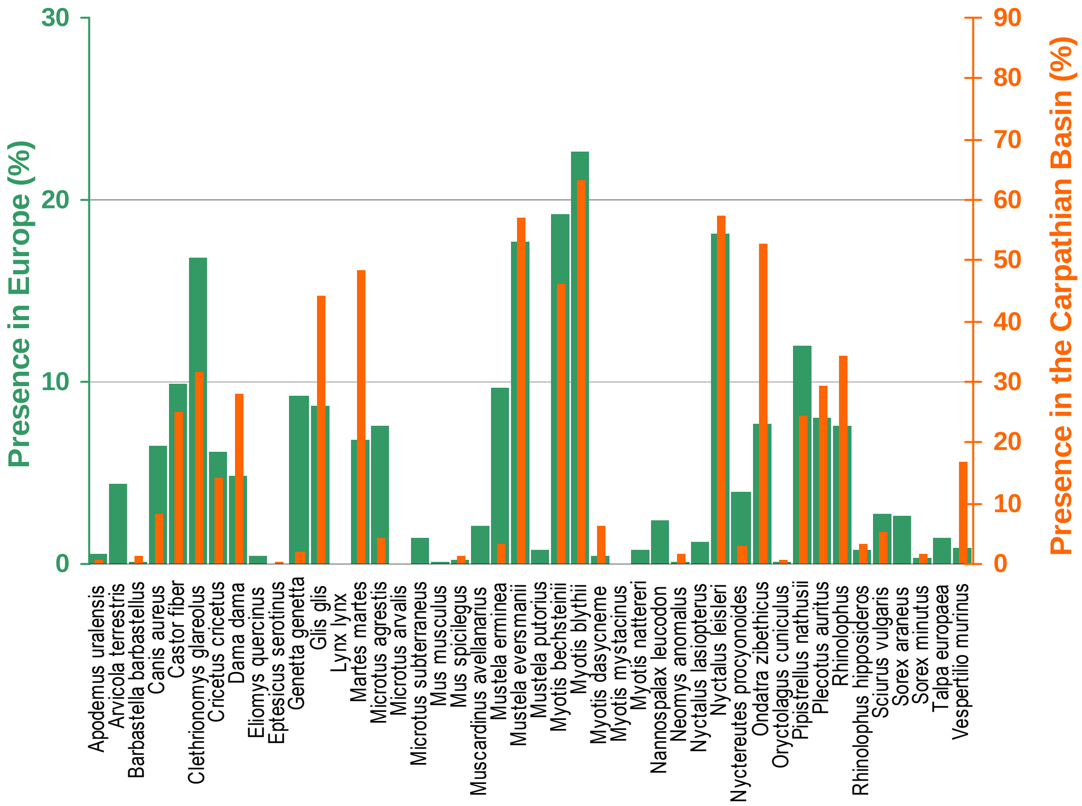

Figure 5. *Current presence of possibly endangered European mammal species in the whole area of the European continent and the Carpathian Basin. (In any climate analogue site the given species' habitat is classified as 'Absent')*

Fig. 6 shows the distribution map of the six mammal species, which are categorized – based on the Atlas of European Mammals database – 'absent' in all three analogue regions, while in the Debrecen region they are categorized as 'marginal' or 'sporadic' living conditions. Our results suggest that it is likely that the future climate of Hungary will not be suitable for these six mammal species.

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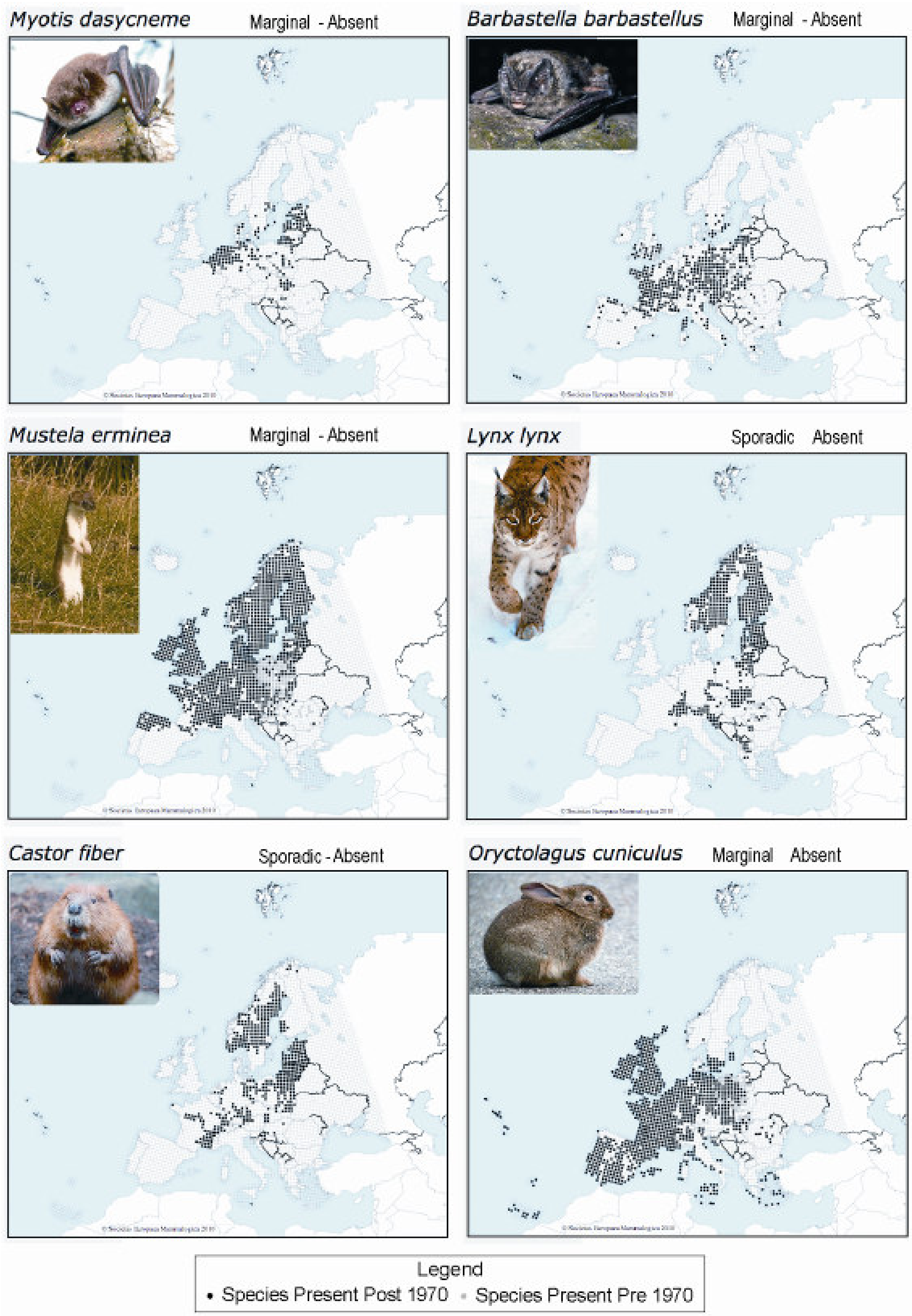

Figure 6. *The species of which the habitats of all the climate analogue sites are classified as 'Absent' are shown in more details on the range maps determined ont he basis of datasets from Mitchell-Jones et al. (1999)*

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Conclusion and discussion

The purpose of this reasearch was to analyze the possible regional impacts of the global warming to the living territory and conditions of the four wild European terrestrial vertebrate groups (amphibians, reptiles, birds, mammals). Climate analogy technique enables us to estimate the migration tendecies of these animals during the 21st century. However, the validity of the results analyzed in this paper is limited since the living territory of the species and its changes are not only dependent on temperature and precipitation.

In case of the four examined vertebrate groups the portion of species with decreasing habitat conditions is estimated to be between 18% and 61%, while that with increasing habitat conditions between 16% and 69% by the end of the 21st century. This result is very similar to that of Petrányi et al. (2007). According to their study 33% of the Lepidoptera species is predicted to have decreasing, while 26% of them to have increasing habitat conditions by the end of the 21st century.

As we proceed southward from Timisoara to Thessaloniki the portion of species with unchanged habitat conditions decreases from 54% to 21% in case of mammals, 78% to 23% in case of birds, 51% to 13% in case of reptiles, and 75% to 25% in case of amphibians. Petrányi et al. (2007) predicted the Lepidoptera species to be between 67% to 41% (79% to 51% in case of Macrolepidoptera, and 61% to 34% in case of Microlepidoptera), under the same conditions, with the same analogue places.

We can predict a 17% decrease in mammal biodiversity, a 45% decrease in bird biodiversity, while a 51% increase in the biodiversity of reptiles, by the end of 21st century (based on Thessaloniki as an analogue place). In the case of amphibians we estimate a 50% species replacement without the change of biodiversity. Based on the data of Petrányi et al. (2007) Lepidoptera biodiversity is estimated to decrease by 7% (a deacrease of 18% in case of Microlepidoptera and a 9% increase in case of Macrolepidoptera).

According to the climate change estimations for the Carpathian Basin, warmer and drier climate conditions are projected. Our results based on the climate analogue technique suggest a remarkable change in the habitats of wild animals and their northward migration in order to find their optimal conditions. More specifically, the following conclusions can be drawn.

1. Among the four animal groups analyzed in this paper, the birds are likely to be affected the most negatively by the regional climate change.
2. Since reptiles prefer warm and dry climatic conditions, therefore, the estimated climate change in the region improves their living conditions.
3. In the case of mammals, species respond differently to the changing climatic conditions, thus, some species may benefit from the regional climate change, while others will lose their habitats.
4. Because of the barrier effect of the Carpathian Basin, some species could suffer extinction due to the lack of escape routes. This effect was not taken into consideration in this study.

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MODELLING THE IMPACT OF CLIMATE CHANGE ON THE HUNGARIAN WINE REGIONS USING RANDOM FOREST

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Abstract. This paper aims to simulate and analyse the impact of climate change on the Hungarian wine regions using spatial layers of temperature-based bioclimatic indices. Random forest classification was used to analyse the similarities between the present and future climate of the wine regions. The model was firstly calibrated for the present period then applied for the expected future climatic conditions simulated by the RegCM3 model with A1B scenario. Results show that in the near future (2021-2050) the grapevine regions typical of the southern may expand in greater part of the country, while at the end of the century (2071-2100) only the northern part of the country shows some similarities with the present climate. Despite these results, Hungary is expected to remain amongst the regions with good quality grapevine growing conditions, but the structure of the cultivation and/or varieties should be changed.
Keywords: *climate change, viticulture, wine regions, Random Forest classification*

Introduction

Climate change has the potential to greatly impact nearly every sector of agriculture, including viticulture. Grapevine is one of the oldest cultivated plants, along with the process of making wine. The cultivated varieties and the overall wine style that a region produces is a result of the average climatic conditions, while climate variability determines vintage quality differences. Climatic changes, which influence both variability and average conditions, therefore have the potential to impact on growth, grape composition, wine style and spatial distribution of grapevines (Hunter and Bonnardot, 2011). Today's viticultural regions for quality wine production are located in relatively narrow geographical and therefore climatic niches that means high sensitivity and risk both in short-term climate variability and long-term climate change (Jones, 2007; Holland and Smit, 2010). Additionally, grapevine is perennial and during the expected productive life of the vineyards the climate is projected to change significantly.

Jones et al. (2005) found that in the last decades the majority of the U.S. and European wine regions experienced now statistically significant warming trends in the growing season. This tendency was observed also in Hungary (Kocsis et al., 2010). As a consequence, phenological changes are expected to occur, too (Hlaszny et al., 2012;

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Ladányi et al., 2010). According to Moisselin et al. (2002) the increase of the mean temperature at a rate of 1°C can cause a geographical shift of the border of the suitable wine regions with 180 km to north. At present Hungary lies at near the northern border of the growing areas, and expected to remain amongst the regions with good quality grapevine growing conditions, but growers must prepare for the expected changes. Analysing the climatic risk factors of Central Hungarian grape growing regions (Szenteleki et al., 2012) it was found that the significant increase of the number of warm and hot days in the future involves the risk of production.

While there are many individual weather and climate factors that can affect grape growth and wine quality (e.g. solar radiation, heat accumulation, temperature extremes, precipitation, wind, and extreme weather events such as hail), growing season length and temperatures are critical aspects because of their major influence on the ability to ripen grapes to optimum levels of sugar, acid and flavour (Jones et al., 2005; Zanathy, 2008, Ladányi, 2010). To evaluate viticulture and wine production in the context of climate suitability and the potential impacts from climate change, various temperature-based bioclimatic indices (e.g. degree-days, temperature of the warmest month, cool night index, average growing season temperatures, Huglin and Winkler indices) can be used (Tonietto and Carbonneau, 2004; Zorer, 2008).

The suitability of an area for vine growing depends also on other ecological factors, e.g. soil, elevation, slope and aspect. In Hungary a production area cadastre with maximum of 400 points was elaborated in the Central Research Institute of Viticulture and Oenology (*Table 1*).

Table 1. *Ecological characteristics for vine areas (source: Szenteleki et al., 2007)*

Factors	Maximum points
Climatic factors (winter and vegetative spring-fall frequency of frost)	95
Soil factors (soil type, subsoil, physical characteristics, water supply, humus content, homogeneity, water content of the soil, danger of erosion/blow-out depression)	112
Geographic terrain factors (direction of slope and exposure, height above sea level, discharge of the cold, need to prepare the site/necessity for terracing	175
Surrounding area (forest, building structures, accessibility)	18

The aim of the present study was to evaluate the expected future climatic conditions in the Hungarian wine regions and compare the possible changes with the present situation. Soil factor was partly considered, but we assume that the other factors (elevation, slope and aspect) will not change, so these factors have not been involved in the analysis.

Materials and methods

Meteorological data

WorldClim is a set of global climate layers (climate grids) with a spatial resolution of 30 arc seconds, often referred to as 1 km spatial resolution. The climate elements considered are monthly precipitation and mean, minimum and maximum temperature. Input data were gathered from various sources and many meteorological stations from the 1950-2000 period, and were interpolated using the thin-plate smoothing spline algorithm (Hijmans et al., 2005). The high resolution of this database does not imply

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that the quality of the data is necessarily high in all places. It depends on the local climate variability and on the quality and density of the observations of a given area.

For the validation, observed monthly mean temperature and precipitation data of 32 Hungarian meteorological stations were used, from the period of 1961-1990. Paired t-tests were carried out for seasonal data. We found that the precipitation values of the WorldClim database and the Hungarian observations can be considered the same, but there are differences in the monthly mean temperatures. In two stations (Martonvásár and Szabadbattyán) the overestimations of the WorldClim database sometimes are greater that 1°C. However there are strong correlations between the datasets, around 0.88 considering all the 32 meteorological stations, and over 0.9 without the two problematic stations. Taking into account that the periods of the two datasets are not exactly the same, and there is no information about the quality of the observed data, WorldClim database was accepted as a good characterisation of the present climate in Hungary.

Expected regional climate change focused to the Carpathian Basin is modelled by four different RCMs, run by the Department of Meteorology, Eötvös Loránd University, Hungary and by the Hungarian Meteorological Service (Bartholy et al., 2009). Climate scenarios applied in the present study were provided by the Department of Meteorology of the Eötvös Loránd University. They applied the high-resolution version of the Regional Climate Model (RegCM3) over the Carpathian basin using the A1B scenario (Bartholy et al., 2009; Torma et al, 2011). The horizontal grid spacing of this dataset is 10 km – the highest reached by RegCM3 model – and the database contains daily data of several climatic elements for the baseline period (1961-1990) and two time-slices in the future (2021-2050 and 2071-2100). From the daily data monthly precipitation and mean, minimum and maximum temperature data were calculated.

Using the climate scenarios the changes (differences in case of temperature and ratio in case of precipitation) were calculated compared to the baseline, than added (multiplying in case of precipitation) to the higher resolution WorldClim dataset.

Grapevine growth is basically determined by the climatic potential of a region, described with different thermal indices. From the present and the expected future climate data biological effective degree days between 10°C and 19°C (Gladstone index, *BEDD*), as well Winkler (*WIN*) and Huglin (*HI*) indices were calculated. Minimum temperature of the coldest (January, *T_Jan*) and the warmest month (July, *T_Jul*) were considered as limiting factors in grapevine cultivation. The cool night index (minimum temperature in September, *CI*), the average growing season temperature (from April to October, *T_avg*), the yearly average temperature (*T_year*) and the seasonal water balance, which profoundly influence grape and wine quality (Jones et al., 2005; Tonietto and Carbonneau, 2004) were additionally considered in the classification process (see Appendix for a comprehensive description of indexes calculations).

Soil data

Besides climate, soil is also an important environmental factor to which the grapevine is subjected. The Harmonized World Soil Database (FAO/IIASA/ISRIC/ISS-CAS/JRC, 2009) was used to determine the soil water storage capacity values (*s_AWC*). The database distinguishes seven AWC classes. Water deficit values (*WAT_def*) were calculated for the present and for the two future time-slices based on a monthly water-balance model (McCabe and Markstrom, 2007; Gray and McCabe, 2010).

Wine regions and land use data

There are 22 wine regions in Hungary, which have their well defined and widely requested characters based on their typical varieties grown there. The map of the wine regions – provided by the Institute of Geodesy, Cartography and Remote Sensing – is available only in picture (*.jpg) format. Therefore, the first step was the digitalization and creation of a georeferenced GIS database of the regions.

The wine regions are potential areas for growing quality wine. The pixels defining the current grapevine cultivated area over each wine region were derived from CORINE Land Cover database (CORINE 2006), at a spatial resolution of 100x100 m. Considering the mismatch of spatial scale between CORINE and WorldClim (i.e 100 m and 1 Km), before downgrading the CORINE information at a lower spatial resolution, loosing much information, 1 Km buffers were created around the CORINE vineyard pixels.

CORINE dataset was additionally used to define the present agricultural land use types in the predicted potential grapevine areas.

Extension of the dataset

The whole area examined was 861x407 = 350427 pixels, from which

- 158924 pixels are within the borders of Hungary
- 41105 pixels belong to the Hungarian wine regions
- 9081 pixels are Hungarian vineyards based on the CORINE dataset (*Fig. 1*).

According to the original datasets, all maps were created using the WGS-84 coordinate system.

Climate data for the present period are available for the whole area, but the climate scenarios characterise only Hungary.

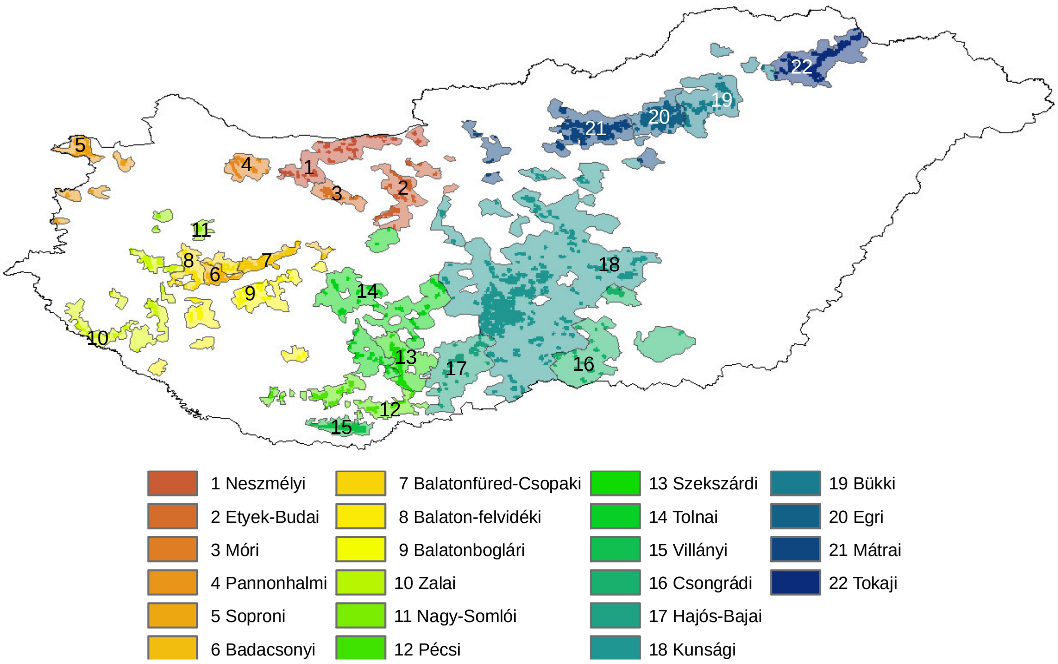

Figure 1. *Location, numbers and names of the Hungarian wine regions the small raster cells indicate the vineyards based on CORINE 2006*

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Random forest classification

Random forest (RF) classification has become a widely-used predictive model in many scientific disciplines within the past few years. The method is receiving much attention in ecological studies, especially for predicting the effect of climate change on species distribution (e.g. Cutler et al., 2007; Benito Garzón et al., 2008; Attore et al, 2011; Evans et al., 2011; Vaca et al., 2011). The unique advantage of the machine learning algorithm is that complex relationships and spatial patterns can be discovered readily (Evans et al., 2011). It can also be applied when predictor variables are highly correlated (Strobl and Zeileis, 2008).

The RF is a classification method that basically consists of a combination of decision trees where each classifier is generated using a bootstrap sample. The bootstrap sample is randomly split into two subsets, which are used for training (66%) and for internal testing (33%, out-of-bag sample, OOB). A classification tree is fit to each bootstrap sample where each node within a tree is constructed by selecting a random subset of the environmental variables (for this parameter *mtry* was set to 4). This feature reduces the problem of correlated variables because these may be extracted in turn, thus contributing independently to the aggregated tree model.

Each tree is fully grown until a final node is reached and then it is used to predict the classes of OOB observations. This procedure is repeated until the desired number of trees has reached. The algorithm includes the computation of the OOB error estimate, which is calculated for each tree over the data split out of the corresponding bootstrap sample, and then averaged. Because the OOB observations are not used in the training of the trees, these are essentially cross-validated accuracy estimates. According to Evans et al. (2011) model selection was based on a minimization of both “out-of-bag” (OOB) error and largest “within-class” error estimates of several runs.

In the prediction mode, a calibrated RF model consists of an ensemble of classification trees, each of which is allowed one vote for the model prediction. The most voted prediction from all of the trees in the random forest becomes the final model prediction.

The RF algorithm also provides measures of variable importance. The most often used measure is based on the decrease of classification accuracy. The mean decrease in accuracy for a variable is the normalized difference of the classification accuracy for the out-of-bag data when the data for that variable is included as observed, and the classification accuracy for the out-of-bag data when the values of the variable in the out-of-bag data have been randomly permuted. The higher mean decrease accuracy (also called permutation importance) value means the higher importance of a given variable. According to Strobl et al. (2009) all variables whose importance is negative, zero or has a small positive value that lies in the same range as the negative values, can be excluded from further exploration, but during the analyses only positive importance values were found. The interpretation or comparison of the importance measures should rely only on a descriptive ranking of the predictor variables, not on the absolute values.

Calculations were done using the ‘randomForest’ package available in R environment. RF classification was firstly calibrated for the present period and used to derive information on the relative importance of the considered parameters. The calibrated RF model was then applied to predict the possible impact of climatic change on wine regions.

Since the RF algorithm should be preferably trained using a similar amount of test cases and considering that our dataset is highly unbalanced towards areas not covered with grapevine (94% of the country) we trained RF algorithm in two sequential steps. In the first stage RF was trained to identify the areas suitable for grapevine cultivation, using the vineyards layer as binary response variable (1=presence, 0=absence). As a second step, RF model was trained to discriminate amongst different wine regions and applied to those pixels which were classified as part of grapevine cultivated area.

In the first case, a preliminary test was initially performed to identify the errors associated to different type of training dataset. Selecting the presence-absence values from the whole country – not considering the unbalanced dataset –, the OOB error is low (around 4.3%), but the classification error of the vineyards is very high (more than 50%). Performing a calibration/validation process in this case (80% for calibration and 20% for validation), only 0.2% misclassification can be seen, but the ratio of the vineyard pixels (due to the unbalanced sample) is very low and this can lead to a false evaluation. As the most commonly used classification algorithms, in fact, RF aims to minimize the overall error rate rather than paying special attention to the minority class. In other terms, RF may result in a very good prediction accuracy even misclassifying all the test cases of the minority class.

Using a dataset with almost the same number of pixels belonging to cultivated and not cultivated grapevine areas, the OOB error is slightly increasing, but the classification error decreases.

As a final solution grapevine areas were sampled with all of the CORINE vineyard pixels (9081 pixels), while the non-cultivated areas were sampled with almost the same number of pixels randomly selected within the boundaries of the country, but outside of the wine regions (using the *sample* function the probability of selecting the pixels was set to 7.7% of the 117822 pixels, resulting samples between 8937 and 9211 pixels).

As the different runs of the model – based on randomly selected samples – give slightly different results, five runs were iterated in both present (1950-2000) and future time slices (2021-2050 and 2071-2100), where the most frequently predicted value was accepted.

Results

Model calibration and validation

Grapevine cultivated area

RF was firstly trained to identify the areas suitable for grapevine cultivation on national scale by selecting almost the same number of pixels for grapevine presence and absence (vineyards and no-vineyard areas). Pixels where grapevine is cultivated were sampled with the CORINE vineyards, pixels where grapevine is not cultivated were selected within the boundaries of Hungary, but outside of the wine region areas. Performing a calibration/validation process for this sample set, the validation showed total agreement with the original presence-absence values.

The RF internal validation resulted into a rather satisfying OOB error (9.4%) where the classification error was always higher in case of the no-vineyards (around 11%). Owing these results, the calibrated RF model was considered robust and coherent and applied to the relevant predictor variables calculated for the 2021-2050 and 2071-2100 time slices to derive the grapevine cultivated areas.

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WAT_def, *T_Jan*, *T_year*, *HI* and *CI* were the parameters having the major importance to predict the presence of grapevine, while *T_Jul*, *BEDD*, *WIN* and *T_avg* were those having the lowest impact for the prediction (*Fig. 2*).

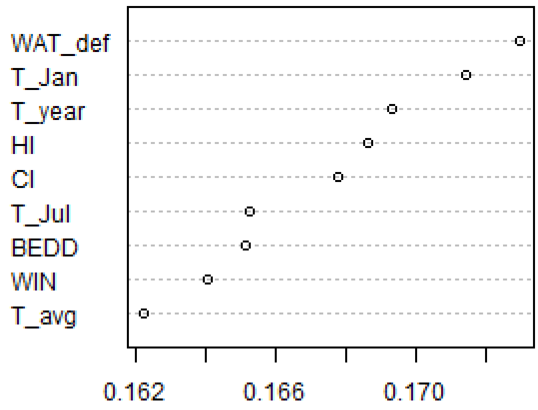

Figure 2. *Variable importance based on the mean decrease accuracy in case of vineyard and no-vineyard areas*

Analysing the 22 wine regions

A second RF model was calibrated to discriminate the 22 Hungarian wine regions.

The result showed nearly complete classification accuracy with an OOB of 6.36% (average of the five runs) during the calibration stage. The highest misclassification can be found in Badacsonyi and Balaton-felvidéki wine regions, which are neighbours, and in case of the Nagy-Somlói wine region, which has the fewest pixels (class errors averaged for the five runs were 22, 23 and 21%, respectively). In the validation test, dataset was randomly split into 80% and 20% of the total cases, which were used to calibrate and validate RF, respectively. The prediction showed almost total agreement with the original regions.

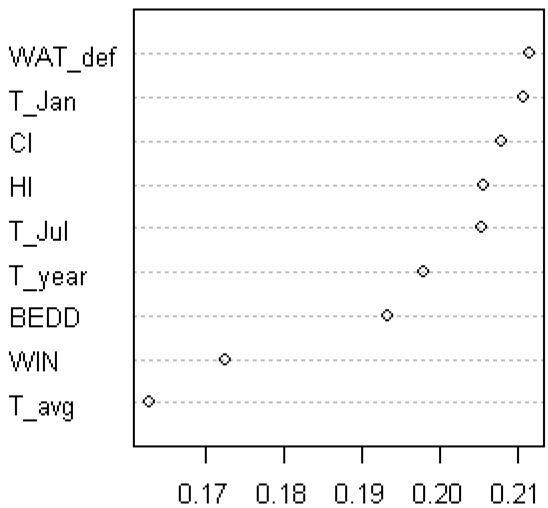

Figure 3. *Variable importance based on the mean decrease accuracy in case of the 22 wine regions*

WAT_def and *T_Jan* proved to be the most important. The cool night index (*CI*), Huglin index (*HI*) and maximum temperature of July (*T_Jul*) have similar importance values, and their relative rank varied depending on the random samples (*Fig. 3*).

The box-plots of the first three important variables may be used to represent the main climatic differences among the wine regions. The whiskers extend to the most extreme data point which is no more than 1.5 times the interquartile range from the box.

The water deficit values (*Fig. 4*) show high variability among the wine regions, but also within the regions. The lowest values can be observed in the western part of the country, in Zalai (10) and Soproni (5) wine regions, while the highest deficit is in Móri (3) wine region.

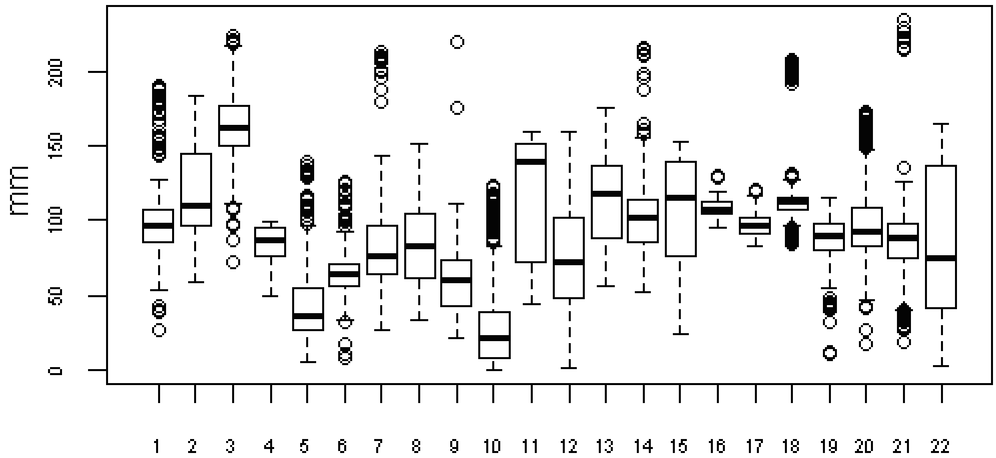

Figure 4. *Box-plots of the water deficit (WAT_def) values in the 22 wine regions 1 Neszmélyi, 2Etyek-Budai, 3Móri, 4 Pannonhalmi, 5 Soproni, 6 Badacsonyi, 7 Balatonfüred-Csopaki, 8 Balaton-felvidéki, 9 Balatonboglári, 10 Zalai, 11 Nagy-Somlói, 12 Pécsi, 13 Szekszárdi, 14 Tolnai, 15 Villányi, 16 Csongrádi, 17 Hajós-Bajai, 18 Kunsági, 19 Bükki, 20 Egri, 21 Mátrai, 22 Tokaji*

Based on the minimum temperature in January (*Fig. 5*) the regions in the northern part of the country (Bükki (19), Egri (20), Mátrai (21) and Tokaji (22)) are very different, the regions in the middle and southern part of the country can form another group, and the regions in the western part can be separated, too.

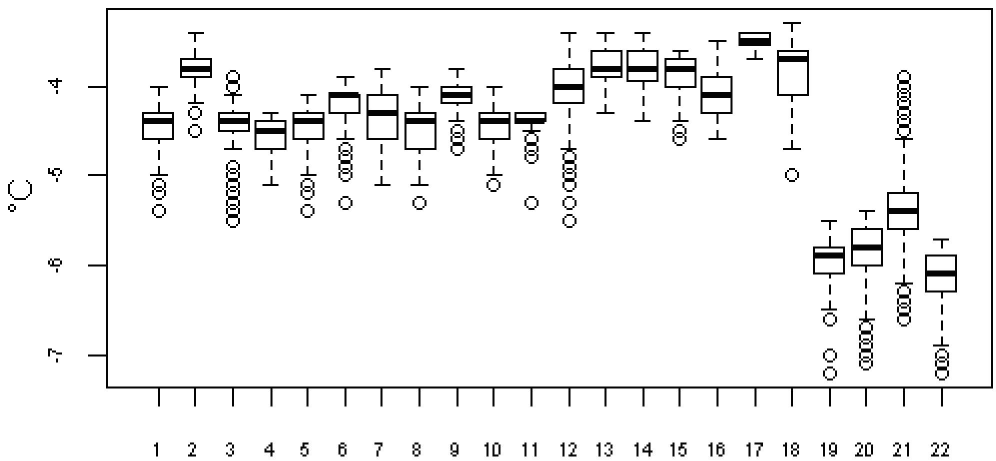

Figure 5. *Box-plots of the min. temperature in January (T_Jan) in the 22 wine regions (region names see at Fig. 4)*

The regions in the northern part of the country are very different from the others also based on the cool night index (*Fig. 6*), but in this case Soproni (5) wine region is very similar to them. The regions in the middle and southern part of the country show the highest temperature, while among the remaining regions in the western part of the country there is still variability.

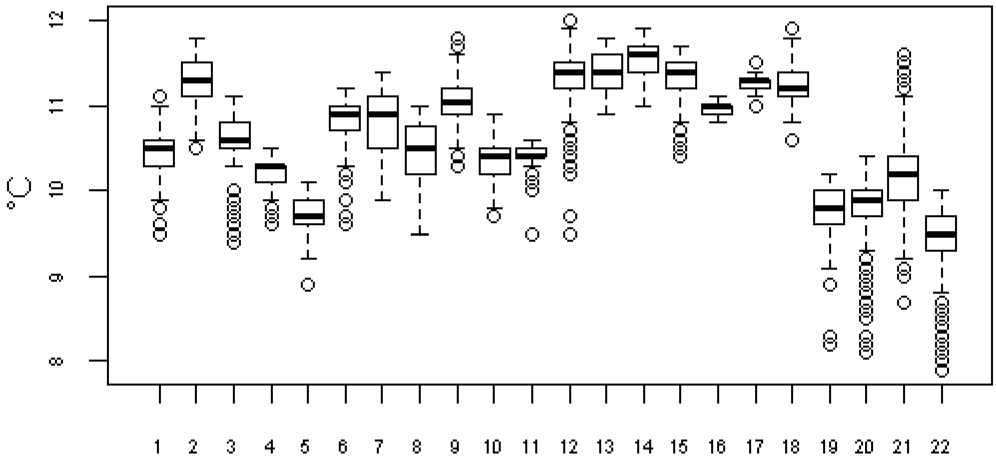

Figure 6. *Box-plots of cool nigth index (CI) values in the 22 wine regions (region names see at Fig. 4)*

To reveal the climatic structure of the wine regions Principal Component Analysis (PCA) was performed over the indexes averaged per wine regions. The first two components explain the 92.3% of the entire variability.

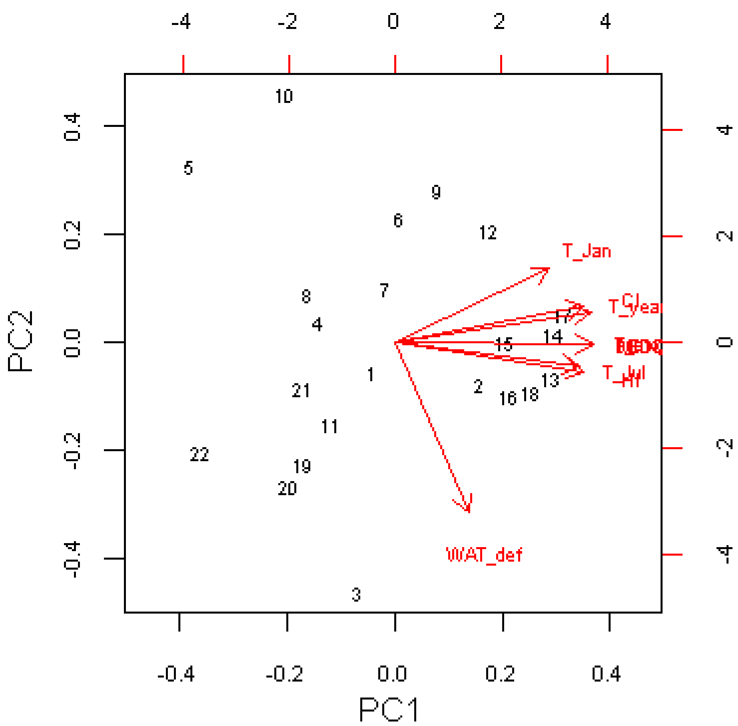

Figure 7. *Principal Component Analysis for the wine regions (region names see at Fig. 4)*

The plot of the factor scores of PC1 and PC2 (*Fig. 7*) shows that the first component (PC1) is positively correlated to all the predictor variables, but the most important ones are the temperature related indices of the growing season (*T_avg, WIN* and *BEDD*).

The warmer regions in the southern and middle part of the country have positive values, while the cooler regions located in the western and east part of the country have negative values.

The second component is determined by the negative effect of water deficit (*WAT_def*) and is positively correlated with the minimum temperature in January (*T_Jan*). Along this axis the outliers are Zalai (10) and Soproni (5) wine regions, where the water deficit is the lowest (compare with *Fig. 4*) as well as Móri (3) wine region with the highest deficit. The effect of *T_Jan* appears as a more or less diagonal arrangement in the figure, therefore regions with the lowest minimum temperature values in January can be found in the lower left part.

Prediction

Grapevine areas

The presence of grapevine cultivated areas was correctly predicted on national scale, considering that the model simulates a potential area (i.e. may include areas that are viable for cultivation) and that the predicted area is in any case included within the limits of wine regions. Additionally, the RF model correctly predicted the presence of grapevine areas outside the Hungarian boundaries (*Fig. 8b*), even though these regions were not considered in the calibration process.

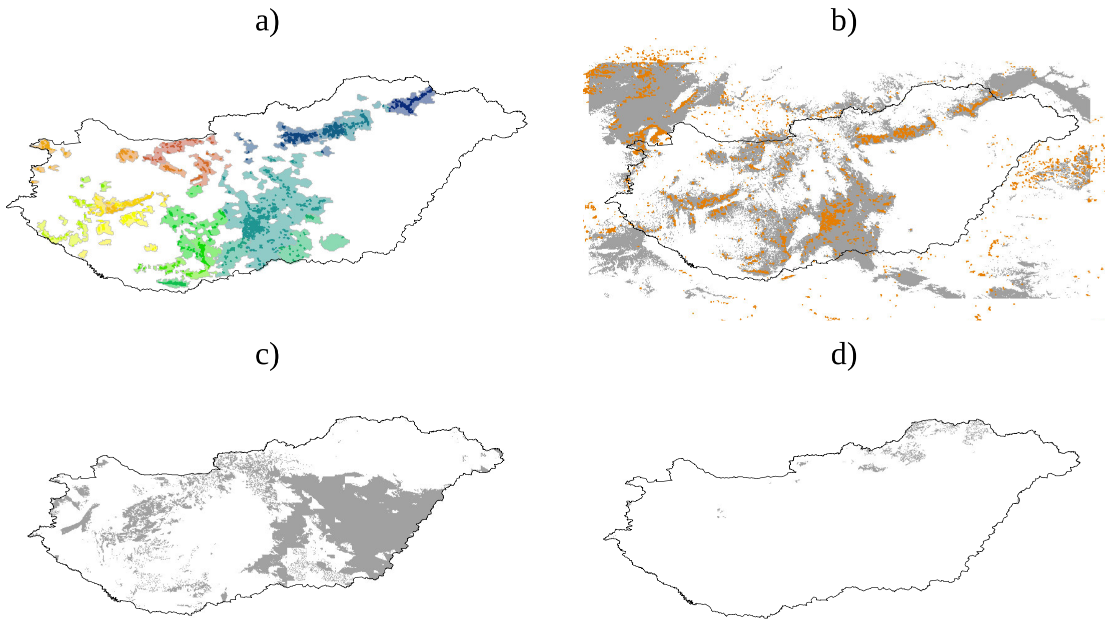

Figure 8. *The present Hungarian wine regions and vineyards (a – for more details see Fig. 1), and the similar grapevine areas (with grey) based on the RF classification in the present (b), 2021-2050 (c) and 2071-2100 (d). In the prediction for the present the orange pixels show the CORINE vineyard areas*

Prediction for the near future (2021-2050) shows a general shift towards the Great Plain (north-east). Surprising result is that in this time slice the simulation does not show any similarity with the present conditions in the north part, e.g. in the famous Tokaji wine region.

At the end of the century (2071-2100) we can hardly find areas similar to the present ones. These areas can be found only in the north part of the country, in accordance with the general geographical shift of the growing areas do to warming (*Fig. 8c and d*).

Predicted wine region types

In the second step, RF was used to predict the presence of specific wine regions within the predicted grapevine cultivated areas (*Fig. 9*).

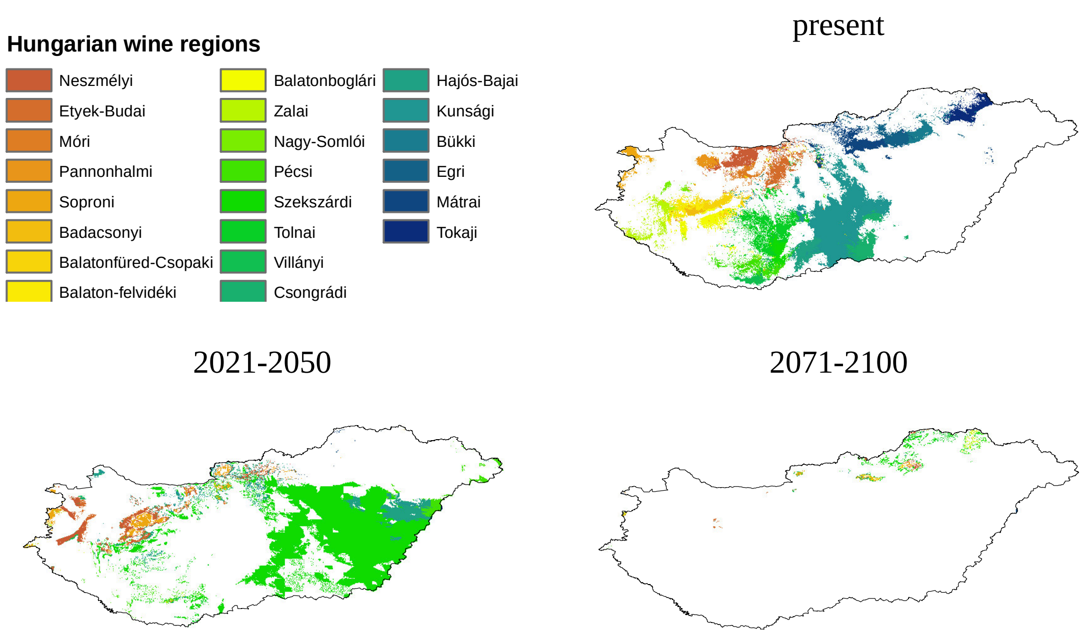

Figure 9. *Predicted wine region types for the potential areas*

For the present period, as expected, RF correctly simulated the placement of each wine region. In the period of 2021-2050 most of the predicted regions become similar to Szekszárdi and Hajós-Bajai wine regions, which are the warmest regions at present. In the Trans-Danubian area similarities with Neszmélyi and Soproni wine regions can be found.

In the period of 2071-2100 there would be a very little area similar to the present ones, and also the correspondence is not really defined, there is a mixed situation. There are similarities with Szekszárdi, Badacsonyi, Neszmélyi, Soproni, Balatonboglári and Zalai wine regions – at present located in the south and western part of the country – so a north-east shift can be observed.

Possible land use changes

At the moment, only a few areas where grapevine is predicted to shift are invested in viticulture. Therefore the possible changes in agricultural land use were examined considering the new areas viable for viticulture in future time slices.

Fig. 10 shows the present agricultural land use types of the predicted grapevine areas, and *Table 2* summarizes it. It can be seen, that the ratio of the vineyards in the predicted areas is only 2.4% and 3.4% in the two periods, respectively. The greatest part of the predicted areas – especially in the Great Plain in the near future – is out of the wine regions and the present land use type is non-irrigated arable land or pastures.

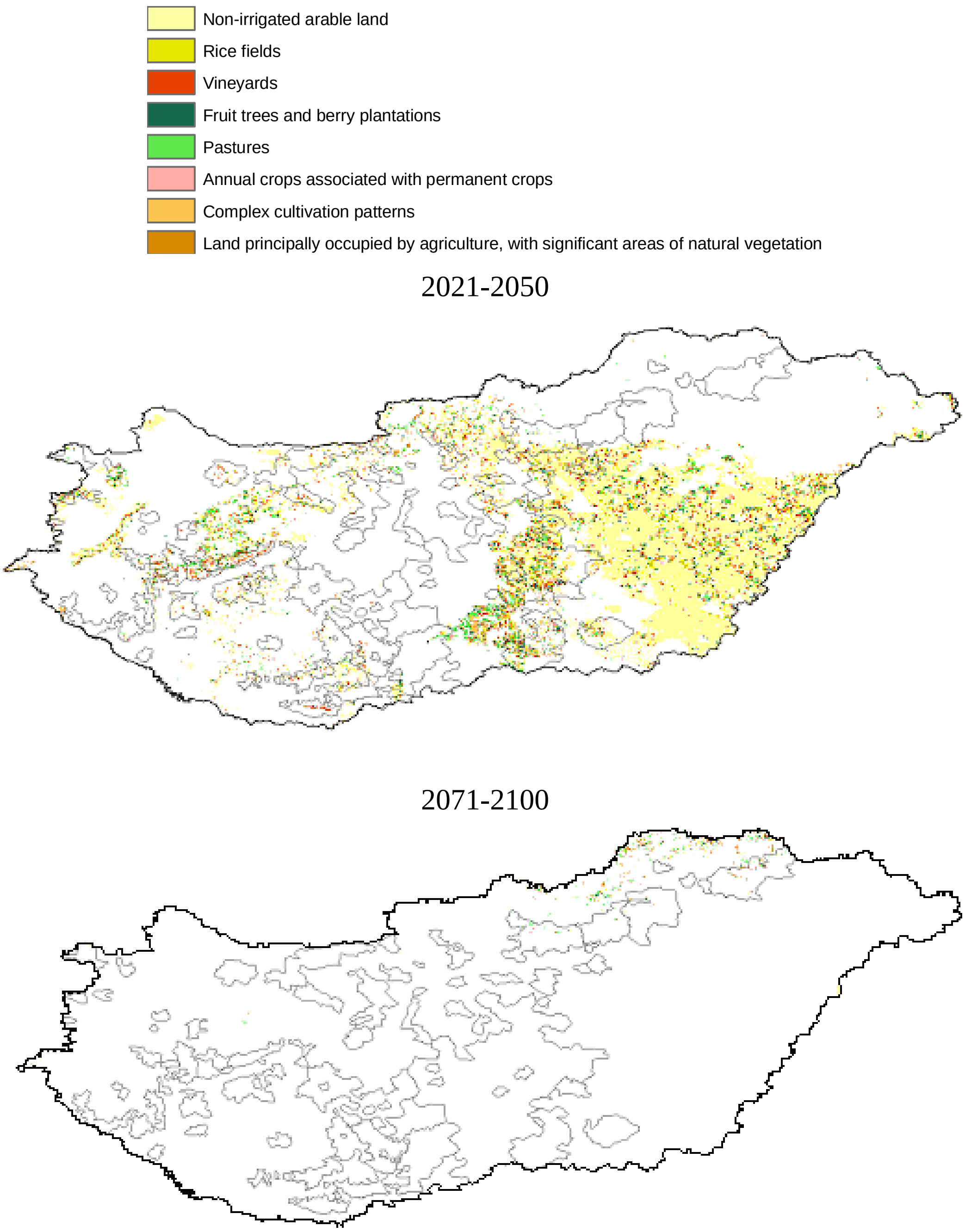

***Figure 10.** The present agricultural land use types of the predicted grapevine areas*

Table 2. *The present agricultural land use types in the predicted grapevine areas*

Present land use type	% in the predicted area 2021-2050	% in the predicted area 2071-2100
Non-irrigated arable land	74.6	67.4
Rice fields	0.3	0
Vineyards	2.4	3.4
Fruit trees and berry plantations	0.8	1.0
Pastures	10.3	10.8
Annual crops associated with permanent crops	-	-
Complex cultivation patterns	6.5	9.1
Land principally occupied by agriculture, with significant areas of natural vegetation	5.1	8.4

The borders of the present wine regions are defined by the Hungarian wine law. One of the adaptation strategies should be the modification of the borders, the other one the modification of the land use structure within the borders of the regions. *Table 3* shows the ratio of the agricultural areas predicted for viticulture compared to the area of the wine regions, as well as the present ratio of the vineyards. According to the data in some regions the expansion of the grapevine areas should be expected in the near future (2021-2050), e.g. Móri, Soproni, Badacsonyi, Balaton-felvidéki, Csongrádi, Kunsági and Mátrai. Some regions, e.g. Szekszárdi and Villányi (which are among the warmest regions), can lose grapevine areas or have to cultivate varieties that are different from the ones at present.

As it was presented earlier, in the period of 2071-2100 there would be a very little area similar to the present ones. From that we can find some parts in the northern wine regions (Bükki, Egri, Mátrai and Tokaji), but the agricultural land use type in the predicted areas is negligible compared to the present vineyards area.

Table 3. *The area of the present vineyards and the agricultural lands predicted viable for viticulture compared to the area of the wine regions (based on the CORINE 2006 database)*

Wine region	Present (%)	2021-2050 (%)	2071-2100 (%)
Neszmélyi	3.93	11.25	0.00
Etyek-Budai	5.09	3.60	0.00
Móri	5.10	21.46	0.00
Pannonhalmi	5.53	5.00	0.00
Soproni	6.96	15.07	0.00
Badacsonyi	19.08	29.95	0.00
Balatonfüred-Csopaki	17.23	21.79	0.00
Balaton-felvidéki	6.57	12.30	0.00
Balatonboglári	5.70	6.46	0.00
Zalai	4.73	4.14	0.00
Nagy-Somlói	5.74	1.22	0.00
Pécsi	4.98	6.13	0.00
Szekszárdi	6.20	3.25	0.00
Tolnai	2.64	1.30	0.00
Villányi	13.05	3.39	0.00
Csongrádi	2.12	29.32	0.00
Hajós-Bajai	2.91	4.62	0.00
Kunsági	5.10	26.3	0.00
Bükki	4.67	1.30	0.03
Egri	13.96	2.93	0.01
Mátrai	8.86	26.85	0.05
Tokaji	9.57	0.00	0.23

Expected changes based on the climatic indices

The climatic classification of the grapevine areas is usually done based on the average growing season temperature *(Fig. 11* and *Table 4*) and the Huglin index *(Fig. 12* and *Table 5*). Both parameters indicate that the wine regions are expected to be warmer with usually one category for each period.

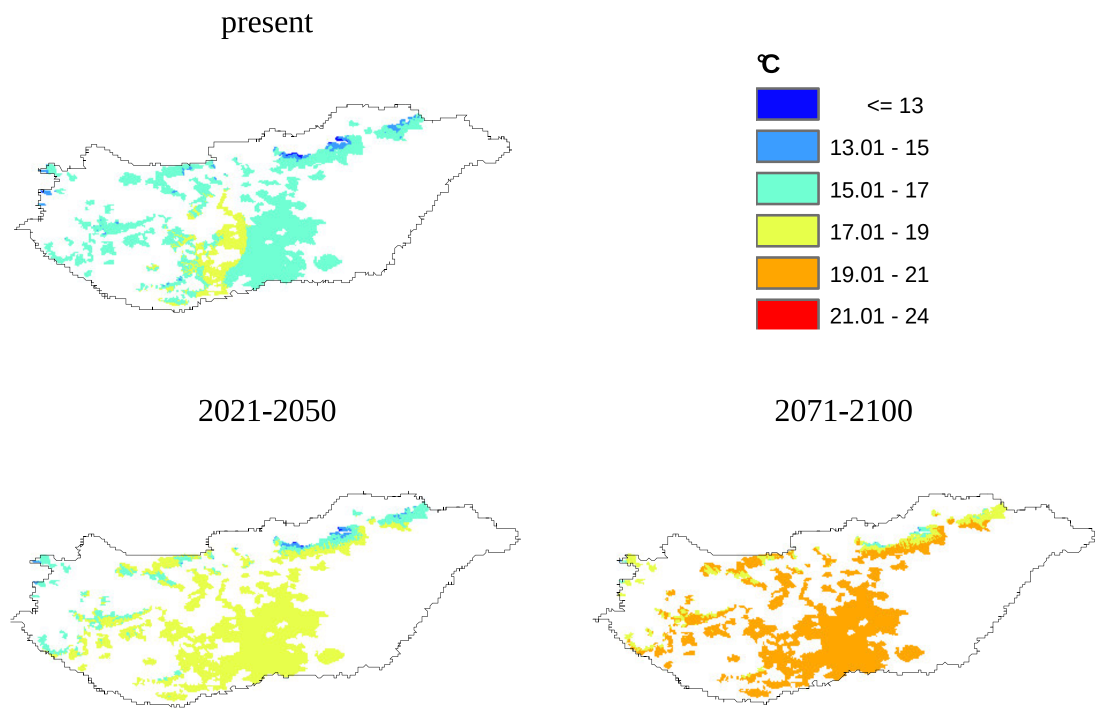

Figure 11. *Average growing season temperature in the periods examined*

Table 4. *Average growing season temperature (Apr-Oct) regarding grapevine maturity (source: Jones et al., 2010)*

Temperature (°C)	Climate group
< 13	too cool
13 - 15	cool
15 - 17	intermediate
17 - 19	warm
19 - 21	hot
21 - 24	very hot
24 <	too hot

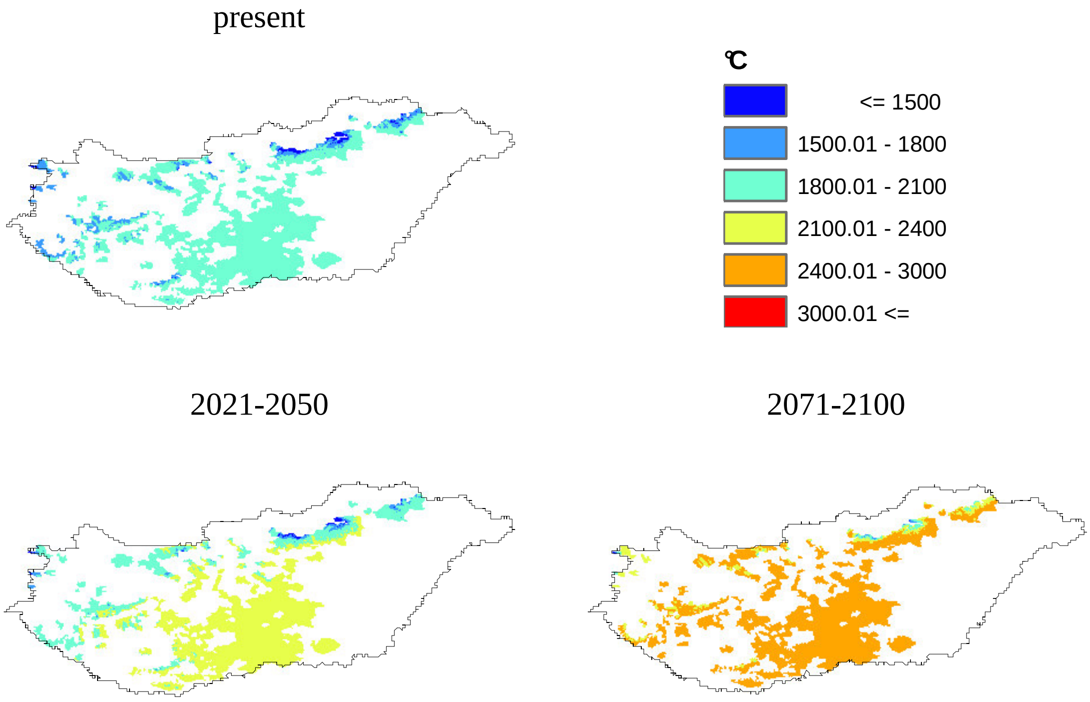

Figure 12. *Huglin Index values in the periods examined*

Table 5. *Groups of site types according to their Huglin Index (source: Tonietto and Carbonneau, 2004)*

Huglin Index (°C)	Class name
HI ≤ 1500	very cool
1500 < HI ≤ 1800	cool
1800 < HI ≤ 2100	temperate
2100 < HI ≤ 2400	warm temperate
2400 < HI ≤ 3000	warm to very warm
3000 < HI	hot

These maps are in accordance with the formerly presented results of the RF predictions, and confirm that in the period of 2021-2050 the greatest similarity would be with the present southern regions (e.g. Szekszárdi wine region), and in the period of 2071-2100 only in the northern part of the country can be found areas similar to the present climatic conditions.

In the areas – first of all in the south part of the country – where the RF classification does not predict areas similar to the present ones, growers must prepare to apply new varieties and/or agrotechnics in the future. However, these regions remain suitable for quality grapevine growing. The "too hot" category is not expected to appear in the country, even at the end of the century.

Discussion

In this paper a set of widely used viticultural climatic indices were used to analyse the spatial distribution of the Hungarian wine regions. This process was performed by Random Forest, a machine learning approach, which has been demonstrated to be one of the most promising techniques for ecological classification (Cutler et al., 2007; Moriondo et al., 2008, Evans et al., 2011). This approach allowed identifying the potential shift/contraction of the wine regions according to the expected climate change.

In the first step RF was trained to identify the areas suitable for grapevine cultivation, using the present vineyards data as binary response variable (1=presence, 0=absence). This analysis resulted into a rather satisfying OOB error (9.4%), therefore the calibrated RF model was considered robust and coherent and applied to the relevant predictor variables calculated for the 2021-2050 and 2071-2100 time slices to derive the potential grapevine cultivated areas.

In the second step, RF was trained to discriminate amongst the different wine regions. The result showed nearly complete classification accuracy with an OOB of 6.36%. The highest misclassification can be found in some neighbouring regions, and in case of the Nagy-Somlói wine region, which has the fewest pixels. This problem of the imbalanced response variables is mentioned by Evans et al. (2011), too.

The analysis of the variable importance indicated that water deficit (*WAT_def*) was the most important variable in the classification process, and this may be related to the high degree of information of this index, which depends on day length, average temperature and cumulated rainfall during the growing season, soil depth and texture. Minimum temperature of January (*T_Jan*) proved to be the second more important. The reason of it should be the significantly cooler values of the regions in the north part of the country (regions 19-22), and the warmer areas in the south and middle part (regions 12-18) compared to the others (*Fig. 5*). The cool night index (*CI*), Huglin index (*HI*) and maximum temperature of July (*T_Jul*) have similar importance values. In case of the *CI* the regions in the northern part, while in case of the *HI* and *T_Jul* the regions in the south and middle part (the warmer parts of the country) show great differences compared to the others.

Huglin Index proved to be a better predictor than the other similar climatic indexes (*WIN, BEDD, T_avg*) calculated for the growing season. This may be related to the additional information included in this index such as the mean day length in relation to the latitude, second to the fact that the calculation of the thermal component is estimated over the mean day length when most of metabolisms are active. The same result was found by Moriondo et al. (in progress) analysing the European wine regions.

Results show that in the near future (2021-2050) the present climatic conditions of the southern regions can be expected in greater part of the country. Some regions may benefit from the changes, as in their area there are predicted grapevine areas with other agricultural land use types, which may be changed. However, at the end of the century (2071-2100) only in the northern part of the country shows some similarities with the present climate. Despite it, Hungary is expected to remain amongst the regions with good quality grapevine growing conditions, but the structure of the cultivation and/or varieties should be changed. These changes were demonstrated also with the average growing season temperature and Huglin Index values (*Fig. 11 and 12*). Both parameters indicate that the wine regions are expected to be warmer with usually one category for each period.

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Appendix

Calculation of the indices

Winkler Index (WIN)

The Winkler Index (Winkler, 1938) was introduced to identify the most suitable cultivars for a region. Winkler index is calculated as Growing Degree Days (GDD) between April and October, where daily degree days is given by the difference between mean daily temperature and 10°C when Tmean >10 °C.

Biologically Effective Day Degrees / Gladstone index (BEDD)

The Biologically Effective Day Degrees (Gladstones, 1992) is a bio-climatic index commonly used for the assessment of the climatic suitability of certain areas for the grapevine cultivation. The BEDD is the same as the GDD process described above, only with the additional constraint that there is an upper limit to the accumulation of degree days. It is based on daily average temperature with a 19°C upper cut-off.

Huglin Index (HI)

The Huglin Index, also called Heliothermal Index (Huglin, 1978) was introduced to classify the different viticultural regions of the world in relation to the heliothermal conditions during the grape growth period. The index is calculated as the sum of daily mean and maximum temperature above +10°C from 1st April to 30th September (1st October to 31st March in the Southern Hemisphere). A coefficient takes into account for the mean day length in relation to the latitude ranging from 1.02 to 1.06 between 40° and 50°.

Cool Night Index (CI)

The Cool Night Index (CI) aims at improving the assessment of the qualitative potential of a suitable region by providing a measure of the coolness of the nights during the ripening period. It is based on the observation that warm night conditions are detrimental from a qualitative point of view (e.g. loss of aromas, lesser coloration in the red varieties) (Tonietto and Carbonneau, 2004). The index is the monthly average minimum temperature in September (Northern Hemisphere) or March (Southern Hemisphere).

Water deficit (WAT_def)

The water-balance model used in this work uses a monthly accounting procedure to analyses the allocation of water among various components of the hydrologic system and it is fully described in McCabe and Markstrom (2007).

The spatial mean monthly temperature (T, °C), monthly total precipitation (P, mm), and latitude (°, used for the computation of day length), were used for the computation of potential evapotranspiration (PET). Actual evapotranspiration (AET) was then derived from PET, P, moisture storage in the soil (ST, mm), and soil-moisture storage withdrawal (STW, mm). Monthly PET was estimated from T according to the Hamon equation (Hamon, 1961):

$$PET = 13.97 \times d \times D^2 \times Wt$$

where PET is expressed in millimeters per month, d is the number of days in a month, D is the mean monthly hours of daylight in units of 12 hrs, and W*t* is a saturated water vapor density term, in grams per cubic meter, calculated by:

$$Wt = (4.95 \times e^{0.062 \times T})/100$$

When P for a month is less then PET, then AET is equal to P plus the amount of soil moisture that can be withdrawn from storage in the soil. Soil-moisture storage withdrawal linearly decreases with decreasing ST such that as the soil becomes drier, water becomes more difficult to remove from the soil and less is available for AET. STW was computed as follows:

$$STW = ST_{i-1} - [abs(Ptotal - PET) \times ST_{i-1}/STC]$$

where ST_{i-1} is the soil-moisture storage for the previous month and STC is the soil-moisture storage capacity, which was derived on a spatial resolution coherent to the framework (i.e. 1km x 1 km) from the Harmonized World Soil Database (FAO/IIASA/ISRIC/ISS-CAS/JRC, 2009) as a function of soil texture and depth. Monthly water deficit was then calculated as PET–AET when the sum of P and STW was less than PET and summed up over the entire year (*WAT_def*).

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METHODS OF MODELLING THE FUTURE SHIFT OF THE SO CALLED MOESZ-LINE

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Abstract. It is important to the landscape architects to become acquainted with the results of the regional climate models so they can adapt to the warmer and more arid future climate. Modelling the potential distribution area of certain plants, which was the theme of our former research, can be a convenient method to visualize the effects of the climate change. A similar but slightly better method is modelling the Moesz-line, which gives information on distribution and usability of numerous plants simultaneously. Our aim is to display the results on maps and compare the different modelling methods (Line modelling, Distribution modelling, Isotherm modelling). The results are spectacular and meet our expectations: according to two of the three tested methods the Moesz-line will shift from South Slovakia to Central Poland in the next 60 years.
Keywords: *Gusztáv Moesz, climate change, GIS, distributional range, climate shift*

Introduction

Gusztáv Moesz (1873-1946) was a botanist, mycologist and museologist who obtained an international reputation by his mycology researches. The most important observation for the Central-European botany and landscape architecture he made was published more than 100 years ago. He discovered that certain plants share a common northern distribution border and this coincides with the line of vine cultivation (Moesz, 1911). This line lying in the Northern Carpathians is named after him. The old maps (*Fig. 1* and *Fig. 2*) primarily have a historical importance. Subordinately, the map showed in *Fig. 1* is the most accurate source of the distributions used in this research. *Fig. 2* shows the Moesz-line updated by the author.

The predicted shift of the Moesz-line in the 21st century and the research methods are summarized in this paper. Our preliminary expectation was that the Moesz-line will shift towards Poland in two nearly equal steps in the modelled future periods of 2011-2040 and 2041-2070.

Figure 1. *'Northern border of the distribution of some plant species in the Northwest Highlands'. The map of the distribution of 12 taxa and the vine cultivation area with the former frontier of the country and hydrography (Moesz, 1911; with some retouching).*

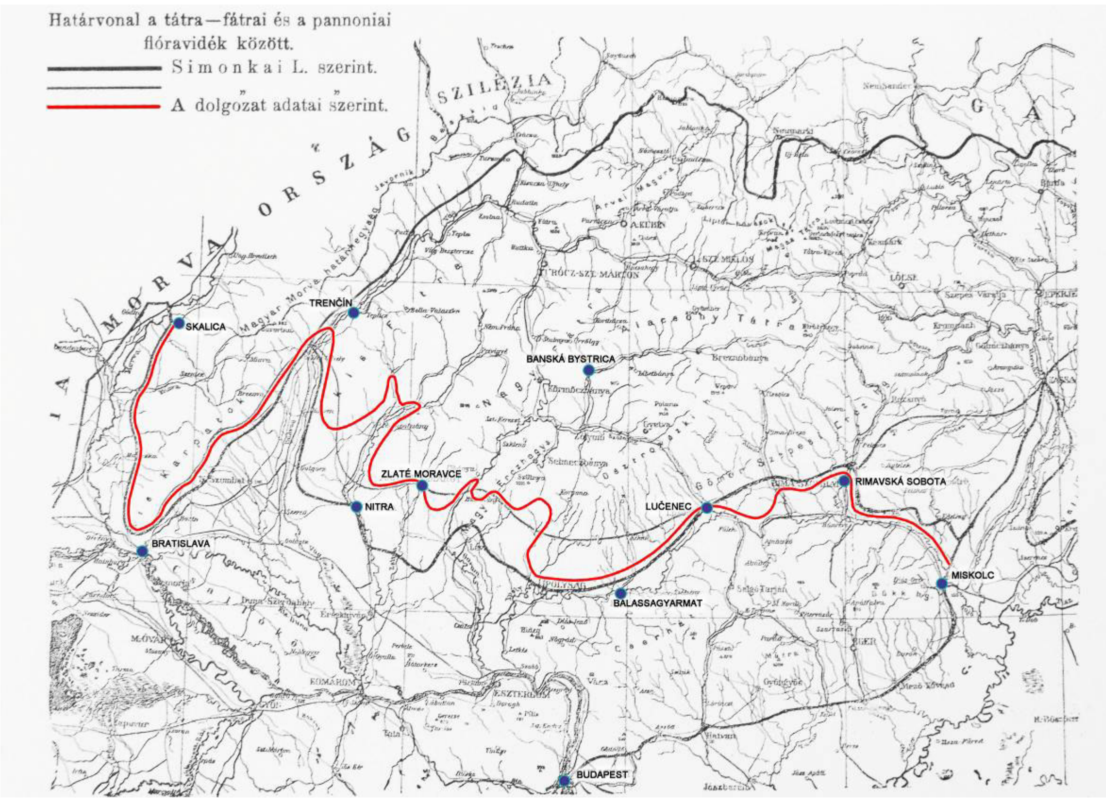

Figure 2. *'Border line between the Tatra-Fatra and the Pannonian floristic region' in a hydrographic chart. The line drawn by Moesz is the red one (Moesz, 1911; retouched and updated by the author).*

Review of literature

The importance of the Moesz-line on botany and landscape architecture

The Moesz-line is hardly ever used in international scientific publications due to its local importance. However, extending the northern line of vine cultivation towards East and West, one can obtain the extension of the Moesz-line, which will be corresponding to the northern distribution border of some other species such as Grape Hyacinth (*Muscari botryoides* (L.) Mill.; Somlyay, 2003), too. The Moesz-line modelling is important for the entire Continent because it is illustrative for the indigenous and ornamental plants not only of the Carpathian Basin.

Originally Moesz included 12 wild plants and the cultivated grapevine (*Vitis vinifera* L.) in his research. *Table 1* shows the originally used and the accepted scientific names of the observed plans and the sources of the distributional maps (Moesz, 1911; Meusel et al., 1965; Meusel et al., 1978; Meusel and Jäger, 1992; Tutin et al., 1964; EUFORGEN, 2009). Species used as ornamental plants in Hungary are highlighted (Bede-Fazekas and Gerzson, 2011).

Table 1. *The list of the 12+1 species originally used for drawing the Moesz-line with the sources of the distribution maps used in our research. The species used as ornamental plants in Hungary are highlighted. Accepted scientific names are according to GRIN (2012), supported by IPNI (2005) and Priszter (1998).*

Scientific name used by Gusztáv Moesz	Accepted scientific name	Source of distribution map of species
Aira capillaria	*Aira elegantissima* Schur	Moesz, 1911 (Meusel, 1965)
Althaea micrantha	***Althaea officinalis* L.**	Moesz, 1911 (Meusel, 1978)
Cephalaria transsilvanica	*Cephalaria transsylvanica* (L.) Roem. & Schult.	Moesz, 1911
Clematis integrifolia	***Clematis integrifolia* L.**	Moesz, 1911 (Tutin et al., 1964)
Eryngium planum	***Eryngium planum* L.**	Moesz, 1911
Euphorbia gerardiana	*Euphorbia seguieriana* Neck.	Moesz, 1911 (Meusel, 1978)
Galega officinalis	***Galega officinalis* L.**	Moesz, 1911
Galium pedemontanum	*Cruciata pedemontana* (Bellardi) Ehrend.	Moesz, 1911
Phlomis tuberosa	***Phlomis tuberosa* L.**	Moesz, 1911 (Meusel, 1978)
Salvia aethiopis	*Salvia aethiopis* L.	Moesz, 1911
Sideritis montana	***Sideritis montana* L.**	Moesz, 1911
Xeranthemum annuum	*Xeranthemum annuum* L.	Meusel, 1992 (Moesz, 1911)
Vitis vinifera	*Vitis vinifera* L.	Moesz, 1911 (area of cultivation)

The importance of Moesz-line is, for the landscape architecture, beyond the investigation of the original 12 species. It plays an important role in agriculture by determining the cultivation area of vine. Moreover, Moesz-line also demonstrates the northern border of the spread of some important species that have been added later to this concept. Among these are the Bladder Senna (*Colutea arborescens* L.; Csiky, 2003), Chestnut (*Castanea sativa* Mill.; Bartha, 2007), Pubescent Oak (*Quercus pubescens* Willd.; Csapody, 1932; Kárpáti, 1958; Kézdy, 2001; Bartha, 2002), Service Tree (*Sorbus domestica* L.; Végvári, 2000), and some pear species (Terpó, 1992). *Table 2* lists the species that have their distribution border near to the Moesz-line. Species having a key role in landscape planning are highlighted. *Table 2* contains the source of the distribution maps, too.

Table 2. *List of the taxa with distribution bound to the Moesz-line. Species having importance in landscape architecture are highlighted. Scientific names are according to GRIN (2012), supported by IPNI (2005).*

Scientific name	Source of distribution map of species
***Acer tataricum* L.**	**-**
***Castanea sativa* Mill.**	EUFORGEN, 2009 (area of cultivation)
***Colutea arborescens* L.**	-
***Cotinus coggygria* Scop.**	Meusel, 1978
***Fraxinus ornus* L.**	Meusel, 1978
Muscari botryoides (L.) Mill.	-
Orchis simia Lam.	-
***Prunus mahaleb* L.**	-
Pyrus magyarica Terpó	-
Pyrus × *nivalis* Jacq.	-
Pyrus × *pannonica* Terpó	-
Pyrus slavonica Kit.	-
***Quercus cerris* L.**	Meusel, 1965
***Quercus pubescens* Willd.**	-
***Sorbus domestica* L.**	-
Vicia sparsiflora Ten.	-
Vitis sylvestris C. C. Gmel.	Meusel, 1978

Visualization of the climate change and ecological modelling

According to the regional climate models the Carpathian Basin will become warmer and drier in the next century, and the extreme precipitations will occur more frequently during the hotter period of the year (Bartholy and Pongrácz, 2008). This will bring a challenging situation for the landscape designers who will have to face and have to be prepared to deal with this issue well in advance. The landscape designers can slightly change the climate (primarily the microclimate), chiefly they can adapt to it so proper adaptation has to be emphasized. To implement the best adaptation policy it is essential to get to know the expected climate of a future period. It is important in case of the landscape designing, horticulture and dendrology, to know the expected natural vegetation and adaptable ornamental plants.

In case of trees the development and growing period can be up to 30 years, so it is high time to address this issue with some easy-to-understand but effective visualization for expected future climate (Sheppard, 2005). In our research the shift of the climate is modelled with the visualization of the predicted Moesz-line. It can serve as an alternative for the modelling of geographically analogous regions (Horváth, 2008). It is necessary to stress that the shift of the Moesz-line primarily affects the Slovakian and Polish landscape architecture by direct means. However, the experiences of the Hungarian landscape architecture, dendrology and ornamental plant usage can help these countries to adapt to the changing climate. Thus, it is the task of our profession to collect and hand over the accumulated knowledge base.

We are unaware of any former ecological modelling research that can be bound to the Moesz-line. However, there are some publications that have similarities to the current research: either in the methodology or in the results. In the Central European region the impacts of the climate change on the distribution of the Sessile Oak was discussed by Czúcz et al. (2011). The distribution of the European Beech was researched by Führer and Mátyás (2006). Czúcz (2010) gives a full synopsis of the impacts of climate change on the Hungarian natural habitats. Bede-Fazekas (2011) modelled the distribution of some Mediterranean species that can have ornamental importance in Hungary in the future. There are some other researches beyond the Central European region. Leng et al. (2008) modelled the distribution of Dahurian Larch, Korean Larch and Prince Rupprecht Larch according to three different climate scenarios. Iverson and Prasad (1998) predicted the abundance of 80 species of the United States. Sabaté et al. (2002) modelled the distribution of five different species in the Mediterranean region according to the HadCM2 model. Iverson et al. (1999) researched the predicted distribution of Virginia Pine under two scenarios of climate change. Bakkenes et al. (2006) made a comparison of the modelling results of different climate scenarios. Rotenberry et al. (2006) illustrates his ecological niche modelling approach with the distribution of California Gnatcatcher. Our research has some essential resemblance to Rotenberry's research, for example in the use of the limiting factors. Guisan and Zimmermann (2000) give a good summary of different ecological modelling methods. Thuiller et al. (2008) points some imperfections of the widely used ecological models. There are some modelling softwares and mellow methods (Carpenter et al., 1993; Pearson et al., 2002; Li et al., 2008) developed for such modelling purposes. The enumeration is, however, not complete, ecological modelling has much wider range of literature.

Materials and methods

Methods of modelling

The expected shift of the Moesz-line can be modelled in numerous ways. In our research three methods were applied. *Table 3* summarizes the characteristics of the methods and shows their advantages and disadvantages.

Table 3. *Methods of the Moesz-line modelling used in our research with their advantages and disadvantages. The quickness of a certain method has an importance if the research is repeated (with other meteorological input or with refined sub-methods) or tested on other subject.*

Name	Description	Advantages	Disadvantages
Line modelling	Modelling the shift of the Moesz-line as the northern border of a fictive distribution	Less accurate clear, evident	Relatively slow
Distribution modelling	Modelling the shift of the distribution of plants bound to the Moesz-line and then redrawing the future line	Follows the original method of Moesz (draws the line on the basis of the area of plant species) Has a detailed result (the drawn map shows not only the Moesz-line, but the distribution of separate species too)	Very slow Subjective
Isotherm modelling	Modelling the shift of the minimum temperature isotherm of January (winter months) correlates with the Moesz-line	Fastest of the three method There is no need for digitalizing distributions	Takes only one (or a few) climatic parameter(s) into consideration Inaccurate Doubtful that it gives interpretable results

All three methods were applied on the REMO ENSEMBLES RT3 climate model (ENSEMBLES, 2012) which contains data of a 25-km horizontal grid cell resolution of Europe (170×190 points). The reference period was 1961-1990 and the forecasted periods were between 2011-2040 and 2041-2070 according to the A1B IPCC SRES scenario. The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. A1B scenario is one of the three from A1 scenario family. It describes a balance across all sources of energy system. (Nakicenovic and Swart., 2000).

The modelling was performed by the ESRI ArcGIS (Geographic Information System) software. For all three methods interpolation was necessary to create continuous data from the discrete dataset of the climate model. For this the Inverse Distance Weighted procedure of the Spatial Analyst extension was used. The given output cell size was 0.11 with a power of 2 and 12 searching points. No DTM (Digital Terrain Model) was used for the accurate interpolation. The horizontal resolution of the original climate model determined the precision of the future dataset; thus, using DTM could not really make the model more accurate.

The *Isotherm modelling* is the most simple of the three methods and it is not a real modelling method. Its essence is to find the minimum temperature isotherm that correlates the Moesz-line and follow the shift of this isotherm based on the meteorological dataset. It takes only one – or a few – climate parameter into consideration, thus, it is the most unreliable method. *Line modelling* is a more detailed method. It creates a fictive distribution (for a non-existent ‘Moesz plant’) that has a northern border equivalent to the Moesz-line. The model is executed on this distribution. The most complex but the slowest of the three methods is *Distribution modelling*. It runs the climate model on the distributions of 18 species and draws the predicted Moesz-line on the basis of the modelled distributions. This method follows the original way of drawing the Moesz-line in a way that it also bases on plant distributions. In our research geographical averaging methods were not used, so *Distribution modelling* is inaccurate from this point of view. (The whole modelling procedure contains so much subjectivity that there is no sense in applying geographical averaging methods on the last step.)

Line modelling and Distribution modelling

As a preparation for the *Line modelling* and the *Distribution modelling*, the original maps of Moesz were digitized and georeferenced using 20-25 control points (frontiers and rivers). For the *Distribution modelling* it was necessary to digitize the areas of each plant, since only the EUFORGEN data contained spatial coordinates. We did not consider the entire distribution of plants. Only the northern segment of the area was taken into consideration. (Additional limitation to the segment was that it did not spread to the south more than the fictive distribution bound to the ‘Moesz-plant’, and was located in the Carpathian Basin). Since only the northern borders were modelled, this did not modify the result at all.

Three parameters of the climate model were used: monthly average temperature, monthly minimum temperature and monthly total precipitation. All the temperature data of the 12 months were used. From the precipitation data only the total rainfall in the vegetation period (April-September) was considered because it had been observed in former similar distribution models that if all of the precipitation data was taken into consideration the results could not be evaluated. Due to the climate change, the precipitation zones would shift to the north with different rates than the temperatures (Bede-Fazekas, 2011). However, the model can be further refined by using additional precipitation data. A more detailed model can be created with operating other climatic parameters such as heat sum.

The minimum of the monthly average temperatures (1×12 parameters) and the minimum of the monthly minimum temperatures (1×12 parameters) were used (since the northern border was modelled) together with the upper and lower values of the total rainfall in the vegetation period (2×1 parameters). So, altogether 26 different logical conditions had to be fulfilled for a given spatial point to satisfy the climatic conditions. The next equation summarizes these mathematical conditions.

$$\left(\prod_{i=1}^{12} I(\langle T_{mean}\rangle_i^f \geq \langle T_{mean}\rangle_{min}^r)\right) * \left(\prod_{i=1}^{12} I(\langle T_{min}\rangle_i^f \geq \langle T_{min}\rangle_{min}^r)\right) * I\left(\sum_{i=4}^{9}\langle P\rangle_i^f \leq max\left(\sum_{i=4}^{9}\langle P\rangle_i^r\right)\right) * I\left(\sum_{i=4}^{9}\langle P\rangle_i^f \geq min\left(\sum_{i=4}^{9}\langle P\rangle_i^r\right)\right) = 1 \tag{Eq.1}$$

In *Equation 1* the indicator function *I(λ)* takes the value of 1 if the condition for *λ* is true, otherwise it takes the value of 0. The symbol *r* means the reference period, *f* stands for future period, *i* is the running variable (through the months).

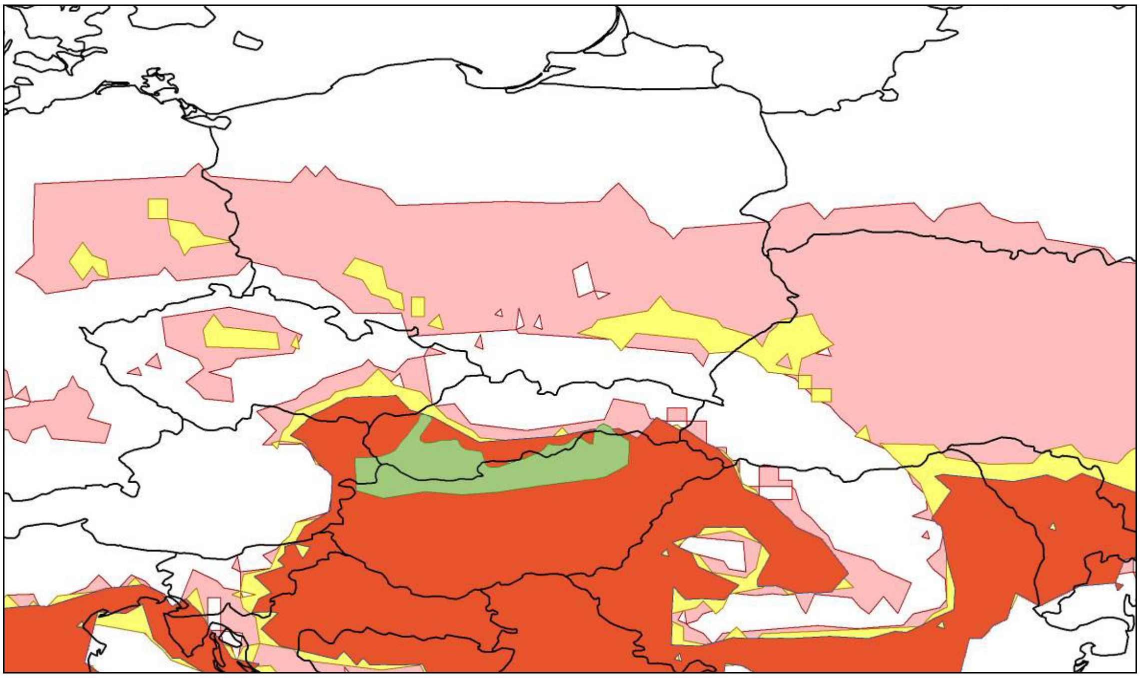

Figure 3. *An example of the distribution modelling (Sideritis montana L.). The map shows Central Europe with frontiers. The key for colours: green – actual distribution, red – modelled distribution in the reference period, yellow – modelled distribution in the period 2011-2040, pink – modelled distribution in the period 2041-2070*

From the individual areas of distributions (and in the *Line modelling* from the fictive distribution bound to the Moesz-line) we have selected 26 extreme values (25 minimums, 1 maximum) that belong to the 25 parameters and we run the modelling for the two future periods (*Fig. 3*) based on these extremities. Actually, this model displays the areas of those climatic conditions the given plant can tolerate but not it's real distribution area. Since just parts of the real areas were chosen only the northern border of the modelled areas will give interpretable result. We have not dealt with edafic and microclimatic data in this research. By modelling the reference period we aimed to display the difference between the real distribution area and the potential distribution area predicted by the model. Thus, the models run for the reference period can validate (and make able to evaluate) the methods.

In the second type of modelling (*Distribution modelling*) we have analyzed the possible distribution of the species originally used for drawing the Moesz-line (*Table 1*) and the 5 species bound afterwards (*Castanea sativa*, *Cotinus coggygria*, *Fraxinus ornus*, *Quercus cerris* and *Vitis sylvestris*).

For one certain species (or the 'Moesz-plant') the detailed method of modelling was the following. Before the interpolation explained previously, the rainfall data of the vegetation period was summarized to a new field (column) with the Field Calculator procedure of the attribute table displayer of the GIS software. After the interpolation (so the base data of the research were the interpolated ones) we used the Zonal Statistics procedure of the Spatial Analyst extension on all the 25 parameters. The output table was set as temporary, since the minimum temperature and the minimum and maximum rainfall data were copied to a Microsoft Excel spreadsheet. From the copied data with the string concatenation and other string functions of Excel the appropriate formulas were created for the next step (for the reference period and the two future periods). Then we started the Raster Calculator procedure of the Spatial Analyst extension of ArcGIS, using the three formulas concatenated with Excel. From the drawn temporary raster files we selected the entities with the value 'true' (or 1) and created shapefiles of the modelled distributions. The Raster to Features conversation tool of the Spatial Analyst extension was used for this. The northern borders of the shapes were finally redrawn on base map, using Adobe Photoshop software. The legend was created with Photoshop too.

Isotherm modelling

The third method, the *Isotherm modelling* has three simple steps. First, we drew some isotherms of the reference period by the Surface Analysis/Contour procedure of the Spatial Analyst extension of ArcGIS. We choose the one most coincident with the original Moesz-line. In the second step we drew the isotherm of the same temperature based on the future datasets. Finally, we plot the isotherms on one map.

Isotherm modelling has a great similarity with the hardiness zones. USDA-zones, or hardiness zones, have a high importance in dendrology. It was developed by the Department of Agriculture of the United States (USDA). It classifies the ornamental plant species by their winter hardiness. The species are ranked among the 26 zones called 0a, 0b, 1a to 12b. The zones are based on the absolute minimum temperature; the lower number the zone have, the more hardy the plant is.

However, in our research we have only used the average minimum temperatures of January instead of the minimum temperature of the winter because in the Central

European region January is the coldest month. Also by this reduction we could benefit the main advantage of this method: simplicity.

Nevertheless, the most significant difference is that, instead of the absolute minimums used for the USDA-zones, the average minimums were accessible from this climate model for us. Likely for the Submediterranean flora the absolute minimum temperature has a higher importance but neither has it described the proper climatic requirements of the plants.

Results

Line modelling

According to the results of *Line modelling* (*Fig. 4* and *Fig. 5*) the modelled Moesz-line for the reference period follows the original Moesz-curve so it shows a really good coherent result regarding the spatial resolution of the model. However, the predicted change of the Moesz-line for the period of 2011-2040 – unexpectedly – does not show a great shift to the north. Moreover, the east part of the Moesz-line between the cities of Rimavská Sobota and Tisovec (Slovakia), in the period of 2011-2040 is expected to lie slightly to the south of the line of the reference period. From the east to Rožňava (Slovakia) the modelled line cannot shift to the north of the original line. This result needs further investigation; however, it is suspected that the lower bound of the rainfall of the vegetation period pushes this line in the section under discussion to the south more than was expected.

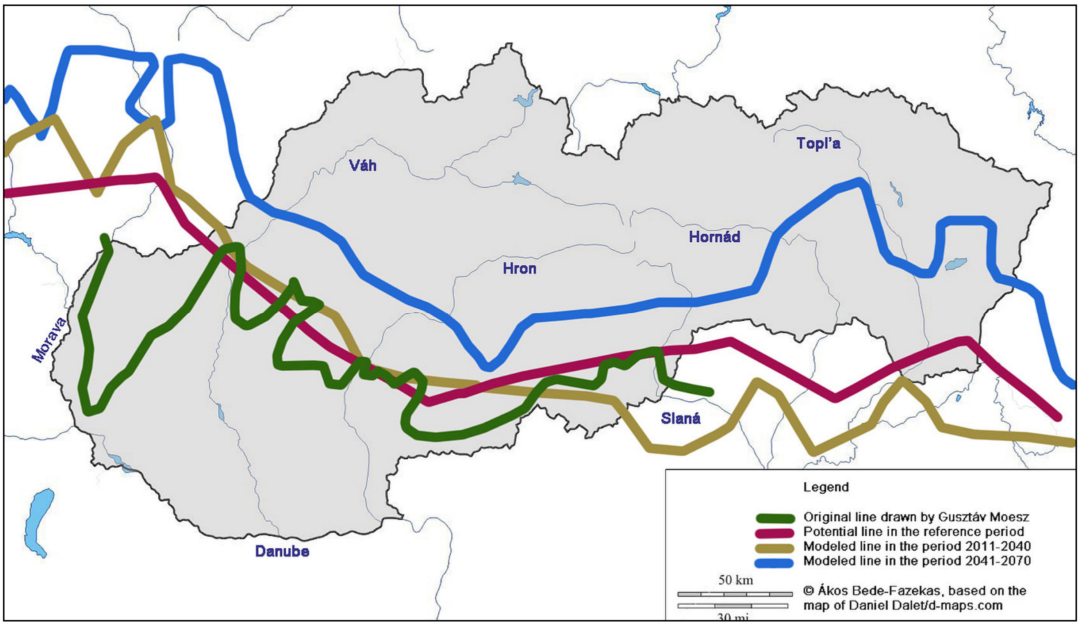

Figure 4. *The results of the line modelling zoomed into Slovakia, printed on a hydrographic chart with country frontiers*

Even so, in the run for the period of 2041-2070, the results clearly show the expected shift of the Moesz-line towards the north. Two, or in other interpretation three different sections can be distinguished. First of all, in the Carpathian Mountains it moves to higher regions (to the north, *Fig. 4*) and from the north of the Carpathian Mountains it reaches Poland (*Fig. 5*). Naturally, an anti-Moesz-line is formed that bounds the climatically optimal regions of Poland to the south (towards the Carpathians). The results coincide with the modelling of geographically analogue regions (Horváth, 2008). The southern part of the new Moesz-line connects Brno and Zlín (Czech Republic), Trenčín, Zvolen, Lučenec, Kosice, Homenne (Slovakia), Soiva (Ukraine) and Bacău (Romania). The northern line connects Berlin (Germany), Poznań, Warsaw, Garwolin, Włodawa (Poland), Novohrad-Volinszkij and Bila Cerkva (Ukraine). The anti-Moesz-line joins Dresden (Germany), Bolesławiec, Rybnik, Częstochowa, Kraków (Poland) and Lviv (Ukraine).

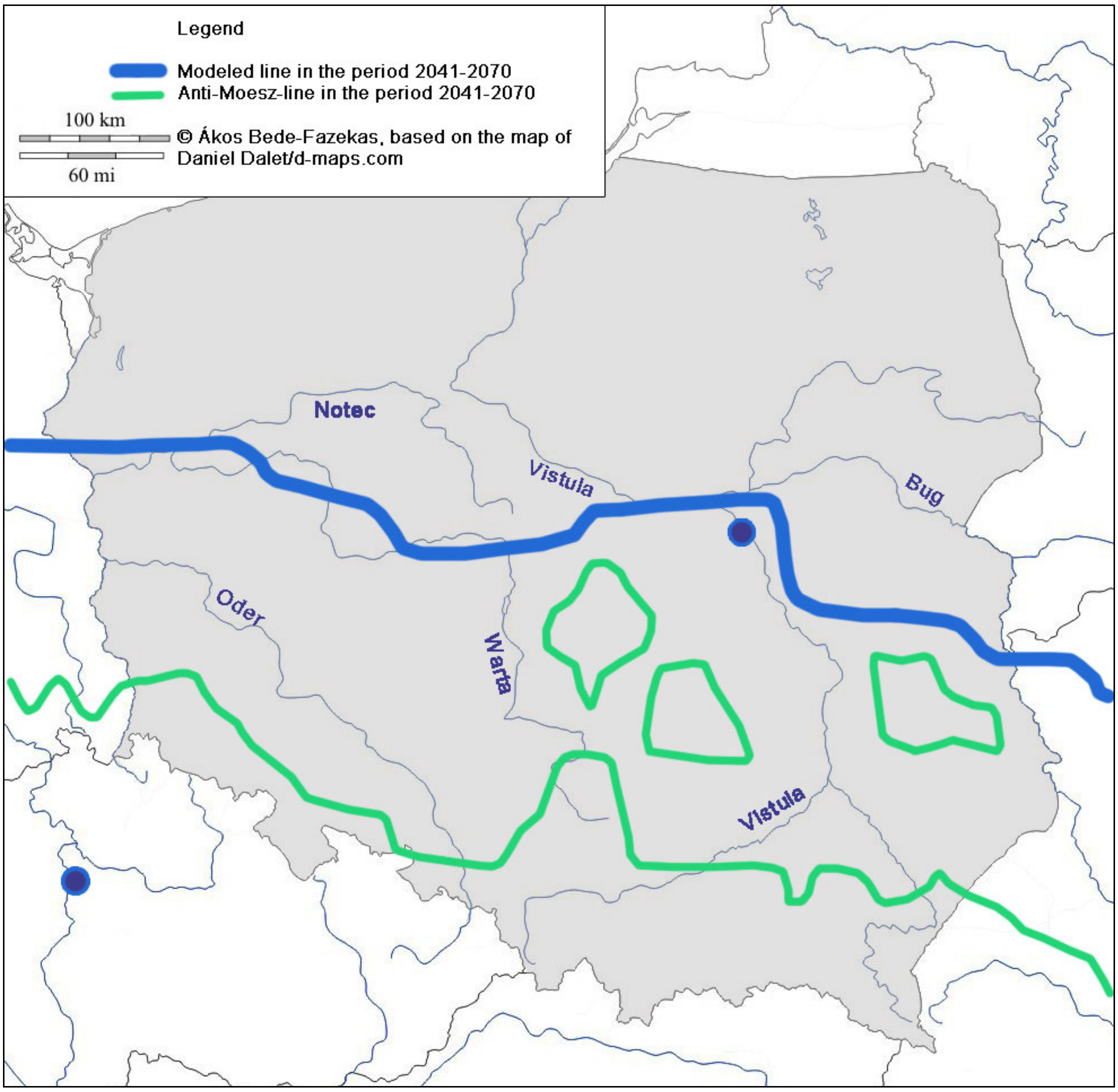

Figure 5. *The results of the line modelling zoomed into Poland, printed on a hydrographic chart with country frontiers. Territories between the blue and green lines are predicted to be the ones equivalent to the territories currently situated to the south of the Moesz-line*

Distribution modelling

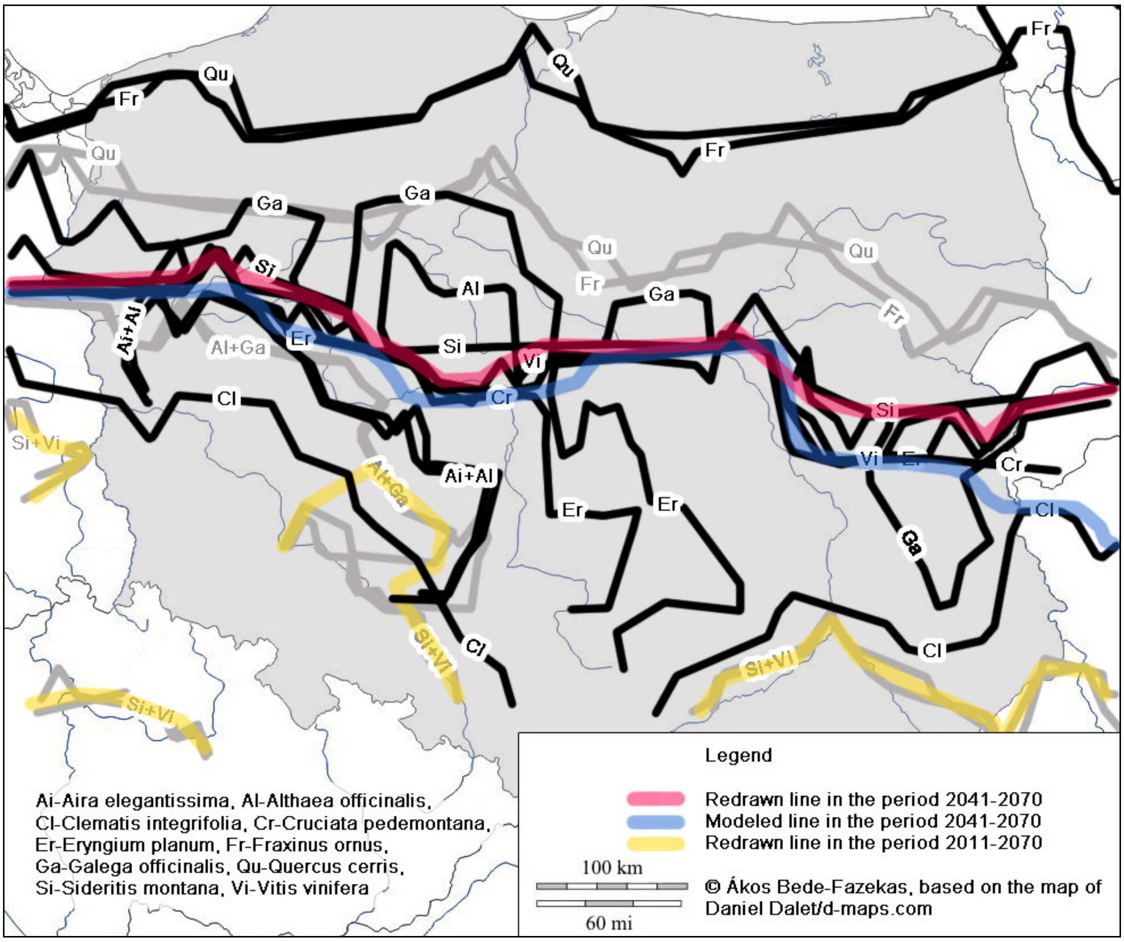

Figure 6. *The modelled distribution of the species (gray: 2011-2040, black: 2041-2070), and the redrawn Moesz-lines, printed on a hydrographic chart with country frontiers*

Distribution modelling – as it was expected – gives a more detailed result of the predicted shift of the Moesz-line (*Fig. 6*). Some species got separated from the others, the distribution of some species shifted to the north of the Carpathians as „early" as 2011-2040 and some of the plants have remained only on the southern parts of the Carpathians even in the period 2041-2070 (*Table 4*). It can be stated that the 12+1 original plants that determined the Moesz-line have produced a more coherent shift of distributions than those plants which were later added to the concept of Moesz-line. The distribution of the Manna Ash (*Fraxinus ornus* L.) and the Turkey Oak (*Quercus cerris* L.) is expected to shift to the north the most and only these two species will show a direct connection between the Slovakian and Polish modelled areas through the Carpathians. In addition to this, it can be stated that the Common Grape Vine (*Vitis vinifera* L.) and the Mountain Tea (*Sideritis montana* L.) will mostly follow the northern line obtained by the *Line modelling* method between 2041-2070.

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Table 4. *The modelled species and their presence on the northern side of the Carpathians. The bold typed ones shift to Poland at latest in the period of 2041-2070*

Scientific name	Shifts to the north of the Carpathians (2011-2040)	Shifts to the north of the Carpathians (2041-2070)
***Aira elegantissima* Schur**	**-**	**+**
***Althaea officinalis* L.**	**+**	**+**
Cephalaria transsylvanica (L.) Roem. & Schult.	-	-
***Clematis integrifolia* L.**	**-**	**+**
***Cruciata pedemontana* (Bellardi) Ehrend.**	**-**	**+**
***Eryngium planum* L.**	**-**	**+**
Euphorbia seguieriana Neck.	-	-
***Galega officinalis* L.**	**+**	**+**
Phlomis tuberosa L.	-	-
Salvia aethiopis L.	-	-
***Sideritis montana* L.**	**+**	**+**
***Vitis vinifera* L.**	**+**	**+**
Xeranthemum annuum L.	-	-
Castanea sativa Mill.	-	-
Cotinus coggygria Scop.	-	-
***Fraxinus ornus* L.**	**+**	**+**
***Quercus cerris* L.**	**+**	**+**
Vitis sylvestris C. C. Gmel.	-	-

Comparing this to the results of the *Line modelling*, we can observe that in the period of 2011-2040 the Moesz-line is expected to pass over the Carpathians although the observed plants will only form some isolated or disconnected distribution regions. On the other hand, the *Line modelling* method has not predicted the future occurrence of the Moesz-line over the Carpathians. *Distribution modelling* and *Line modelling* have given almost the same results for the far future period, although the former displays the future Moesz-line slightly more to the north. The Slovakian segments of modelled line are not displayed separately, since it has produced, considering the horizontal resolution of the climate model, almost identical results with the *Line modelling* method.

Isotherm modelling

The *Isotherm modelling* has produced weaker results than it had been expected (*Fig. 7*). The isotherm of the average minimum temperature in January (-3.86°C) which mostly coincides with the Moesz-line in the reference period, oversteps the Carpathians in the reference period already. Moreover, the position of the curve is not parallel with the Carpathians but perpendicular. Probably, it is due to the climate balancing effect of the sea nearby. However, it cannot be taken into consideration since the Moesz-line is much more exposed to the continental climate impacts. So we can conclude that *Isotherm modelling* is not too useful for predicting the future shift of certain plants or the Moesz-line – no matter if we use the winter minimum or a monthly minimum temperature. One can observe that in the period of 2011-2040 the Carpathians will make a separating blockage but in the period of 2041-2070 – in terms of the isotherm of January – it will ensure free passage for the species. Due to the above mentioned problems we did not continue to evaluate the results of the *Isotherm modelling* further more.

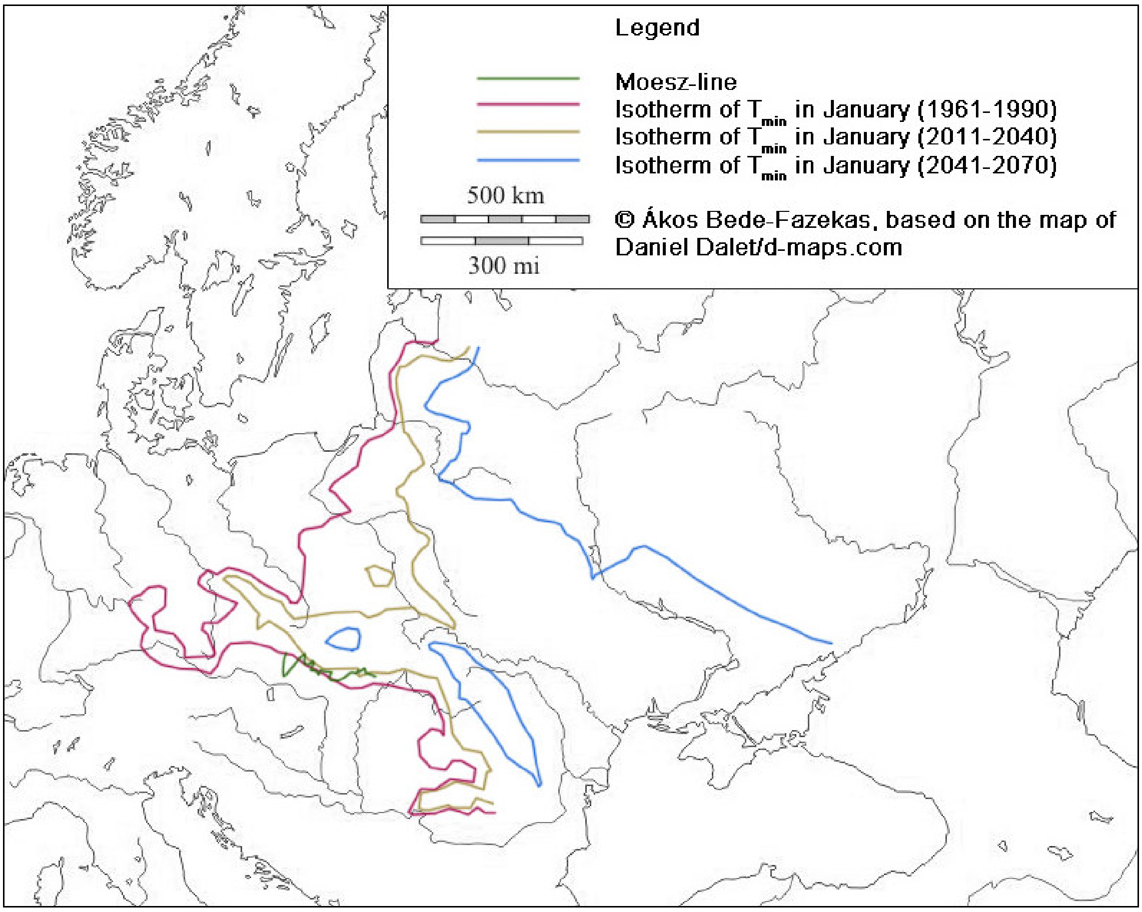

Figure 7. *The shift of the minimum temperature isotherm of January*

Discussion

In this research three different methods were tested to predict the future shift of the Moesz-line due to climate change. The evaluation of them can be seen in *Table 5*.

Table 5. *The evaluation of the methods used in our research*

Name	Usable	Gives results according to expectations
Line modelling	+	- (2011-2040) + (2041-2070)
Distribution modelling	+	+
Isotherm modelling	-	- (It was expected to get doubtful results but not get unusable results.)

It can be stated that the shift of the line toward north is smaller for the period of 2011-2040 than we expected, while for 2041-2070 it coincides with the pre-estimation. We think the results of this research are worth presenting to the landscape architects and botanists. We can observe the expected change of climate in the next 60 years according to the A1B climate scenario.

In summary we can say that the *Line modelling* and *Distribution modelling* produced very similar results for 2041-2071. However, for the period of 2011-2040 only

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Distribution modelling predicted possible shift to the north of the Carpathians. In spite of this the *Distribution modelling* does not give significantly more information than *Line modelling*. Nevertheless, the procedure takes a lot of time and it is fairly difficult to model so many different species separately. The only reason to use *Distribution modelling* is the tradition and scientific respect towards Moesz's work, otherwise there is very little practical reason. The *Isotherm modelling* produced doubtful predictions and it worked even weaker than expected. As an overall conclusion we found the first method to be the most effective and reliable.

The shortcomings of the methods are that they select only a few of the infinite combinations of the finite climate parameters and the selection is arbitrary. The further improvement of such modelling could be based on more advanced statistical methods (which make the selection easier and more objective), or could use artificial intelligence methods. Among them (decision tree, evolutionary algorithm, and artificial neural network) the application of neural networks seems to be the best solution. There are some researches (Carpenter et al., 1999; Özesmi and Özesmi, 1999; Hilbert and Muyzenberg, 1999; Özesmi et al., 2006) on the subject of floristic modelling with artificial neural networks that have some similarities with this approach.

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LANDSCAPE CHANGES AND FUNCTION LOST LANDSCAPE VALUES

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Abstract. Land use and valuable landscape features are such kind of elements of the landscape, which are worth to be taken into account in a landscape plan that deals with the continuous sustainable transformation of landscapes, and provides frame for management, development and protection. The ratio of land use types and landscape features can be determined as landscape values that are relevant for management, protection, or planning purposes. The article focuses on land use driven landscape changes of the last few decades in general, and in a study area in Budapest Agglomeration called Southern Buda Region. It concentrates on changing landscapes represented by land use changes and remaining landscape values with lost functions in transformed or abandoned landscapes. The statistical documentation of land use types is relevant from the end of the 19th century but surveying, inventarisation and protection of landscape values started at our department at the end of the 1970s. From that time it is obvious that the sprawling settlements endanger the existence of the valuable characteristic landscape elements of the past. This paper interprets such an analysis which concentrates on transforming character, altering landscape functions and the re-usability of landscape values of past landscapes in the pilot area.
Keywords: *landscape, land use changes, landscape values, landscape elements, cellar, vineyard*

Introduction

Landscape scenery, landscape character and all what people perceive as landscape depends partly on natural conditions like topography, geology, soil, climate, hydrography, natural habitats, and partly on human activities. The evidence and most basic remnants of human influence are land use types and distinct landscape features.

This paper focuses on land use, which is one of the most dominant scenic elements in the landscape. Its change determines the tendency of landscape transformations of human scale in the 20th-21st centuries. Sometimes the landscape elements of the former land use type can remain function lost, abandoned, in vain. But these can be regarded as values of the landscape representing the rural past of the former landscape. Even distinct patches of land use types of rural landscapes (pastures, vineyards, orchards) can become values in a suburban landscape.

European landscapes have been changing dynamically in the last few decades (Antrop, 2004; Feranec et al, 2010) and the management of landscape values can have enormous role in preserving, or in enhancing distinct landscape character. The sustained diversity of landscapes and the well interpreted character of landscapes can provide extra touristic income, support adequate land use. It can secure ecosystem processes and the preservation of habitats, specialise agriculture, food production and lift food industry, it can strengthen local identity of inhabitants and farmers, and these all mean further steps towards a sustainable future.

The dominant changes of landscapes in Europe are driven by land use or land cover changes, coming from transformation of social, economic and ecologic attitudes towards landscape sites are:

- increase of built up land (Fischer et al., 2010; Antrop, 2004), e.g. sprawling settlements, industrial, logistical and commercial sites
- development of built linear infrastructure, e.g. highway, railway, energy and information transport
- appearance or increase of power plants (Möller, 2010; Frantál and Kunc, 2010), e.g. wind, water, atomic power, bioenergy plants
- increase of wasteland (waste dump sites, abandoned mines or agricultural sites)
- biomass energy plantation (Fischer et al., 2010), e.g. forest, crop, grass
- loss of pastures (Feranec et al., 2010), e.g. disappearance of grazing animals, increase of meadows
- decrease of land use types of rural landscape (Verburg et al., 2006; Hunziker, 1995), e.g. vineyards, orchards, gardens, arable land
- abandonment of built infrastructure elements of rural landscapes, e.g. wells, mills, cellars, granaries
- various impacts of climate change, e.g. disappearing glaciers, snow surface or aridity symptoms
- habitat rehabilitation sites, e.g. increase of semi-natural vegetation and wetlands
- transformation of touristic sites (Lasanta et al., 2007; Caletrío, 2010), e.g. adventure and wellness parks, ski resorts, mass and rural tourism
- increasing role suburban green, e.g. green belts and greenways, park forests in suburbs
- increasing social, economic and ecological function of city parks, e.g. multifunctional city parks.

Budapest Agglomeration has experienced most of the above mentioned landscape changes in the 20th century, and this progress accelerated during the last decades (Schuchmann, 2008). The territory of Budapest Agglomeration was inhabited in the Roman era already. According to written records it was crossed by roads leading in direction of Szentendre, Aquincum, Csákvár and Tác which was used by the inhabitants up till the medieval ages. For a long time the main economic sector was agriculture but since the beginning of the 20th century many inhabitants were commuting to work to the capital. "Prosperity" came in the second half of the 20th century when during the industrialization after the World War II, people got work in the capital city. Many (especially the poorer ones) could not afford to buy a flat in Budapest and lived in the settlements next to the capital city in today's agglomeration. From that time the formerly agrarian villages with low population density continuously became towns and suburban settlements. This initiated the first significant wave of urbanization in the traditional rural region.

The second wave of population growth came in the 1980s when the people living in the capital started to move into the agglomeration to reach a better life quality and green environment. That time mostly white-collar families with small kids moved to the surrounding settlements to enjoy outstanding natural conditions in the vicinity of the capital city. This caused significant population growth in the area. The growth in number of inhabitants brought about the growth of the proportion of built up areas as well. The structure of settlements has become less dense, former agricultural areas or natural areas become built up land (Sallay and Kapovits, 2011).

Today the Budapest agglomeration (*Fig. 1*) is a concentration of urban areas around the core of Budapest creating an organic unit from the point of view of economy, infrastructure, labour market and services. 81 settlements belong to the agglomeration where 2 457 787 inhabitants, a quarter of the population of Hungary, lived in 2007. From this amount, 755 290 lived out of Budapest.

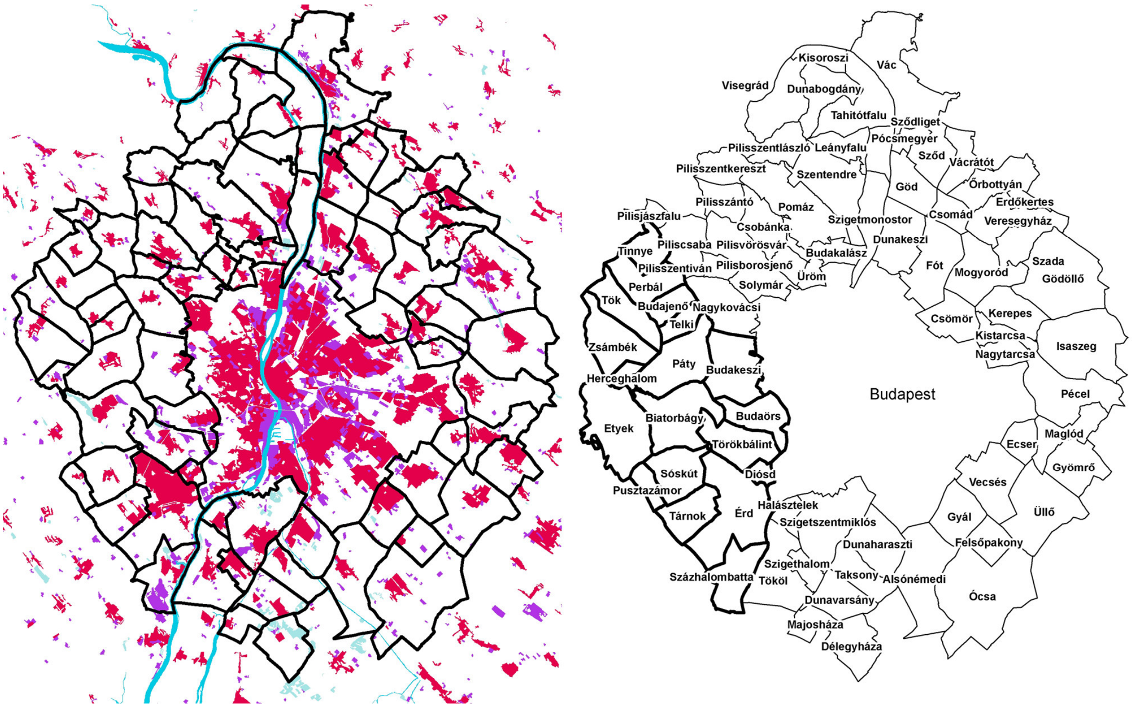

Figure 1. *Budapest Agglomeration and the Southern Buda Region study area*

Materials and methods

Of course all landscapes are continuously changing as the definitions and the general idea of European Landscape Convention highlights (Council of Europe, 2000). But many of them are transformed by enhancing or loosing characteristics. As the European Landscape Convention sentences in the 6th article there is need for specific measures to manage landscapes. The countries besides raising awareness, training and education, need to:

- identify landscapes throughout the territory
- analyse landscape characteristics
- analyse the forces and pressures changing landscapes and their characteristics
- take note of changes
- assess the landscapes taking into account the particular values assigned to them by the interested parties and the population concerned.

Our research concentrates on the Southern Buda Region because of the rush transformation around the millennium. It focuses on these tendencies, characteristics, pressures and changes meanwhile it assesses landscape values. Southern Buda Region study area is the south-western “gate” of the Budapest Agglomeration (*Fig. 1*). Most of

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the above mentioned processes did or do appear in the area and continuously transform the character of the landscapes. The most dominant process is suburbanisation and decrease of rural landscape. The upcoming part of the article is dealing with the land use changes and landscape values of the Southern Buda Region.

The method of land use and landscape value analysis in the study area was complex. It was based on more components of different sources to explore the relevant characteristics of Southern Buda Region landscapes. The work started with literature overview and analysis of previous landscape value surveys, interpretation of historical maps and aerial photographs. Additionally it was extended with land use statistical data collection and analysis. After analysis of remote sensing and land cover data, the field survey of present landscape values with GPS and digital photographs started. The work ended with landscape value cadastering, validation and evaluation of results.

At the end landscape characterisation was done based on dominant land use types and related landscape features. As a result of character assessment the function analysis of landscape values was done. The function lost or function altered landscape values were defined and grouped. The future preferable use of these values could be defined and proposed, with regard on the new landscape functions of a suburbanised landscape (*Fig. 2*).

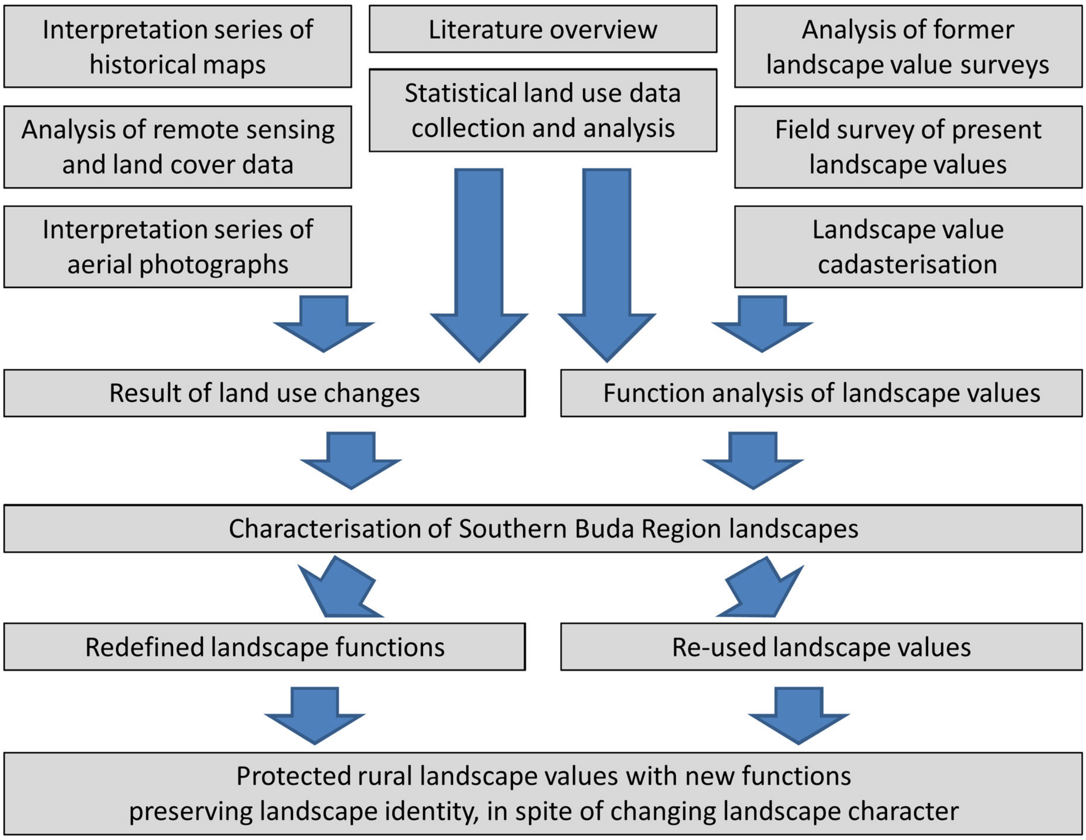

Figure 2. *Research methods*

The dominant transformation process in Southern Buda-Side is, that the built elements of the suburban landscape sprawl all over the region and take over the dominance in rural landscape continuously. The tendency of transformation *(Fig. 3*) is documented by historical maps from the 18th century, aerial photographs from the 1940s and satellite images from the 1980s up till today (Jombach and Sally, 2011).

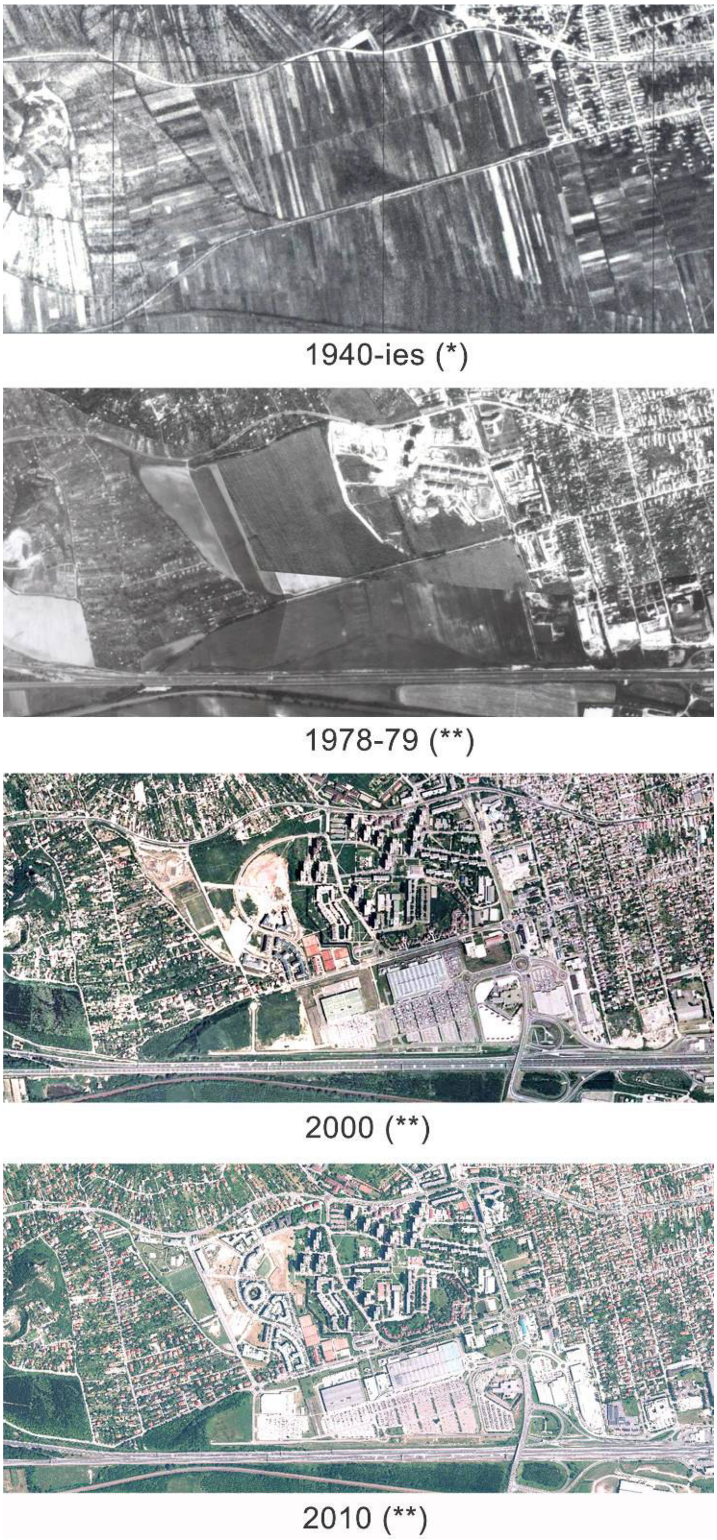

Figure 3. *Landscape change in Southern Buda Region study area at the edge of suburban and rural landscapes (source of aerial photographs and orthophotographs: *Military Museum, ** Institute of Geodesy, Cartography and Remote Sensing)*

Landscape value survey was managed in the frames of the Landscape Value Cadastre (TÉKA) research project in 2010 (Kollányi, 2009). More than 15 000 landscape values of about 431 settlements were surveyed, uploaded and registered in the database (*Fig. 4)*. As an average it means 35 values per settlement. The survey focused mostly on the area of Budapest Agglomeration the Danube-bend and the region along river Ipel. Further surveys are related to other pilot regions or other projects as the survey of landscape values is fundamental part of landscape assessment and planning projects (Kollányi and Csemez, 2011; Sallay and Jombach, 2011).

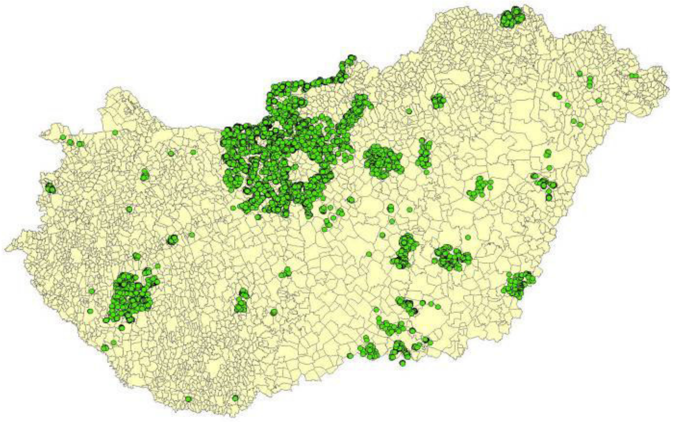

Figure 4. *Landscape values surveyed in the TÉKA project (2010)*

The surveyors have registered more than 5000 (5138) landscape values in the agglomeration and more than 1200 in the Southern Buda Region. The landscape values were grouped according to the standard (MSZ 20381): cultural-historical (red), landscape scenery (blue) natural (green). *Fig. 5* shows the distribution of the particular categories.

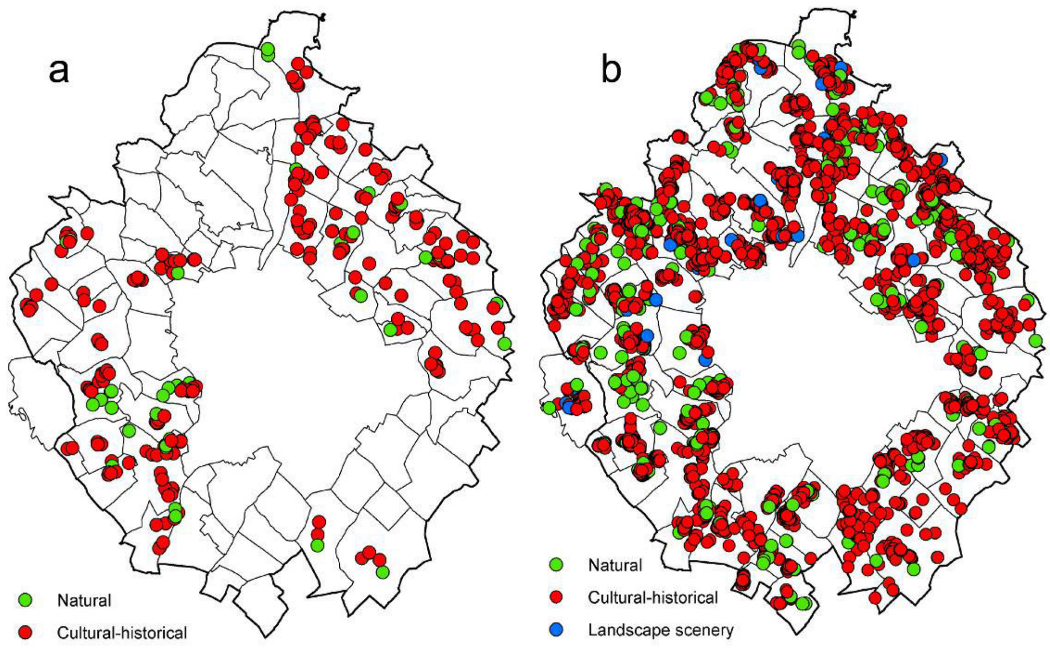

Figure 5. *a) Natural and cultural-historical values of Budapest Agglomeration in the 1970s b) Distribution of landscape values in 2010*

According to *Fig. 5*, most of the values are of cultural-historical character. The hardest definable values proved to be the values of landscape scenery (Sallay, 2011). Our surveyors indicated that it is difficult to determine what kind of landscape feature is representing actually the value of landscape scenery and in many cases they have not designated landscape scenery values because of the poor accessibility of lookout points.

Parallel to the surveys we processed the results of former projects of landscape value survey as well. The most complete project of this type was carried out in 1979, which registered the "significant environmental values" of several counties. In the frames of the TÉKA project we uploaded all data concerning Pest County. In the present area of the agglomeration during the survey of 1979, 110 values were registered from which 97 are cultural values, 13 natural values according to the present categories (Pestterv, 1979).

If we compare the two periods we can see different distribution of the points: the survey in 2009 covered all settlements while in the 1970 just the settlements which were important from the point of view of tourism or other aspects. In the '70s the natural values appeared less important in the survey as the public has not recognized its significance that time.

Results

We experienced dramatic changes in the land use ratio of the Southern Buda Region during the analyzed period 1895-2010 (*Fig. 6*). Besides that the share of non-cultivated built up areas has grown from 4% to 32% the formerly dominant arable land (66%) is reduced greatly (to 37%). The relatively low ratio of meadows and pastures has shrunk to half and it is far below the country average. This fact already highlights that pastures provide unique landscape scenery and can be regarded as landscape values that sustain a special kind of "land use" like horse riding in this region. Forests are growing mostly according to the tendency perceived in the whole country, thus we can consider that the share of forests has grown gradually making up 18% of the area corresponding to the national average.

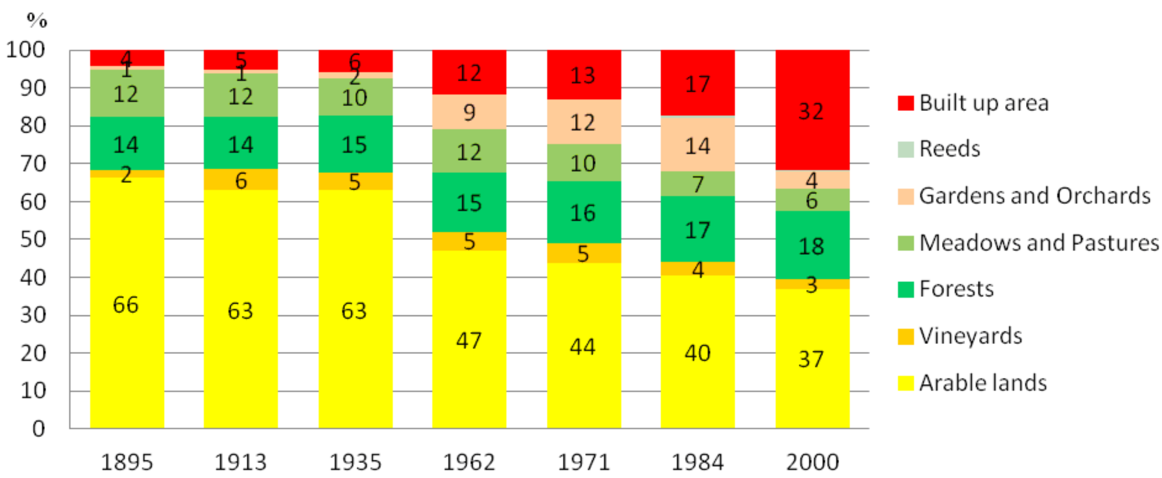

Figure 6. *Land use changes in the Southern Buda Region in the 20th century (source: KSH (http://ksh.hu) and TakarNet (http://takarnet.hu))*

The sprawl of built up land is part of a very significant landscape character changing process today as the remote sensing and land cover data overview proved and as the land use statistical data analysis proves the process started already in the beginning of the 20th century but the rush sprawl happened in the last 30-40 years (*Fig. 7*). It is clearly visible that the process strengthened the most in the last decade. Today in case of many settlements built up land reaches the 40% and in one case exceeds the 90% (Diósd).

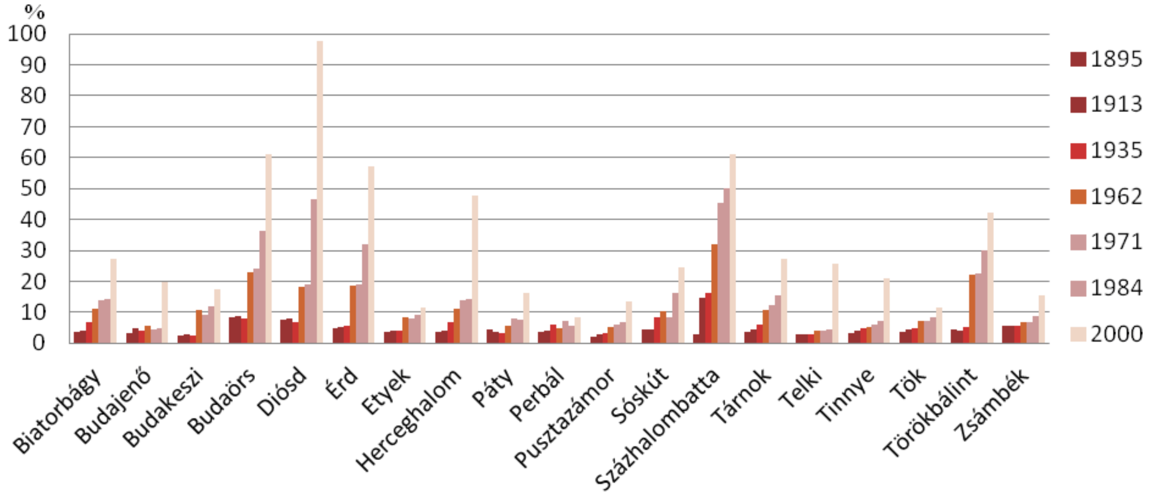

Figure 7. *Changes of built up area in Southern Buda Region (source: KSH (http://ksh.hu) and TakarNet (http://takarnet.hu)*

The dataset shows that in spite of the public opinion and literature overview the orchards and gardens flourished not at the beginning of the 19th century, but only during 1970-80s with a share of 12-14% in the land use ratio, and nowadays we have again only a few percent of this land use type in the territory.

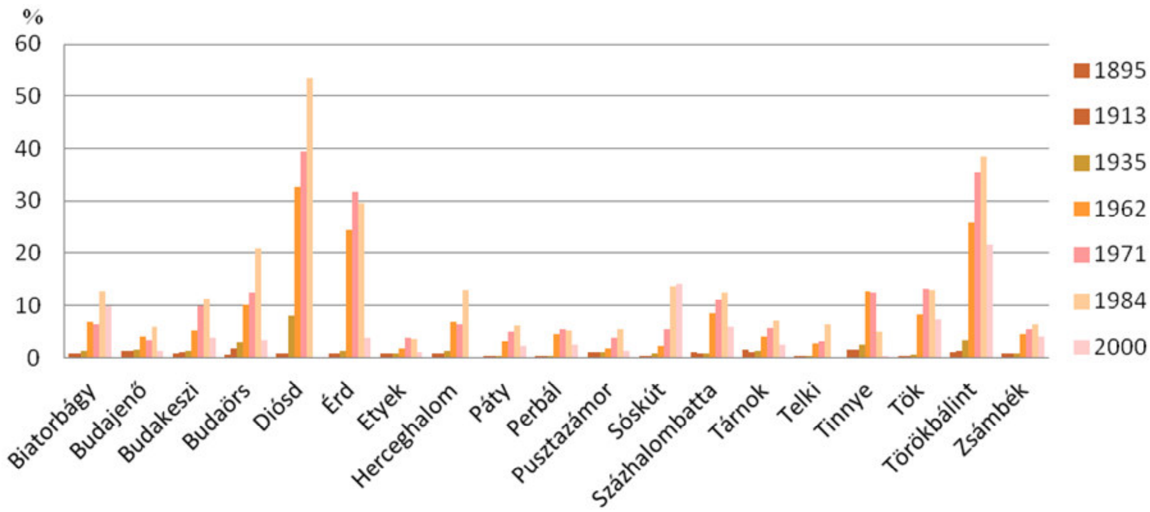

Figure 8. *Changes of gardens and orchards in Southern Buda Region (source: KSH (http://ksh.hu) and TakarNet (http://takarnet.hu))*

In case of settlements Diósd, Érd, Törökbálint and Budaörs the map and aerial photograph overview proved that the big ratio of gardens and orchards provided the development potential in direction of residential kind of built up land use. These four settlements had the largest ratio of gardens and orchards in the region, more than 20% in 1984, and this land use provided the breakaway option to residential development. Thanks to this history we can find a lot of fruit trees might be regarded as landscape values in newly developed residential parts of these settlements (*Fig. 9*).

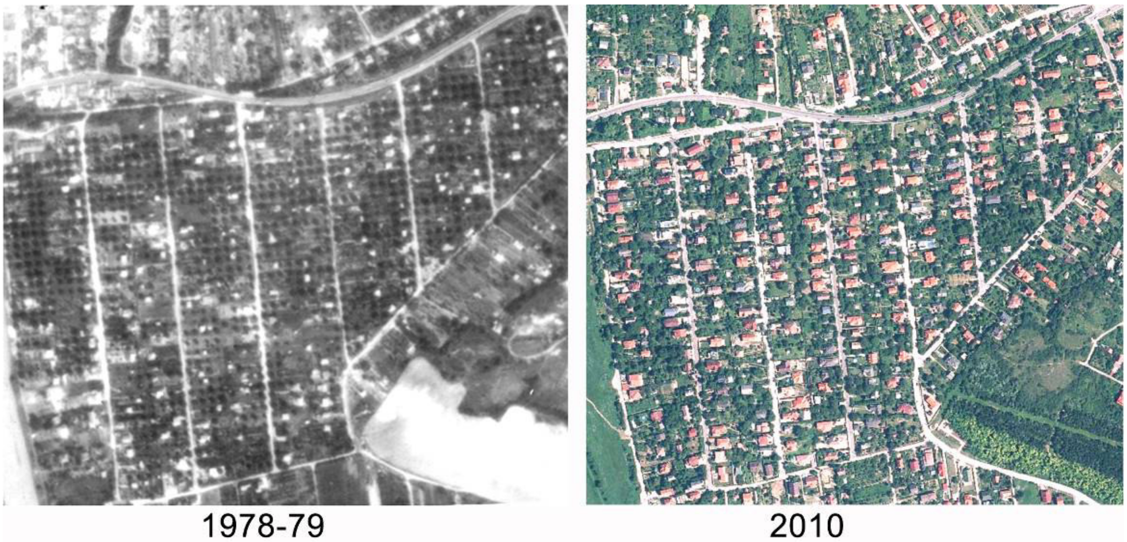

Figure 9. *Orchard-residential area transformation in Budaörs (source of aerial photograph: Military Museum; orthophotograph: Institute of Geodesy, Cartography and Remote Sensing)*

The literature overview already showed that viticulture is a traditional activity in the region since ages, and in spite of the vine pest in the second half of the 19th century, vineyard was all the time a characteristic land use type of the region (Filipszky, 2000). Especially in the middle and the early second half of the 20th century the Southern Buda Region was significantly planted with vineyards (*Fig. 10*). This and the decline of this land use from the 1980s were proved by the interpretation of aerial photograph series from the 1940s to 2010, as well as the growth of the built up land partly here too.

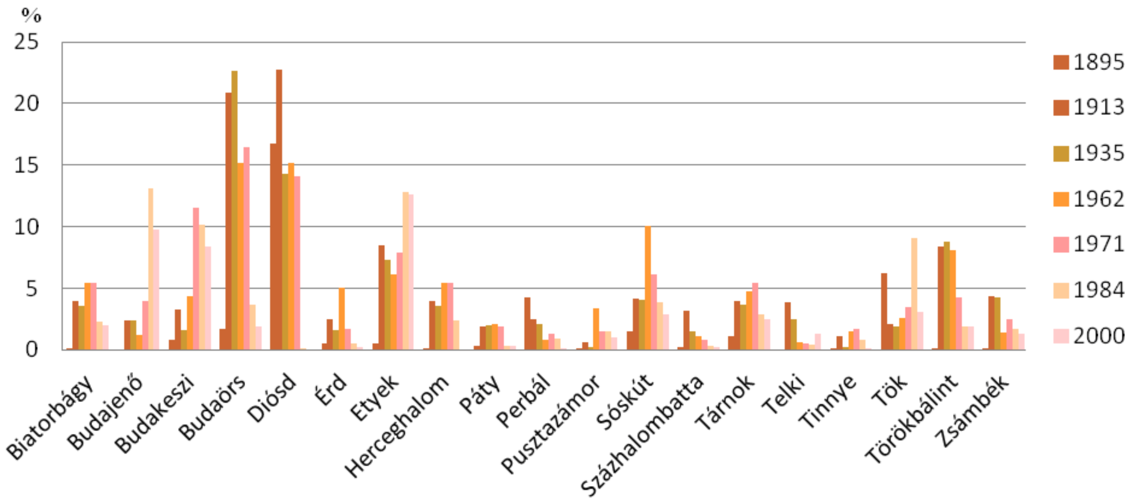

Figure 10. *Change of vineyards in the settlements of Southern Buda Region (source: KSH (http://ksh.hu) and TakarNet (http://takarnet.hu))*

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The vineyards of small parcels almost disappeared from the most developed towns or settlements of the region (Budaörs, Diósd, Érd). Even in villages like Zsámbék, Tök, Budajenő, Etyek do have low ratio of small parcelled vineyards, and the tendency is that large parcels of vineyards become dominant and they can support the competitive vine production. According to the data of 1895 the vineyards covered small areas, because the first available data show already the conditions after the vine pest (phylloxera) when the traditional viticulture was shrunk. The most significant vineyards remained in Diósd after the vine pest but for now the vineyards disappeared without leaving a trace just the wine cellars give evidence of the formerly flourishing viticulture. From the point of view of viticulture Perbál was significant and we can still find a few vineyards nowadays, but the ratio of built up areas has grown dramatically. New vineyards were established only in Etyek which is related to the relatively new identity of the settlement: there is hardly any traditional landscape value connected to viticulture and the majority of cellars were built in the last decades. The expansion and popularity of viticulture in Etyek is marked by the statues related to viticulture raised by the self-government.

The results of the landscape value survey reflect that in the South-Western sector of the agglomeration there are only a few settlements where viticulture has not been significant. The survey shows that there are no cellars registered as landscape values in the settlements where the vineyard land use ratio was less then 1%. We find cellars in the greatest number in those settlements where viticulture was really significant and dominant land use form in the beginning and the middle of the 20th century (*Fig. 11*).

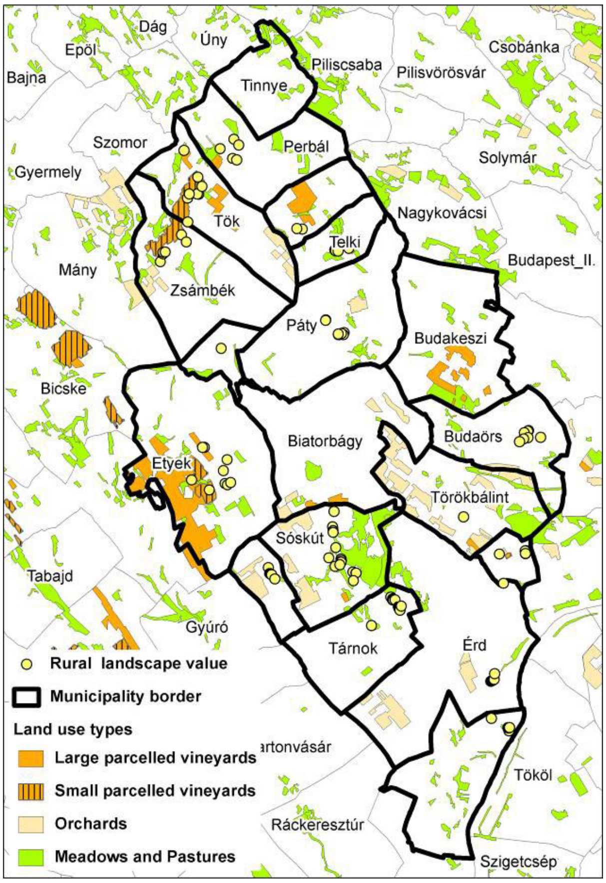

Figure 11. *Landscape values related to agriculture in 2010 and certain rural land use types in 2000 based on CLC50 (data source: Institute of Geodesy, Cartography and Remote Sensing)*

These settlements are: Diósd, Perbál, Tök and Budaörs. Even then, there are all around nice wine cellars in the region of different state and use, like the cellar hill in Páty, the row of cellars in Budajenő or Tárnok, and Sóskút.

Comparing the two landscape value surveys we see that during the '70s several agrarian buildings have lost its function and begun to decay (*Fig. 12*). Buildings without function disappeared by now, so regrettably these cannot be included in the register of 2010. These are definite symptoms of the continuous shrink of rural landscape in this region.

Figure 12. *Cellar in Diósd in 1975, granary in Sóskút in 1979, cellar in poor condition in Budaörs, 1980 (source: TÉKA, http://tajertektar.hu)*

The agricultural buildings, which were re-used even if the related land use has disappeared, became significant values of the settlements included in both landscape value surveys (1970 and 2010). These values are mostly cellars (*Fig. 13*). In many cases the buildings were preserved by getting new functions: converted to family house, cottage or catering (*Fig. 14*). In case the agricultural buildings were neither for the owner nor for the settlement valuable then these are already in trouble, abandoned or disappeared. Sometimes these get into poor conditions and homeless do move in that accelerates the decaying process of neighbouring values.

Figure 13. *Cellars of Páty in the 1970s and in 2010 (source: TÉKA, http://tajertektar.hu)*

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Figure 14. *Former cellar transformed to dwelling house in Diósd, and cellar in Diósd from 1881 (source: TÉKA, http://tajertektar.hu)*

Figure 15. *Disused cellar in Diósd, and cellar in Budaörs (source: TÉKA, http://tajertektar.hu)*

Cellars are built in settlements where viticulture gained significance in the last decades such as Etyek, which is one of the active members among the settlements of the former wine region of Etyek-Buda. The newly built cellars are potential landscape values. In these settlements the master plans have a great role in regulation of construction in order to preserve the existing landscape character (*Fig. 16 and 17*).

Figure 16. *Modern cellars in Etyek and old cellars in Budajenő (source: TÉKA, http://tajertektar.hu)*

Figure 17. *Old press house next to large parcelled vineyards in Etyek*

Discussion

The perceived landscape changes usually can be represented with exact landscape elements, land use types, landscape values. In case of Southern Buda Region we can say that the landscape function has altered as well in last few decades. The rural landscape of the 1970s represented by vineyards, orchards, arable lands and others has partly disappeared and the suburban landscape of built up land with increasing urban woods appeared (*Table 1*). Some landscape elements of the former landscape functions continuously lose their functions like cellars in the suburbs without vineyards. These remnants of the former rural landscapes can be considered as values in the stakeholders mind and can be re-used and vitalized with the original function or with a new function.

Table 1. *Summary of dominant changes in landscape elements in Southern Buda Region*

Rural landscape elements disappearing in the 2^{nd} part of the 20^{th} century	Suburban elements sprawling in the 2^{nd} part of the 20^{th} century
Arable lands, pastures, vineyards, orchards	Roads and highways, various residential areas, Commercial, store or logistic areas, Forests and urban woods
Artificial landscape elements related to rural life and agriculture (wells, bridges, granaries, dirt roads, cellars, grazing domestic animals etc.)	Artificial landscape elements related to urban / suburban landscapes (petrol stations, parking lots, noise barriers, billboards, fences, traffic lights, etc)

The protection of landscape values can result a good solution for a monument but the revitalization of the landscape element would mean the internal use in the society's life. This case the rehabilitation of built landscape elements with restrictions and value-specified regulations could result the sustainable maintenance. Re-use of a landscape value can be various. A specimen or a well in a pasture land, a granary at the side of an arable land, or a mill on the hillside can become a revitalized landscape value, representing the past or the present rural use of land and to visualize the presence of working human hands in the landscape. In a suburban landscape such sceneries can seem very ancient like, native, and unique, that strengthens the historical identity of the landscape. The potential use of wine cellars in a suburban landscape can be one of the followings:

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- the original function: cellar for small parcelled vineyards
- the original function: large parcelled vineyards in cooperation with cellars
- commercial building, store, souvenir shop
- tourist information office
- venue of various events (village gatherings, forums)
- base of residential development
- Local History Collection
- protected monument status with any of the essential functions mentioned above.

Conclusions

As the statistic data and the historic maps show the share of land use forms has changed dramatically in the region during the last century however in different ways in the settlements. Basically the shrunk of arable land and the increase of built up areas is dominant all around the region. If we look at the data of the different land use forms we see the following progresses and results:

- The share of cultivated areas has decreased first gradually than dramatically since the beginning of the 20th century in the South-Western part of Budapest Agglomeration.
- The areas taken out of cultivation (especially by development of residential areas) were formed in the areas of former gardens and orchards, vineyards, plough fields.
- The viticulture was withdrawn by the end of the 20th century in all settlement except Etyek. Generally the area of former small parcelled vineyards transformed mostly to residential areas.
- The share of gardens and orchards which has been significant land use form during the 19th century, have shrunk drastically giving place for residential areas. In all settlements we have witnessed a drastic expansion of residential areas especially in Diósd of which administrative area became almost totally built up area in the last decades.
- In the case of land use changes of great scale the landscape values as cellars, granaries etc. preserve the memory and traces of the traditions of Southern Buda Region.

These changes of land use forms have resulted in the transformation of rural landscape to suburban sites changing the landscape character drastically. As the landscape structure and land use have changed the function of former (mostly) agricultural buildings have changed as well. Those buildings are preserved which got new functions: the former farm buildings are mostly used as cottages, family homes, local museums, restaurants etc. Unfortunately the buildings which have lost their functions are in decay:

- the state of disused farm buildings is deteriorating, regardless of property relations
- the granaries serving several settlements in the past remained without functions.

We have found one good example: the granary in Budajenő got just new function – a tourist centre will be installed in the building.

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As final conclusion we can state that because of the drastic changes of the land use forms, the landscape character transformed from a rural landscape into a suburban landscape. The traces of the former landscape character are preserved just by the surviving landscape values. We consider it important to retain and enhance local identity by preserving, reusing these architectural values. We promote the intention of local communities to give new functions to the deteriorating but unique landscape values. The remained farm buildings with new functions can enhance the identity of local population and give new identity for the settlers in spite of the changed landscape character.

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THE POSSIBILITIES OF DECREASING THE URBAN HEAT ISLAND

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Abstract. The urban heat island phenomenon is one of the greatest challenges of the present days regarding the sustainability of our cities and settlements. A great amount of research has already been completed considering the urban heat island, with a significant part of them based on the utilization of remote sensing. The results show that in the case of the densely built-up areas of Hungary the maximal intensity of the urban heat island can be experienced in the industrial areas and in the extremely densely built-up zones, while water bodies and surfaces covered by vegetation proved to be the coolest zones under all circumstances. Thus, according to the results only water and green surfaces are capable of effectively reducing the urban heat island. Firstly, urban green surfaces and water bodies must be created to become capable of decreasing the urban heat island to the maximal extent. Secondly, it is possible to maximize the rate of green and water coverage within settlements only with the tools of urban planning. Thus it is essential in the case of urban planning to implement the existing regulation tools to prevent or minimize the further intensifying of the urban heat island.
Keywords: *urban heat island, urban climate, climate adaptation, urban green system*

Introduction

In the recent 200 years a heretofore unknown problem has appeared in relation to the liveability of the cities, and by now this relatively young phenomenon has become one of the most important issues (if not the most important one) in the same context. The phenomenon was already recognized almost exactly 200 years ago (Howard, 1818) in a study describing the urban climate of London. Basically this problem has become significant due to the industrialisation and the consequential expansion of the cities happening on an extremely large scale. In fact this problem obviously existed beforehand as well, however, it was not reasonably perceivable in everyday life, or at the most as a positive phenomenon (e.g. the weather in wintertime was less cold).

It has been in the last 50 years that the phenomenon has become really serious, as several factors have added to its intensity and size beside the basic reasons. The greatest additional factor is global warming, which also has rapidly become an increasingly serious factor in the last 50 years. Its impact is very complex, in certain cases it might even happen to decrease the intensity of the urban heat island phenomenon (e.g. if the number of cloudy days increase locally), but in Central Europe and especially in Hungary the two phenomena unluckily intensify each other (Mika, 1999).

The other serious factor is a consequence of motorisation, which led to the extreme expansion of cities even beyond the size of the settlements which formed during the industrial revolution (e.g. London, 19th century). The third phenomenon is the radical growth of the number of inhabitants and the migration of people from the rural regions to the city; consequently besides the geographical expansion of these urban areas the

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intensity of their usage is also increasing. These altogether mediately increase the range and intensity of the urban heat island.

The consequence of the above mentioned factors is that nowadays the urban heat island endangers the urban liveability to a higher extent than the air pollution does, which used to be considered as the most unpleasant component of urban life for several centuries. The heat wave of 2003 in Europe, which only in France resulted more than 14 000 deaths in three weeks, clearly showed that global warming, together with other factors increasing the temperature (urban heat island) can have direct radical impacts on everyday life. There has been made also a very detailed study about the distribution, length and intensities of heat waves in Hungary (Révész, 2008).

The essence of the following research is firstly the examination of the structure of the urban heat island, particularly regarding how the different land use types and land covers can modify the urban heat island on the given site. Thermal infrared satellite images (NASA, 1999) were used in undertaking the examination, since these images were the ones that provided sufficient information on the examined area.

The examined area is Budapest, the capital of Hungary. Geographically the city is located in the Pest Basin and is divided into two parts by the River Danube. The western part is mostly hilly, while the eastern part is plain. Due to its location in a basin, smog appears very easily when the macroclimatic conditions are appropriate for it; furthermore due to its protective relief the local climate is basically somewhat warmer than in the surroundings, which unluckily further increases the urban heat island. The dominant direction of the wind is western, north-western.

During the detailed examination first the satellite image database was analysed and on the basis of the results an architectural, open space design and an urban planning proposal and directive system was developed, which in essence recommends such land covers and land use on the newly built-up or transforming areas, that minimizes the rate of the urban heat island and sets a limit to its further spatial extension.

Review of literature

First of all the book of Probáld (1974) has to be highlighted among the literature related to the topic; this book summarizes the knowledge on the urban climate of Budapest in 1974. No other similar summarizing work has come into existence ever since, thus it is still the only book to provide the most comprehensive overview on the urban climate of Budapest. However, the global climate has changed a lot since 1974, and on the other hand Budapest and its neighbouring settlements have significantly transformed. This transformation is still in process. Finally some new technologies have appeared which enable a much more detailed analysis of meteorological phenomena, thus many more conclusions become available in relation to the coherence of the meteorological processes taking place in the given area.

In relation to the Hungarian urban climate researches in the present days it is very important to mention the work at the University of Szeged and to highlight the name of János Unger. One of his most important results is the synchronizing of thermal measurements performed on the surface and thermal infrared photos taken from aeroplanes, and by combining these measurements a very detailed temperature distribution map was produced of the town of Szeged (Unger, 2009).

The PhD dissertation of Gál (2009) is also very important, which deals with the interaction between the complex urban surface and the urban heat island. In his thesis he examines the correlation of the sky view factor (SVF) and the urban heat island in detail. Basically in this work is proven the anticipated result, that the greater is the SVF, the smaller is the Urban Heat Island.

Furthermore we have to mention the article of Szegedi and Gyarmati (2009), in which on one hand the Oke formula (Oke, 1973) is proved through the examples of settlements in the Hajdúság (an East region in Hungary), and on the other hand – through the example of the so called 'Great Forest' Park of Debrecen – the phenomenon of the park cool island (PCI) of urban green surfaces was also clearly evinced.

Last but not least the research programs still in progress at the Eötvös Loránd University, Department of Meteorology must also be mentioned. The thesis of Dezső (2009) summarizes the satellite image measurements of Budapest. This can be considered as a very detailed work in the aspect of meteorology, but it does not contain any detailed urban research, nor any recommendations (as basically this was not an aim of this work). Principally it contains a very detailed examination and description of the urban heat island of Budapest in the last decade, displaying the spatial structure and the development of the phenomenon in detail. However, the examination of those satellite images (ASTER) with a spatial resolution fine enough for urban studies (NASA, 1999) is only a minor chapter of this work. The research was previously published in detail by Pongrácz et al. (2007). Another very interesting work of this institute is a long term forecast for the climate change of the Carpathian Basin (Bartholy et al., 2007). Here must be also mentioned the extreme vulnerability of the climate of the whole Carpathian basin, which comes from the climatically border situation of this region (the oceanic, the mediterranean and the continental effect can be all dominant and the balance is very sensitive). The climatic sensitivity of this region is well introduced in another study of this research group (Bartholy et al., 2009).

Considering the international literature the number of relevant studies is much smaller, as in this case the examined area is very specific (Budapest). Nevertheless it is important to note the name and work of Oke and the article about the energy balance of the inner part of Mexico City during the dry period (Oke et al., 1999), which is very important in the case of a city, in which's macroclimate a lot of mediterranean features had appeared in the last decades, and this trend seems to continue in the future.

Another very interesting study was made in Barcelona (Moreno-garcia, 1994), which shows some details about the day and night periodicity of the urban heat island. According to these measurements the temperature maximum was a little bit lower (with about 0.2°C) by day, but the night temperature minimum was remarkably higher (with about 2.9°C). These values are very interesting from our point of view, but it must be taken into consideration that the geographical location, the macroclimate, the relief and the vegetation are all absolutely different in case of Barcelona than in case of Budapest.

Furthermore there exist well known examples for the remote sensing of the urban heat island (Lee, 1993). It was proven in this study that in case of daytime and cloudless weather the structure of the urban heat island is mainly determined by the different albedos of the different surfaces.

From the energetic point of view it is very important to note the radically increasing energy consumption, which is required for air conditioning. According to some estimation it can be cost tens of million US dollars in case of certain North-American cities (Rosenfeld et al., 1997).

Materials and methods

As the urban heat island is a very complex phenomenon with several causes, it is very important to measure this symptom as accurately as possible. The measurement would be extremely difficult if traditional temperature measuring methods were used, as this would require an extremely dense measuring network, which would be impossible even in the richest cities of the world. Consequently a database consisting of satellite images produced by the ASTER sensor (NASA, 1999) has become our primary data source. The usage of satellite images is particularly advantageous when considering the fact that this way it becomes possible to obtain information on the entire territory of the city in the same second. This way the spatial structure of the urban heat island and its correlation with the different land covers and land use types can be accurately examined.

The satellite images used in this research are the so called thermal infrared satellite images, which cover the entire territory of Budapest, while their spatial resolution is 90 m that can be considered relatively accurate, as they enable the examination of even single urban blocks; however, they do not allow accurate analysing on a deeper level than the city blocks. It is very important to note that these temperature data are so called surface kinetic temperature data and not the traditional air temperature data (measured at a level of 2 m in shade). They are derived from the thermal infrared radiation intensity of the surface. The difference between these two kinds of temperature values is not remarkable in the aspect of this research, only approx. 1-1.5°C (Dobi et al. 2009).

The basic method of the measurement was a comparison between the temperature data (the satellite images) and the land use (as it is stated in the regulation plans) together with the detailed surface cover (Google Earth images). Following the layering of these different images the comparison continued by examining the isotherm lines, meaning that all satellite images were transformed into image sequences. Each element of these sequences has an index number, which is a threshold temperature value.

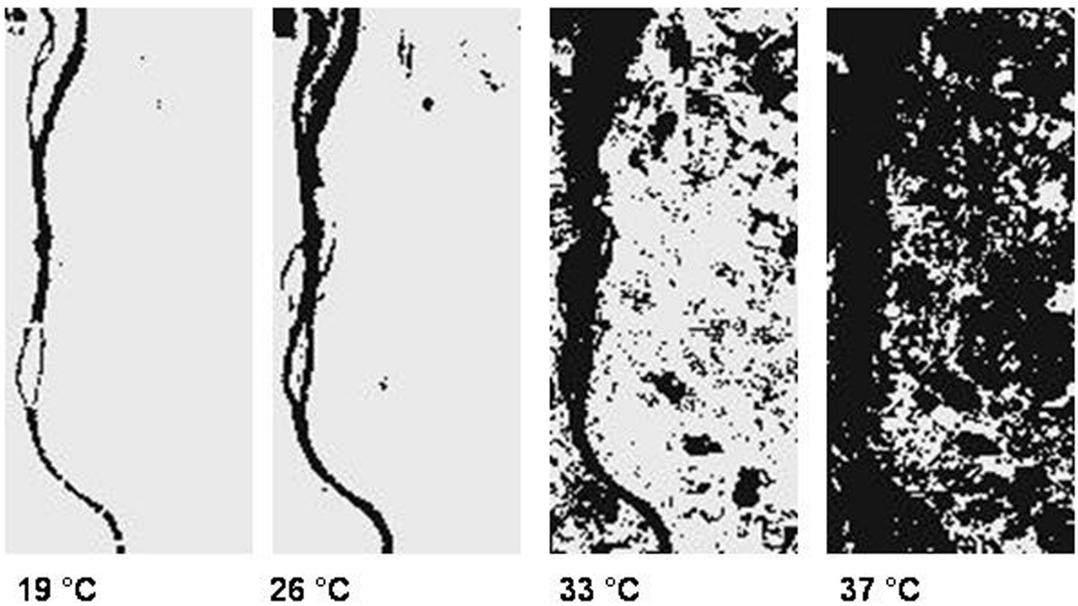

Figure 1. *The role of the threshold temperature value by the examination of the central part of Budapest. The dark zones are colder, while the light zones are warmer than the given threshold temperature. (shot on 4th May 2002)*

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The areas warmer than this temperature value are brighter, while the areas colder than this value are darker *(Fig. 1)*, this way it becomes possible to measure the temperature distribution in correlation with the land cover.

By using the temperature threshold values the hot and cold spots can be accurately identified in the city, consequently the anomalies become simply detectable and their size and rate can be measured exactly, furthermore in certain cases the isotherms clearly indicate the differences resulting from the various land uses and land covers.

The other method of processing the satellite images is the examination of the so called thermal cross sections. In this case it is the temperature distribution along a path which is measured (on a graph). Since the spatial resolution of the satellite images is 90 m, this line is a 90 m wide band in practise. Furthermore by examining three similar neighbouring bands it becomes possible to depict and analyse graphically a 270 m wide band (*Fig. 2*).

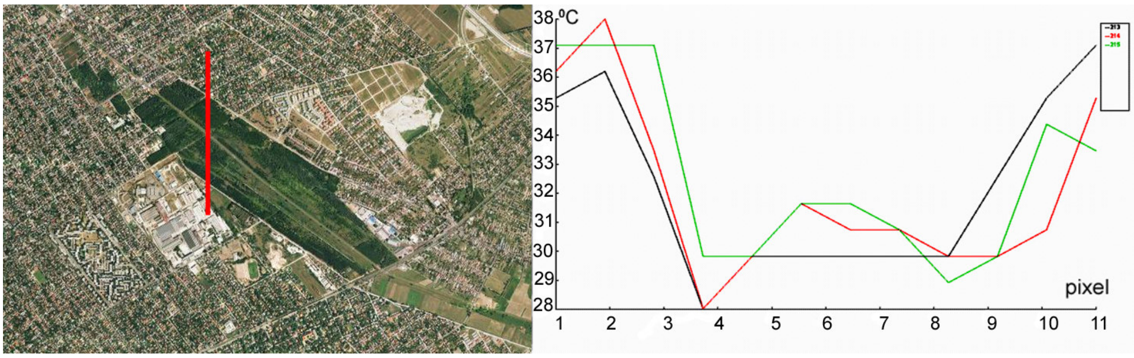

Figure 2. *The so called thermal cross sections and their lines of recording on the map. Each line represents a pixel sequence of the thermal infrared satellite image. The examined area is a young poplar forest on the banks of the Szilas Creek in the 16th District of Budapest. (shot on 6 May 2008)*

Through the two above mentioned methods cross sections with vertical and horizontal section planes were set on the urban heat island, which can be displayed as an inflected surface in the 3 dimensional spaces (the temperature values indicated in the 3rd dimension above the 2 dimensional maps). These planes enable the accurate and comprehensible illustration of the phenomenon, and on the other hand they enable the achieving of not only qualitative but also the quantitative results.

It is very important to note that these are only case studies in the present work, opposite the thesis of Dezső (2009) for example, in which the entire urban heat island of Budapest was examined on a daily basis for a several years long period based on the MODIS satellite image database (NASA, 1999). However, the measurements taken in different years but under similar macroclimatic and seasonal conditions (4th May 2002 and 6th May 2008) show very close similarities. This was in a way predictable, seeing the daily average temperature values and weather conditions of these days provided by the Hungarian Meteorological Service. The data show that these days were bright, clear and unclouded (anticyclonic conditions). Particularly this macroclimatic similarity made it possible to detect the anomalies in the structure of the urban heat island unequivocally caused by the change of the land use.

There is a very interesting possibility to increase the spatial resolution of these images (Jung et al., 2007). Its base is the fact that the NDVI indices highly correlate with the temperature values in some certain regions. As it is well known the NDVI index is derived from visible near infrared (VNIR) and short wave infrared (SWIR) radiation. The spatial resolution ability of these spectral bands is far better (30 m and 15 m) than that of the thermal infrared band (90 m). On this way a 30 m spatial resolution can be achieved, but only in areas covered by vegetation. Because of the urban fabric of Budapest is very complex and detailed, moreover huge parts of the city are biologically absolutely inactive, it is not worth to deal with this method, because it could be used only very limitedly.

On the whole, even though only case studies were analysed, still the fairly good spatial resolution (90 m as against the 1 km spatial resolution of the MODIS images), furthermore the mindful selection of the case studies and their deliberate comparison provide a good opportunity to examine the effects of the different land use forms and land cover types on the urban heat island.

Results

The results of the examination can be summarized as follows: the correlation between the urban heat island and the different land use form and land cover types is unequivocally proven. The examination also proved the significant role of the various albedo values in the development of the urban heat island. In the following the land cover types and surface materials with the most significant impact and their effect on the urban energy balance will be introduced according to the examinations.

Water bodies

Water bodies possess the most efficient urban heat island reducing effect in the summer period. The larger the water surface, the greater the impact; however, these are not proportionally related, since even relatively small water bodies (e.g. the lake in the Orczy Garden) have a significant temperature-reducing ability. The size of the Orczy Garden is about one hectar and considering the spatial resolution (90 m) of the satellite images and the fact that this small lake appears significantly on all spring and summer pictures it can be declared that the cooling effect of even such small water bodies are unequivocally remarkable. The rate of this cooling effect depends on many factors, however, it can be generally stated that water surfaces can reduce the temperature of their surroundings by even 10°C or more. At the same time water bodies appear as the warmest surfaces on the winter images (except for certain hot spots), thus, they are capable of moderating the local climate even in the winter period, which is very advantageous in the aspect of the liveability of the cities.

It is very interesting that in the case of the River Danube, which is the greatest water body of the city, the bridges above the river also appear on the satellite image (as warm pixels), even though their average width is only about 40 m, while the spatial resolution of the images is 90 m. The reason for this is probably that the temperature of the paved surface of the bridges is so much warmer than that of the water surface that they can influence the average temperature value of the given pixel even if they cover only a part of its area. Unfortunately these temperature values are a random average of the temperature of the water body and the surface of the bridge. Consequently only qualitative analysis is possible in these cases, however, it is interesting to see in *Fig. 1* that at 19°C the bridges over the Danube all clearly appear, even though this is theoretically impossible.

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Tree stands with closed canopy layers

The next very important land cover type consists of forests, park forests, parks and other tree stands. In this case it can be declared that the urban heat island reducing effect of this land cover type is very significant both in the summer and in the winter period. The rate of this effect depends on several more factors than in the previous case. The plant species and age of the tree stands, the level of the subsoil water are all highly important. Furthermore the same abiotic factors impacting on the entire urban heat island itself play a significant role in the case of tree stands as well. All in all it can be declared that a multilevel tree stand with a closed canopy layer, consisting of well evaporating tree species with a sufficient water supply (a relatively high level of subsoil water or irrigation in the dry periods) can reduce the temperature even by approx 5-6°C.

The role of the evaporation and photosynthesis (which transforms a significant part of the incoming radiation into chemical and not heat energy) is extremely important when examining the effect mechanisms. The effect was anticipated, according to the study, which showed the correlation between the biological activity and land surface temperature (Gábor and Jombach, 2009). Furthermore the shading effect of the vegetation must also be mentioned. To exactly understand the role of shading, it is necessary to examine the intensively maintained (thus intensively evaporating and photosynthesising) grassy surfaces. The examination of these areas show that their urban heat island reducing ability is approx. only 2-3°C. Considering furthermore the wide repertoire of shading tools and double facades of the contemporary architecture, which are used for reducing the warming up of these buildings in the summer period, it can be said that simply the shading effect of the trees (without even considering their metabolism) is a very significant urban heat island reducing factor on its own (Olah, 2010b).

Pavements

It is necessary to highlight pavements among the urban land cover types strengthening the urban heat island. These are typically artificial (mostly concrete) or natural stones, furthermore concrete and asphalt surfaces. The majority of roof cover materials also belong to this category, e.g. ceramic tegula covering, bituminous flat roof pavements. The common feature of these materials is that their specific heat is relatively low, which means that they warm up very fast, furthermore the rainwater flows off from these surfaces in almost 100%.

In the aspect of the heat balance the above facts together mean that these pavements are in many orders of magnitude poorer than the natural covers. Depending on the colour of the given artificial paving the warming effect can be 10°C or even more – the darker the pavement, the more it warms up, namely the bituminous flat roof cover and the asphalt pavement are the worst (Olah et al., 2010).

Glass and metal covered buildings

Glass and metal covered buildings need to be mentioned separately. These are typically huge institutional or commercial buildings, e.g. the new Coliseum (which is totally covered by metal) or large shopping centres (e.g. Arena Plaza), which usually have huge glass transom-windows *(Fig. 3)*.

These buildings have practically become the hottest spots of the entire city immediately after their completion *(Fig. 4)*, taking over the leading position from the industrial territories, e.g. railway stations, factories, power plants (Olah, 2010a).

Figure 3. *The new buildings: Arena Plaza and the Coliseum, the hottest points of the city.*

Figure 4. *The effects of the new buildings: new hot points and absolutely new thermal distribution appear on the image shot on 6th May 2008 (right) unlike the previous image shot on 4th May 2002 (left)*

Different built-up types

The qualitative analysis of the 6th district of Budapest based on the image sequences featuring the threshold temperatures *(Fig. 1)* confirms the connection between the urban structure and the sky view factor (SVF), and the structure of the urban heat island, pointed out in the thesis of Gál (2009). Essentially, the urban land use forms and the surface temperatures of the examined area are the followings: those urban blocks, which fall eastwards from Bajza Street are significantly cooler than those, which fall westwards (towards the city centre) from this line *(Fig. 5)*. This street appears to be a significant borderline also in the urban fabric, for on the western side there is a continouosly built-in row of buildings, while detached standing buildings (villas with gardens) can be found on the eastern side. In the case of continous rows of buildings the sky view factor (SVF) is much smaller in the first place than in the case of any other built-up types. In the current case this is the only real difference between these two urban areas, as all other features (usage intensity, number of building levels) the differences are only minor.

Figure 5. *The role of the different built-up types: next to the City Park (towards the city centre) can be found a small cooler area represented by yellow color on the left infrared image, which can be exactly coupled with the detached built-up type area represented on the regulation plan (right). The infrared image was shot on 6th July 2001.*

Summary of the results

By summarizing the results we came to the conclusion that the factor predominantly responsible for the urban heat island is the albedo of a given area. In the case of artificial surfaces this is truly the most significant factor; however, in the case of natural surfaces other kinds of effects appear as well, e.g. the metabolism of the vegetation, biological activity and evaporation (Olah, 2011). The increase of both the biological activity and the evaporation causes the decrease of the temperature in the given area. It is very important to mention the water surface separately, which is basically considered as a natural surface; however, in this case it is unnecessary to calculate with such complex effects like plant metabolism. The primary aspect of the examining of the water bodies is its vaporizing ability, but its extremely high specific heat is also very important (if not even more important), as it enables the water bodies to very effectively decrease the daily temperature fluctuation.

Discussion

Discussion is relatively difficult in this case, as the aim is creating specified directives and guidelines for urban planning, for open space design and architectural design based on the results and particularly the conclusions of detailed urban meteorological examinations.

Nevertheless it must be declared that the results of this study are in accordance with the results of the professional literature and mostly certify and specifies the anticipations. The most important point is that the phenomenon of the cool island generated by large urban green areas, parks (called park cool island PCI) was unequivocally detected during this research as well, which is fully in accordance with the results of Szegedi and Gyarmati (2009). Moreover, thanks to the good spatial resolution of the utilized satellite images it was possible to make some statements about the structure of the given green area from the aspect of their urban heat island

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modifying ability. As against the anticipation, in certain special cases the spatial resolution of the applied satellite images enabled the possibility of a more accurate analysis than on the level of urban blocks. However, occasionally this more accurate analysis could only be a qualitative measuring, due to the strong limits set by the spatial resolution.

The most important result of this research is that it became possible to rank the different types of land covers in the aspect of the urban heat island. The consequences of this fact are particularly promising, since they provide the opportunity of a kind of feedback, namely the conscious influencing of the urban climate with the tools of urban planning, open space design and architecture.

The unequivocal detection of the park cool island (PCI) in Hungarian setlements (Szegedi and Gyarmati, 2009) provides the opportunity of a feedback, for the establishing of an urban park in a city is unequivocally a good example of urban planning and development because this way the urban climate can be consciously formed in a positive direction.

In point of the energy balance of settlements the role of the water bodies is extremely important, on the one hand as huge vapourizing surfaces, and on the other hand as huge heat reservoirs, which can very effectively balance the urban climatic conditions with a special regard to the daily temperature fluctuation. This fact is evident on a larger scale for everyone, but the detailed survey has proved the positive effects of relatively small water bodies as well.

The final conclusion of this study is that we got detailed data about the different urban heat island generating effects of the different urban surfaces. Moreover it was also proven that huge commercial buildings eventuates directly enormous heat impact on their environment. On the strength of this research the urban planning, the open space design and even the (building) architecture can have such new priorities which can eventuate the minimizing and preventing the development of the urban heat island phenomenon both locally and on the scale of the whole city. We have the opportunity and the tools of consciously influencing the urban climate in a positive direction, mainly by creating urban tree stands and green surfaces, furthermore by creating water bodies in greater size, number and density with the help of creating more environment conscious regulation plans and rules.

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SUSTAINABILITY AND GREEN DEVELOPMENT IN URBAN POLICIES AND STRATEGIES

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Abstract. Adaptation to climate change is increasingly becoming a priority for policy action. In April 2009, the European Commission released a White Paper outlining a proposed framework for action to reduce vulnerability and adapt to climate change (European Commission, 2009). The White Paper refers to the importance of a climate adaptation strategy and sustainability that integrates all areas of regional and municipal development including agriculture, forestry, fishery, energy, public infrastructure (incl. building, transport, energy and water supply), tourism, human, animal and plant health, water resources and ecosystem loss (including marine ecosystems and biodiversity). One of the main issues is how to and why integrating the green developments into urban policies. In this paper we show the main objectives of London's greening program, and some possible elements of the green developments in Csömör's adaptation strategy. Comparing the two examined cities there are differences according to their size, population, greening possibilities and financial backgrounds. However, it can be seen that the focus points of the adaptation strategies are more close to each other.
Keywords: *climate change, sustainability, urban policy, green development*

Sustainability and urban policy

The significance and relevance of sustainable development is not to be contested, as it is clear that the anomalies in natural cycles and the reproduction of goods endanger human existence. The term sustainable development by the definition of United Nations World Commission on Environment and Development (Brundtland Commission, 1987) is “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”.

Sustainable development is a global ambition and the European Union assumed significant role in fostering the practical implementation. Furthermore, sustainable development is one of the fundamental objectives of the EU, as confirmed in its Treaty as well.

In 1992, on the first Earth Summit (Rio de Janeiro), the European Community made a commitment to implement sustainable development. In 2001, the Gothenburg European Council adopted the EU Sustainable Development Strategy. This Sustainable Development Strategy was renewed in 2006. In 2007 and 2009, progress reports were published according to the EU Sustainable Development Strategy.

The EU Sustainable Development Strategy recognized that holistic approach is a basic need to enhance the realization and in the long term environmental protection,

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social cohesion and economic growth has to develop collateral. The main threats of sustainable development related to the future well-being of European society were defined in the Gothenburg EU Sustainable Development Strategy:

- Possible effects of climate change;
- Severe threats related to public health, food safety;
- Poverty and social exclusion;
- Ageing of the population;
- Loss of biodiversity;
- Eroding agricultural land;
- Increasing waste volume;
- Transport related problems.

In relation to the issue of climate change it is worth mentioning that from the viewpoint of the both term sustainability and climate change a holistic approach is needed to be able to examine the interactions, moreover to find the possible solutions. According to the statement of the IPCC Report climate change can be one of the biggest dangers, risk of sustainable development. Nevertheless, the third report of IPCC emphasized in relation to sustainability that it can be an advantage in the mitigation of climate change (IPCC, 2001; IPCC, 2007). In 2006, the Renewed EU Sustainable Strategy identified 7 key challenges:

1. Climate change and clean energy;
2. Sustainable transport;
3. Sustainable production and consumption;
4. Better management of natural resources;
5. Public health threats;
6. Social inclusion, demography and migration;
7. Fighting global poverty.

Sustainability – which is a way of thinking, life, production and consumption – covers all dimensions of human existence, its relation to natural resources, the economy and society. Sustainability can be the solution – beside research and development processes – to global problems like globalising economy and market competition, global warming, poverty and famine. The actions of the United Nations from Rio to Johannesburg and EU decisions seem to underpin this.

It seems to become evident from previous experiences that among the levels of sustainability (global, regional and local) the local level is where the implementation of sustainability can be actually highlighted, in accordance with the interests of local communities (Csete, 2009). On local level, especially in the cities, urban policy and planning has significant role in case of each key challenges that were defined in the Renewed EU Sustainable Development Strategy (2006).

Sustainable urban development has been firstly highlighted in the social research (Banister and Button, 1993; Owens, 1992; Rickaby, 1991). It has been continued by an increasing awareness in Europe and in other parts of the world. Recently, the European ministers responsible for urban policy and spatial development also have been realized the importance of sustainable development related issues. In 2007, the Leipzig Charter on Sustainable Cities and the Territorial Agenda of the European Union highlighted the role of local strategies, urban policy and planning tools in order sustainable urban development. Furthermore, joint objectives were identified and possible solutions were evaluated.

The adoption of the Leipzig Charter shows the growing importance of urban areas in social, cultural and economic issues. On the other hand, it is pivotal to underpin the emissions of urban lifestyle and the possible green developments in order to decrease the negative externalities. The central message of the Charter is the importance of "integrated strategies" and "coordinated actions". In favour of this message a reviewed institutional background is needed. The sustainable, healthy and environmental friendly cities are important for all levels of governments (local, regional, national).

In addition to this, the Leipzig Charter focuses on two key objectives. Firstly, an integrated urban development should be applied in Europe. Secondly, the especially disadvantaged urban neighbourhoods have to become an important part of the integrated urban development policy. The Charter identified 5 main problems on which urban policy should concentrate:

1. Dealing with deprived neighbourhoods;
2. Improving the public spaces;
3. Modernising infrastructure with a focus on saving energy;
4. Better education for young children and refresher training for workers;
5. Better and more efficient public transport in and between cities.

The Leipzig Charter can underpin the increasing role of green developments focusing urban policy tools related to energy efficiency, energy saving, sustainable mobility, development of green areas and the take into consideration their environmental services as well. All of these factors play pivotal role in the urban quality of life as well (Nijkamp and Perrels, 2009).

In 2008, the Marseille Statement also reconfirmed the main focus points of the Leipzig Charter and in addition draws special attention to the importance of the possible impacts of climate change on urban territories. Besides a practical toolkit development has been also decided toward the better understanding of common sustainability goals. The basic concept was the forming of a common European Reference Framework for Sustainable Cities.

In summary, it can be stated that sustainable cities have increasing importance according to global environmental phenomena and living circumstances. Sustainable cities are cities where socio-economic interests are brought together in harmony with environmental and energy concerns in order to ensure continuity to change (Nijkamp and Perrels, 2009).

The "Green" in urban policy

Nowadays facing the ecological and climate related problems in urban policies, is one of the biggest issues of municipalities. Most cities are met with similar environmental problems, such as high levels of traffic and congestion, greenhouse gas emissions, poor air quality, high noise level, urban sprawl, poor quality built environment and the treatment of wastewater and waste. The increasing resource utilization of the urban inhabitants plays a significant role in these negative externalities caused mostly by the changes in urban lifestyle. Furthermore, these problems are strictly related to poverty and socio-economic conditions as well.

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It can be stated that climate change is a growing problem for urban areas. Actions on local level are important both in adaptation (protection against the possible effects) and in mitigation (decreasing or slowing down the effects of climate change). Climate change can have direct impact on urban areas caused by extreme weather conditions, floods, droughts, soil damage and erosion etc. Cities are peculiarly vulnerable to the possible effects of climate change and the inhabitants need to be protected from risks related to their health or well-being. The mitigation or adaptation actions can lead to the reduction of cities environmental performance. The new urban policy tools and solutions may resulted in new economic opportunities and investments through cleaner technologies, eco-innovations etc. Thus cities also can have major role in fostering environmentally friendly industries, technologies, products and last but not least sustainable lifestyle. The green surface proportion of settlements also plays significant role especially related to city-climate effects (Bakay, 2012).

More than half of the world population living in urban areas, thus the sensitivity and the vulnerability is higher than at the countryside. For instance, currently over 70% of EU citizens live in urban areas and most of the EU’s population live in medium-sized (over 50 000 inhabitants) cities (EC DG for Regional Policy, 2009). According to this, 25% of the US population lives in metropolises (over five million inhabitants) against the 7% in the EU-27. There is no doubt that cities have increasing importance in regional development.

Realising the above mentioned problems the main task in urban policies is how to build the “green” into the adaptation strategies. The significant consequences of green developments are:

- Keeping and increasing the green spaces;
- Care about the urban ecosystems and stop the biodiversity loss;
- Rule and ease the urban microclimate;
- Improve human health, the quality of living;
- Increasing adaptation;
- Blunt the effects of harmful meteorological events.

Green areas can help to regulate floodwater, mitigate urban heat, improve air quality and provide space for sustainable social activities. The related environmental services and those economic, social and environmental benefits have increasing importance in sustainable and climate friendly urban development (Westphal, 2003). Not only the green areas however the related positive externalities are threatened by heat stress and flooding (worse by climate change) but also by urban sprawl and development; they are the same time becoming more valuable and more threatened. For instance, special examinations were focusing on the green surfaces of the housing estate in Budapest. The main aim of this research was to elucidate how these green areas can influence the urban ecological system of a city (Bakay, 2012) and due to the results the open space- and green-system planning can be developed in accordance with mitigation and adaptation efforts.

In case of initiating urban climate policies and strategies, the developers should follow some simple, but very important key rules. There is no doubt that cities are dynamic and complex systems. Climate change will interact with existing urban problems: some problems will get worse, some new problems will emerge. Vulnerability to climate change is definitely concentrated in cities, and urban climate change adaptation strategies need to be developed to integrate with – and build on –

existing sectoral and cross-sectoral agendas at the city level. However, old solutions will not solve new problems. Urban adaptation requires innovation, learning and new governance structures. Complexity and uncertainty present real barriers to decision-makers on the ground, particularly give the complex interaction of vulnerabilities at the city level. No single type of measure is able to eliminate vulnerability to climate change, a portfolio approach, for example combining institutional, technological and infrastructure responses, is likely to be the most effective.

In the frame of the GreenKeys project a Guide For Urban Green Quality (Costa et al., 2008) was developed in order to foster new urban green policies. The GreenKeys project was part-financed by European Union Community Initiative INTERREG III B CADSES and the German Federal Ministry of Transport, Building and Urban Affairs. The GreenKeys Guide is focusing on problem solving and containing methods, tools and the available case studies and best practices in the 12 cities of 7 countries. It describes the approach for formulating Urban Green Space Strategies and gives useful recommendations for the management of urban green spaces.

Adaptation to climate change occurs through adjustments in human and natural systems to decrease vulnerability in response to observed or expected changes in climate and associated extreme weather events (SEC, 2007). It involves changes in perceptions of climate risk and in social and environmental processes, practices and functions to reduce potential damages or to take advantage of new opportunities. Adaptation is a cross-sectoral, multi-scale and trans-boundary issue, which requires comprehensive and integrated modelling methodologies (Uhel and Isoard, 2008) in urban planning as well.

Mitigation and adaptation are closely related and should be considered together rather than separately (Csete and Szendrő, 2011). Fostering local sustainability can also play an important role both in adaptation and mitigation strategies according to the precautionary principle causing several positive externalities and synergic effects (Biesborek et al., 2009). Urban green spaces are important in adaptation, however they also have role in mitigation as well. All kind of urban green areas contribute to the adaptation of cities to the possible effects related to climate change. Furthermore, open spaces within cities support adaptation more efficiently compared to greenbelts. According to mitigation due to green spaces the plants clean the air, reduce CO_2 level, their cooling effect decrease the demand for energy-intensive appliances, e.g. air-conditioning (Ministry of Interior, Hungary – VÁTI, 2011).

Different modes of local governance can be applied by the municipalities, regardless of the settlement size, in order to strengthen mitigation and adaptation activities (Bulkeley and Kern, 2006) These main types of governing climate change are usually utilized in parallel on local level: self governing, provisions, regulations, enabling and partnership (Bulkeley et al., 2009). All five local governing types can underpin urban greening programs. Self-governing is mainly focusing on the activities and organizations of the municipalities mainly focusing on mitigation. Provisions are related to the services or the municipality, such as the ability to ensure climate-friendly transportation, energy consultancy or direct financial support that can help to improve green areas as well. Regulation is usually focusing on the implementation of national laws and different kinds of regulations related to climate change. Occasionally the local regulation can be stronger than the national one that can be useful for the green areas related environmental services and those socio-economic benefits as well. Enabling means the ability to motivate different settlement stakeholder groups in order to foster the practical implementation of mitigation and adaptation actions. The motivation usually means providing useful information. Partnership can help to manage local climate actions between different non-state and state stakeholders.

There are settlements on different levels with divergent characteristics (e.g. amount of local incomes, level of GHG emission, share of green surfaces, possible effects related to climate change, vulnerability, number of residents etc.) that can basically influence the possible urban greening management tools. The aim of the case studies is highlighting urban greening programs and activities as part of urban adaptation strategies. This article is focusing on two special settlement types in Europe. One of them is a well-known megacity that has over 10 million inhabitants. Despite the huge number of stakeholders the city has leading role in climate change related urban activities that can give good examples for other cities as well. The other example is a Hungarian city located in the suburban region, in the commuter belt of Budapest. The examinations highlight the possible adaptation tools and urban policy developments in this settlement to be able reinforce the urban greening activities in the settlement.

Urban greening programs, a case study: London

London was one of the first cities that established an urban greening program as a part of its adaptation strategy. Developing urban greening programs is one of the best solutions to fight against climate change and to foster the practical implementation of more sustainable and resilient cities. Urban greening offers improvements in air, water, and land resources by absorbing air pollutants, increasing water catchment and floodplain surfaces, and stabilizing soils. Urban forests act as temperature buffers providing shade in the summer, and wind break in the winter in addition to reducing noise pollution and CO_2 levels, and providing a habitat for wildlife. Lastly, the overall benefits to society, particularly to low-income residents, are significant. They include the contribution of trees and vegetation to the mental and physical health of the populace, and the provision of recreational opportunities and an outdoor classroom for environmental education. In addition, they provide aesthetic improvements to an environment otherwise dominated by asphalt and concrete.

Effectiveness of greening

One of the key objectives of the urban greening programs is to reduce the risk and sensitivity of people, property and nature to the urban heat island effect and surface water flooding.

The measure aims to address the adaptation challenges of river floods, intense precipitation, drainage and flash flooding, heat waves and urban heat island effect, increased health and disease and biodiversity loss. An urban greening programme has standalone benefits, so even if climate scenarios and socio-economic scenarios change, increased green space will still be effective.

Side effects

The urban greening programs have numerous side benefits including conservation of biodiversity and improving air quality, which enhance quality of life at the neighbourhood level. Also has the potential to improve public health and some elements of the programme are designed to meet social objectives, such as reducing current areas

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of deficiency for access to nature. In particular, street tree planting has been prioritised according to the coincidence of areas with lowest street tree density; areas of multiple deprivation; poor air and noise quality; and, areas of deficiency for access to nature.

Climate change mitigation

Extensive tree planting can make a small contribution to carbon sequestration; also possibility for use of trees as carbon neutral fuel source for combined heat and power etc. Green roofs can provide additional insulation, thereby reducing energy usage.

Environmental objectives, conservation of biological diversity

Habitat creation can be through woodland creation and improvement/linking of existing green space. Increasing vegetation cover (especially trees) can help improving air quality. A climate change adaptation driven programme could have adverse impacts by encouraging creation of low grade habitat (e.g. secondary woodland) on existing high quality habitat (e.g. flower-rich grassland). Increasing tree cover can increase the pressure for water resources, especially in warm summers. However, this risk is somewhat mitigated by choosing the right tree species and the right locations, with the projected impacts of climate change in mind.

Economic objectives

Increased green cover can have important economic benefits for both residents and businesses in terms of increased property value and desirability. Green roofs can increase the lifetime of a flat roof membrane, reducing the frequency at which roofs need to be replaced. Green infrastructure as a whole also acts to attenuate rainfall, reducing the total volume of water that enters sewers (and thus requiring treatment) and can reduce the adverse economic impacts of surface water flooding. Beside the environmental objectives, the climate security is a very important issue. Planting of street trees has been overseen by expert bodies in order to reduce the risk of trees causing damage to buildings.

Quality of life/social objectives

The programs have the potential to improve public health and some elements of the programs are designed to meet social objectives, such as reducing current areas of deficiency for access to nature. In particular, street tree planting has been prioritised according to the coincidence of areas with lowest street tree density; areas of multiple deprivation; poor air and noise quality; and, areas of deficiency for access to nature.

Adaptation strategy and urban policy at Csömör

Csömör is located in the Region of Central Hungary. It is a suburban town near to Budapest, basically a sleeping city with approximately 9000 residents. In 2011 the Municipality of Csömör decided to develop an adaptation strategy. Our examinations related to Csömör are focusing not only on a climate change strategy, but to cover the existing other related development programs and local strategies. Behind the decisions some practical reason stands. It is very clear, that the new developed strategy should cover all the existing programs, from the urban greening programs, the environmental programs and the urban development programs as well. Because it only can work if everything is under the adaptation strategy in order to foster the practical implementation of local sustainability.

As Csömör has a big area around the town, and most of the area are industrial parks. The other usable area's ownership structure is very divers. Thus the biggest challenge is, how and where to develop new green areas.

Recommendations, possible developments

Horse stables

After the financial crisis Csömör faces new challenges. The municipalities can't continue the inner city greenings, like urban forestry, developing public parks. They should develop a new strategy related to greening which could be self-supporting and could satisfy the needs of greening program, mitigation needs, and beside that it could create new jobs in the town. The town is the first in the world in the numbers of horse stable/capita. It is now obvious, that the town should open into this direction. It is important to be able to produce enough hay or food for horses. This is not the best solution, but could satisfy most of the needs.

Energy cooperation

To other unbalanced fact is, that near to Csömör there is a big factory is located that needs energy. The company decided to change to use renewable energy, mostly biomass. The other development trend could be the reforestation on the surrounding area, and to produce energy wood. In the co-working, the town could provide enough wood to factory. Beside the mitigation, it could be used as a recreational forest, which is very common in that area.

Involve the residents

In the town the residents are living in family houses, and of course they care about their small environment. The municipality do everything to help them, but there are no clear directions, how to help them. In these years, when the residents are in difficult financial situation, the solution could be to help them to learn the urban gardening. On one way they will care about their gardens, the produced vegetables or orchard could be higher quality, and they can involve into the greening the mostly private, but unused areas. Re-entering the “Tiszta udvar, rendes ház” (Clean yard, clean house) certificate could generate a competition between the residents.

The possible developments can be useful for local decision-making support especially in case of climate action. According to our recommendations it needs to be emphasized that four main modes of adaptation can be defined: passive, direct, indirect and non-climate-friendly adaptation (Csete and Szendrő, 2011). Green area related developments mainly belong to indirect adaptation tools e.g. urban planning tools in order to decrease urban heat island effect, shelterbelt development, open spaces, rainwater storage, irrigation etc.

From the above mentioned recommendations, it is clear that the municipality has a lot opportunity in urban greening. But for support these suggestions, they need to develop a new integrated strategy and examine the possible solution and all the additional benefits, which could lead Csömör and its resident to live in a sustainable, green and not vulnerable way. However, based on our on-site interviews it can be stated that the practical implementation can be endangered mainly, regardless from the financial uncertainties, by the lack of awareness and environmental or climate consciousness of local inhabitants.

Summary

The role and importance of urban green spaces was highlighted in the present paper. Developing urban greening programs is one of the best solutions to fight against climate change and make sustainable and resilient cities. Furthermore, the improvement of urban green spaces can be a pivotal step towards more sustainable cities. To be able to enhance the positive externalities of urban green areas it is crucial to analyse the current state of the green spaces of the examined city. The physical, functional, ecological and economic aspects of green spaces need to be evaluated and monitored. Physical aspects can be qualitative (e.g. site structure and condition, historic and cultural values etc.) or quantitative (e.g. average of the city territory, m^2 of urban green space per inhabitant, grassland and water areas etc.). Functional aspect is linked to accessibility; the ecological aspect is mainly focusing on the ecological values, biodiversity, environmental issues influencing human wellbeing etc. Finally, the economic aspect is focusing on the costs of the maintenance and the planned developments. Moreover it can give an outline related to the financing background that is crucial for the practical implementation of urban greening projects. The identification of local needs and demands, the involvement of local stakeholders also play significant role in urban green spaces development. It is fundamental to define strategic issues and priorities in order to develop an effective urban green space management plan fostering the liveability of cities. Summing up, it can be stated that urban greening plays significant role in enhancing the quality of life. This pivotal role can be encouraged by careful thought and planning regarding the countless potential socio-economic and environmental benefits due to urban and community greening programs. Through enhanced experiences of green landscapes and programs fostering active involvement in greening, green urban policies and strategies can be a very real part of the solution.

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STUDIES ON ESTIMATION OF LEAF GAS EXCHANGE OF ORNAMENTAL WOODY PLANT SPECIES

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Abstract. Instrumental measurements were carried out on urban tolerant *Acer, Fraxinus*, and *Tilia* species and varieties in the Buda Arboretum (N 47°28’47.7” E 19°02’19.6”) in order to evaluate differences between their photosynthetic and gas exchange performance. Stomatal conductance, transpiration, net photosynthesis and photosynthetic active radiation (PAR) on sample leaves were measured and calculated using the LCi infrared gas analyzer (IRGA). Meanwhile the photosynthetic activity (net CO_2 assimilation) of leaves showed correlation to PAR, stomatal conductance and leaf temperature, there are significant differences found between genera and species of urban trees, which suggests that their CO_2 assimilation capacity differs. This influences the value of genera and species considering the urban air cleaning due to their CO_2 fixation. Under the examined conditions leaves of *Tilia* sp. showed higher photosynthetic capacity compared to *Acer* or *Fraxinus* sp. The transpiration rate of leaves correlates to stomatal conductance and leaf temperature. The low transpiration rate of *Fraxinus excelsior* ‘Westhof’s Glorie’ leaves suggests more economic water use. We also found considerable differences in water use efficiency (WUE) between species and genera. *Tilia* sp. *Acer platanoides* and *Fraxinus excelsior* ‘Westhof’s Glorie’ showed higher WUE compared to *Acer negundo*.
Keywords: *CO_2 fixation, stomatal conductance, transpiration rate, water use efficiency, urban trees*

Introduction

Due to a long selection process the studied tree species and varieties (*Fraxinus excelsior* ‘Westhof’s Glorie’, *Tilia tomentosa* ‘VI’, *Acer platanoides* ‘Crimson King’) adapted well to urban climate. Besides their aesthetical and theoretical values the currently used species and varieties in urban areas also help to make the human environment much more comfortable due to their CO_2 fixation and water vapour emission. Calculations were made recently to estimate their value expressed in money to aid the efforts of protecting the trees (Radó, 1999; Jószainé Párkányi, 2007). There is little information about the yield on environmental benefits of urban trees and there are only few references about systematic measurements.

Knowledge about the CO_2 fixation and water vapour emission of trees and shrubs has to be confirmed with onsite instrumental examinations to get actual information. There are little reliable data about LAI values and photosynthetic activity of such trees and shrubs which are exposed to various stress factors (air pollution, drought, human impacts) in different environmental conditions. Trees in urban spaces are exposed to several harmful factors (heavy metal accumulation on and in them, drought- and heat stress, human impacts), so it can easily be seen that these trees have to cope with significantly different conditions than the ones living in forests.

Series of measurements began in autumn 2010. The aim of our *in situ* instrumental examination on urban park-trees was to evaluate their photosynthetic activity, water use efficiency and developing methodology for accurate instrumental examination, which can be used in cities and can estimate the trees' health state, photosynthetic activity and their impact on the urban microclimate and air quality.

Review of literature

There are estimated values for CO_2 assimilation and H_2O emission mainly from earlier studies under forest conditions carried out on trees between 20 and 90 years of age (Radó, 2001). Urban climate, of course, creates different environmental conditions. Several studies emphasized the importance of environmental conditions for leaf gas exchange. Endres et al. (2009) found that light environment influence the CO_2 fixation. The correlation between PAR (photosynthetic active radiation) and photosynthetic rate of *Tabebuia chrysotricha* differs depending on light environment: the correlation was stronger (R^2=0.6699) at plants grown under shade and lower (R^2=0.29) at plants grown in sunlight. They also found different correlation levels between PAR and leaf temperature (R^2=0.86 under shade; R^2=0.25 in sunlight), and between PAR and water use efficiency (R^2=0.71 under shade; R^2=0.4299 in sunlight). Fini et al. (2010) studied the effect of light environment to leaf gas exchange and found that response to shade is species-specific. *Rhododendron hybr*. responded to shading by decreasing its transpiration and stomatal conductance. Shading increased carbon assimilation of *Choisya ternate* while *Viburnum ×pragense* showed a great adaptability to the different light environments: plants grown in full sun and under 60% shade had similar leaf gas exchange. Several studies on woody species have found increased photosynthetic activity in elevated CO_2 in controlled circumstances (Ceulemans and Mousseau, 1994; Curtis, 1996; Heath and Kerstiens, 1997).

In Spain, Gortan et al. (2009) measured daytime stomatal conductance on *Fraxinus ornus* in different drainage places and the average value was 0.3-0.4 µmol m^{-2} s^{-1}, the maximum measured value was 0.58 µmol m^{-2} s^{-1}. In Switzerland, Leuzinger et al. (2010) measured midday stomatal conductance in park and street circumstances and the results ranged from 0.124 to 0.247 µmol m^{-2} s^{-1} for all measured species, for example *Tilia tomentosa* (0.193 µmol m^{-2} s^{-1}), *Acer platanoides* (0.143 µmol m^{-2} s^{-1}) and *Platanus acerifolia* (0.247 µmol m^{-2} s^{-1}).

Several studies showed wide range of stomatal conductance measured on woody plants. On *Tabebuia chrysotricha,* Endres et al. (2009) measured average 0.14 µmol m^{-2} s^{-1} stomatal conductance in full bright and average 0.15 µmol m^{-2} s^{-1} under shade. Rodrigues et al. (2010) measured daily stomatal conductance from 8:00 to 18:00 and found maximum stomatal conductance in the morning on *Artocarpus heterophyllus* (0.78 µmol m^{-2} s^{-1}) and at noon on *Annona squamosa* (0.93 µmol m^{-2} s^{-1}).

Although it is generally assumed that stomata close at night, Daley and Phillips (2006), Snyder et al. (2003), Bucci et al. (2004) and Grulke et al. (2004) measured stomatal opening in some species. For example Daley and Phillips (2006) measured that the stomatal conductance dropped just by 25% in *Betula papyrifera*, but in *Quercus rubra* and *Acer rubrum* they measured the stomatal conductance approaching to zero.

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Considering the water use of *Tamarix chinensis,* Anderson (1982) measured that the plant transpires more than its own fresh mass each hour in bright sunlight conditions.

The measurements of photosynthetic activity and transpiration rate of the leaves are frequently used tools on horticultural crops, but raises questions of methodology when applied on urban trees. On fruit trees it has a great significance as a great part of the light energy absorbed by the leaves can be turned into yield (Hrotkó, 2002). Gyeviki (2011) measured 9-17 μmol m^{-2} s^{-1} CO_2 fixation and 4-10 mmol m^{-2} s^{-1} transpiration on cherry (*Prunus avium*) leaves in field conditions, while also on cherry, Noitsakis and Nastis (1995) reported 3-4 mmol m^{-2} s^{-1} and 10-20 mmol m^{-2} s^{-1} transpiration, in field and under shelter, respectively.

Materials and methods

We have chosen sample trees for the measurements (species from *Tilia*, *Acer* and *Fraxinus* genera) which are suitable for modelling urban park- or street-trees. For the sake of proper statistical evaluation and data comparability measurements were made in bright sunny weather (average temperature: 20.2 °C, air humidity: 57.67 %, maximum wind blow: 7.63 m s^{-1}) in the middle of September.

For the measurements we have chosen differently located trees in Buda Arboretum. The leaf gas exchange was measured using the LCi equipment on 10 leaves per tree in 4-5 repetitions, so in all we got 40-50 measurements on single leaves per each variety of trees.

To measure the photosynthetic activity, an infrared gas analyzer was used (LCi device of ADC Scientific Ltd.). It measured and calculated various parameters such as the H_2O and CO_2 exchange rates of the leaves, the atmospheric pressure, the temperature, the PAR (photosynthetic active radiation) value at the surface of the leaf, the CO_2 concentration between cells, the transpiration and stomatal conductance.

From among the measured data the photosynthetic active radiation (PAR), the surface temperature of the measured leaf, the transpiration rate, the stomatal conductance, the photosynthetic rate and water use efficiency (WUE) were evaluated.

The statistical analysis of data was carried out using the statistical software PASW18. Since the data were positively skewed and/or strongly kurtic, first a Box and Cox (1964) transformation was made. As the examined variables are strongly correlated we run a multivariate overall analysis of variance (MANOVA) with a fixed factor of the species and a follow-up between-subject analysis. We calculated the observed power using alpha=0.05 and we also considered the effect size measure (denoted by partial η^2) which gives the variance explained by a given explaining variable of the variance remaining after excluding variance explained by the other variables. Normality of the residuals of the MANOVA model was checked with d'Agostino (1990) test. Homogeneity of variances was tested with Levene test and in case the result was insignificant ($p>0.05$) we run a Tukey post hoc test, while in case it failed, we applied Games-Howell post hoc test, both indicate significance differences at $p<0.05$ level.

Correlation and multiple regression analyses were conducted to examine the relationship amongst stomatal conductance, transpiration, photosynthesis, leaf temperature and PAR in different model structures written in general form of

$$Y = p_0 + p_1 X_1 + p_2 X_2 + p_3 X_3 + p_4 X_4 + \varepsilon, \quad \text{(Eq. 1)}$$

where Y denotes the dependent variable (chosen one from leaf surface temperature, transpiration rate, stomatal conductance and photosynthetic rate),

X_i denote the explaining variables (selected suitably from variables PAR, surface temperature, transpiration rate, stomatal conductance and photosynthetic rate), multiplied by coefficients p_i and

ε denotes the normally distributed error term with zero expectation.

The explaining variables were chosen with stepwise method as the significance level of the *F* value of the model was below 0.05 and were removed from the model if the significance of the *F* value was over 0.1. The parameter estimations were tested with t-test. Normality of the error terms was proved with d'Agostino (1990) test ($p>0.05$). Since there was significant correlation between explaining variables, the tolerance was also calculated for each explaining variable. In case the tolerance was below 0.1, the model was reduced to a smaller number of explaining variables.

Results and discussion

During our measurements in Buda Arboretum in autumn 2010, leaves of *Acer*, *Fraxinus* and *Tilia* genera were investigated with the LCi device. The overall MANOVA test was significant (Wilk's lambda=0.027; $p<0.001$). The between-subject ANOVA was significant for all variables ($p<0.001$) with observed power higher than 0.99. The effect size was the highest of leaf surface temperature (partial η^2=0.219) followed by the ones of transpiration and stomatal conductance (partial η^2=0.581; 0.406, respectively). The effects of photosynthetic rate of leaves, water use efficiency and photosynthetic active radiation are low (partial η^2=0.379; 0.290; 0.219, respectively).

Photosynthetic active radiation (PAR) values measured on leaf

Considering the absorbed PAR values it is clearly visible that the measured trees were located in different PAR-exposed conditions (*Fig. 1*). The different PAR may greatly influence the photosynthetic activity of plants (Endres et al., 2009). These values were measured in a period from 12 am to 14 pm which means the highest radiation during the day. The more shaded *Acer platanoides* and *Tilia tomentosa* 'Balaton' trees were exposed to significantly lower PAR exposition compared to the free standing, sun-exposed *Tilia cordata*. This should be considered in further evaluation.

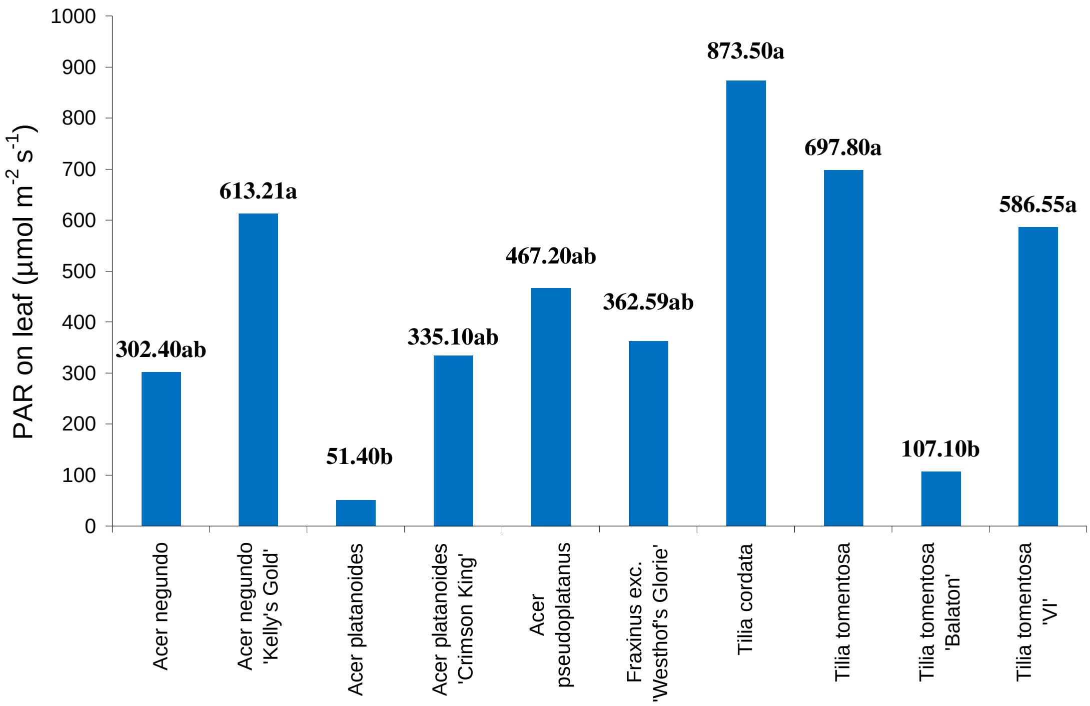

***Figure 1.** Average PAR values on leaves (µmol m^{-2} s^{-1}) of the measured plants. Different letters mean significant differences according to Games-Howell post hoc test ($p<0.05$).*

Leaf surface temperature

Considering leaf surface temperature there are significant differences found between the trees of different genera (*Fig 2*).

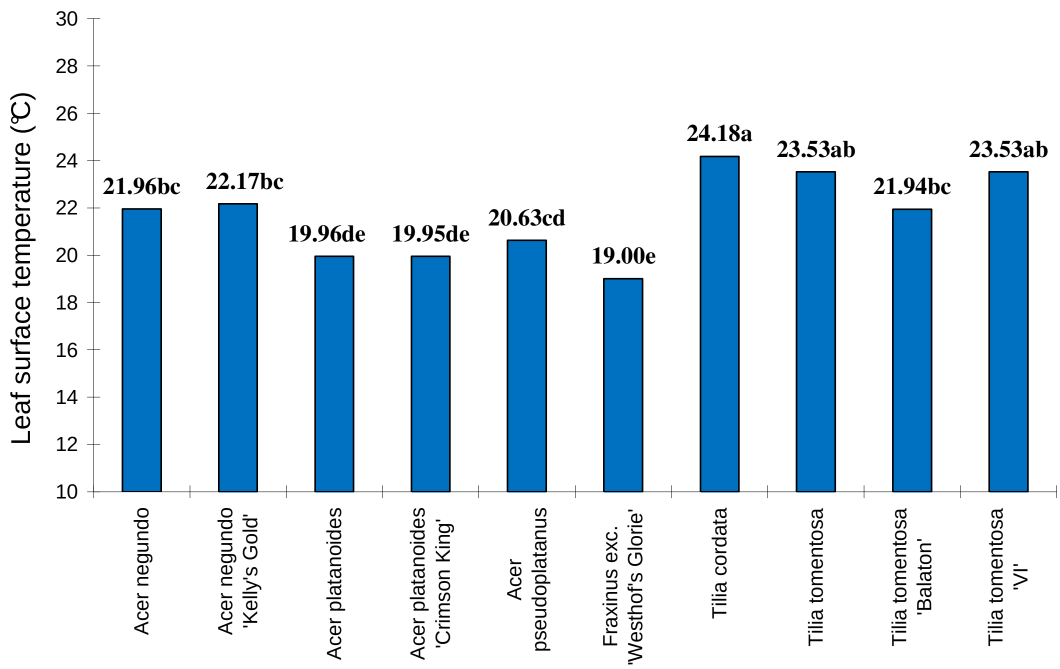

***Figure 2.** Leaf surface temperature (°C) with the mean values of the measured plants. Different letters mean significant differences according to Games-Howell post hoc test ($p<0.05$).*

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Within genus *Tilia* the low PAR exposed 'Balaton' did not show significant lower leaf temperature. Despite the great difference in PAR absorption, there is no significant difference in leaf surface temperature either within *Acer* species, or within *Acer negundo*. However, the PAR absorption differences are reflected in the leaf temperature, so we can say that the leaf surface temperature of the plant can be a subject of genera features under similar environmental conditions.

The results showed that at the same time and under same conditions three species of Tilia genus had the highest leaf surface temperature when PAR exposition was similar. The low PAR-exposed *Tilia tomentosa* 'Balaton' had some lower leaf surface temperature but it is not proportional to the low PAR values. Species from the *Fraxinus* genus had significantly the lowest leaf surface temperature in the measured period (*Fig. 2*) though the PAR exposition of the leaves was intermediate.

Table 1. *Regression diagnostics of the model of leaf surface temperature (°C)*

Model		Corr. R^2	Parameters		*t*	Toler-ance	*F* with df	Variance explained by the model
Dependent variable	**Explaining variables**							
Leaf surface temperature	constant		p_0	17.435	73.52***	-	(3;112) 130.34 ***	0.777***
	transpiration	0.723**	p_1	5.497	14.45***	0.146		
	photosynthetic rate	0.570**	p_2	0.172	6.00***	0.612		
	stomatal conductance	0.504**	p_3	-38.527	-10.65***	0.14		

*p <0.05; **p <0.01; ***p<0.001

Table 1 summarizes the regression analysis results: the bivariate correlation between the leaf surface temperature and the explaining variables such as transpiration, photosynthetic rate and stomatal conductance, the estimated parameters, the *t* values of the estimated parameters, the tolerance of the model variables, the *F* value of the ANOVA model test with its degrees of freedom and the variance explained by the model.

Table 1 shows that the leaf temperature depends from the tree's non-environmental conditions which is indicated by the significant correlation between the leaf temperature and transpiration, photosynthetic rate as well as stomatal conductance. The correlation is negative in case of stomatal conductance. The estimated parameters are all significant and the explained variance of the model is high (0.777).

Stomatal conductance of leaves

We have found significant differences in stomatal conductance between species and genera even under similar temperature which suggests again different responses to environmental conditions (*Fig. 3*).

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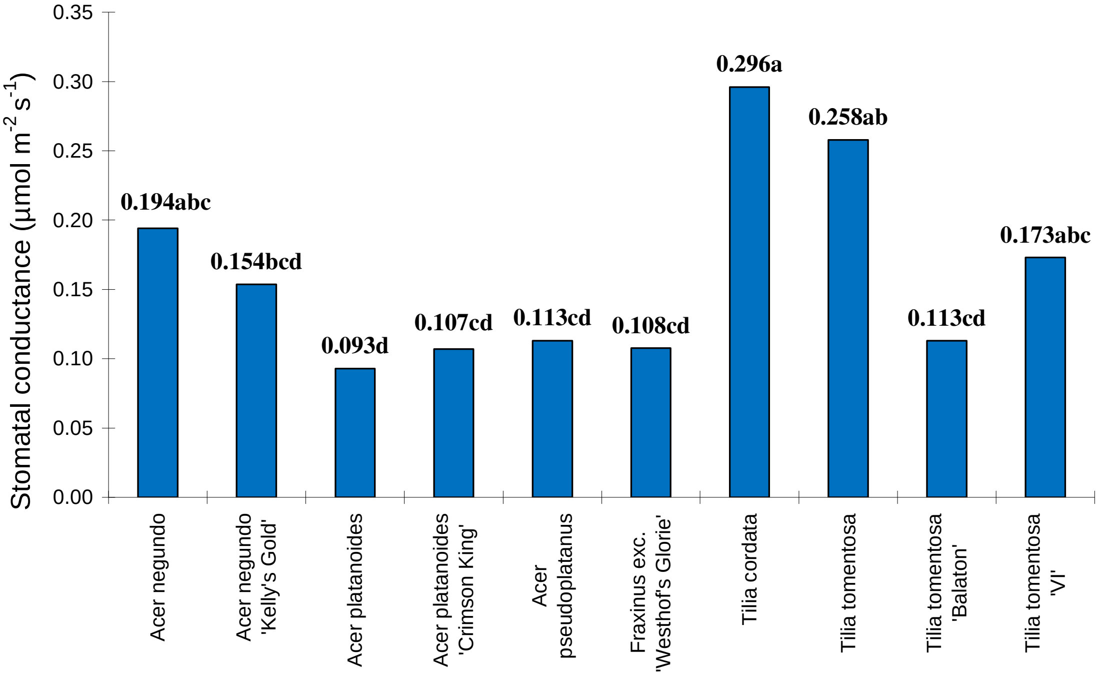

Figure 3. *Stomatal conductance (µmol m^{-2} s^{-1}) with the mean values of the measured plants. Different letters mean significant differences according to Tukey post hoc test (p<0.05).*

Table 2 summarizes the regression analysis results: the bivariate correlation between the stomatal conductance and the explaining variables such as transpiration, photosynthetic rate, leaf surface temperature and PAR, the estimated parameters, the *t* values of the estimated parameters, the tolerance of the model variables, the *F* value of the ANOVA model test with its degrees of freedom and the variance explained by the model.

The correlation between stomatal conductance and transpiration, photosynthetic rate as well as leaf surface temperature are all significant, the latter two variables are negatively correlated to stomatal conductance (*Table 2*). The estimated parameters are all significant and the explained variance is as high as 0.937.

Table 2. *Regression diagnostics of the model of stomatal conductance (µmol m^{-2} $s^{-1)}$*

Model		Corr. R^2	Parameters		*t*	Toler-ance	*F* with df	Variance explained by the model
Dependent variable	**Explaining variables**							
Stomatal conductance	constant		p_0	0.208	9.62***	-	(4;111) 414.27 ***	0.937***
	transpiration	0.924**	p_1	0.119	30.34***	0.42		
	photosynthetic rate	0.619**	p_2	0.004	6.80***	0.557		
	leaf surface temperature	0.504**	p_3	-0.012	-10.20***	0.429		
	PAR	0.367**	p_4	-1.20E-05	-3.52**	0.649		

*p <0.05; **p <0.01; ***p<0.001

Transpiration rate of the leaves

The leaves of trees of different species also showed significant differences in transpiration rate (*Fig. 4*). The results revealed that varieties *Acer platanoides, Acer platanoides* 'Crimson King'. *Acer pseudoplatanus* and *Fraxinus exc.* 'Westhof's Glorie'showed low transpiration contrary to the other measured species of this genus.

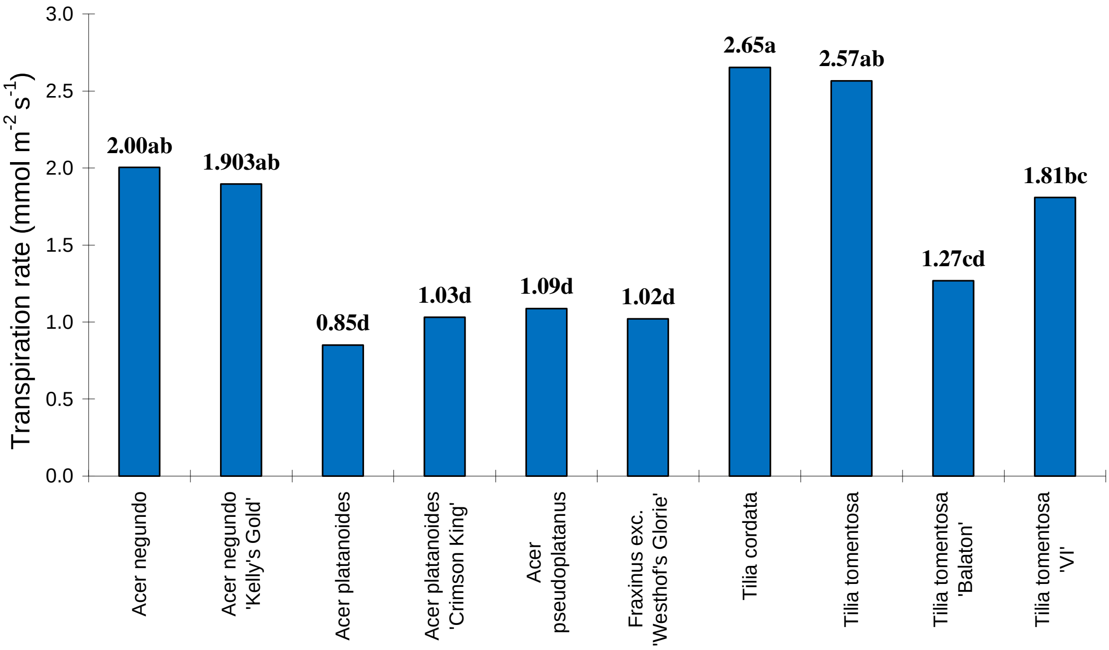

Figure 4. *Transpiration rate (mmol m^{-2} s^{-1}) with the mean values of the measured plants. Different letters mean significant differences according to Tukey post hoc test ($p<0.05$).*

Leaves of the *Tilia* genus had high leaf surface temperature and transpired more in the measured period than leaves of other species measured at similar PAR values. In comparison to *Prunus avium* leaves measured by Gyeviki (2011), ornamental trees transpired significantly less on a leaf surface basis. The transpiration rate measured on *Tilia tomentosa* leaves is close to the rate measured by Noitsakis and Nastis (1995). Within the *Acer* genus assuming proportional transpiration and PAR values, *Acer platanoides* 'Crimson King' transpirated significantly less, while *Acer negundo* transpirated as double as the other *Acer* species.

Table 3 summarizes the regression analysis results: the bivariate correlation between the transpiration rate and the explaining variables such as stomatal conductance, photosynthetic rate, leaf surface temperature and PAR, the estimated parameters, the *t* values of the estimated parameters, the tolerance of the model variables, the *F* value of the ANOVA model test with its degrees of freedom and the variance explained by the model.

Strong correlation was found between transpiration rate and stomatal conductance (*Table 3*). This is in correspondence with the results Gortan et al. (2009) measured on *Fraxinus ornus*. The transpiration rate of the leaves correlates with leaf surface temperature, too (*Table 1*), the highest transpiration rate was measured on leaves showing leaf surface temperature above 25°C.

The estimated parameters are all significant and the explained variance of the model is high (0.955).

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Table 3. *Regression diagnostics of the model of transpiration rate (µmol m^{-2} s^{-1})*

Model		Corr. R^2	Parameters		*t*	Toler-ance	*F* with df	Variance explained by the model
Dependent variable	Explaining variables							
Transpiration	constant		p_0	-1.799	-11.48***	-	(4;111) 585.77 ***	0.955***
	stomatal conductance	0.924**	p_1	7.487	30.34***	0.583		
	photosynthetic rate	0.600**	p_2	-0.023	-5.07***	0.484		
	leaf surface temperature	0.723**	p_3	0.109	13.34***	0.576		
	PAR	0.495**	p_4	1.03E-04	3.72***	0.656		

*p <0.05; **p <0.01; ***p<0.001

Photosynthetic rate of leaves

Although *Acer platanoides* 'Crimson King' and *Tilia cordata* showed greater differences in stomatal conductance, their CO_2 assimilation was higher which suggests differences in CO_2 fixation capacity of leaves (*Fig. 5*). The genus *Tilia* showed highest net CO_2 assimilation except for the tree 'Balaton' which was exposed to lower PAR value. Gyeviki (2011) measured similar CO_2 fixation values on *Prunus avium* trees in a high density plantation. The photosynthetic activity of the leaves of other species was significantly lower compared to *Tilia*.

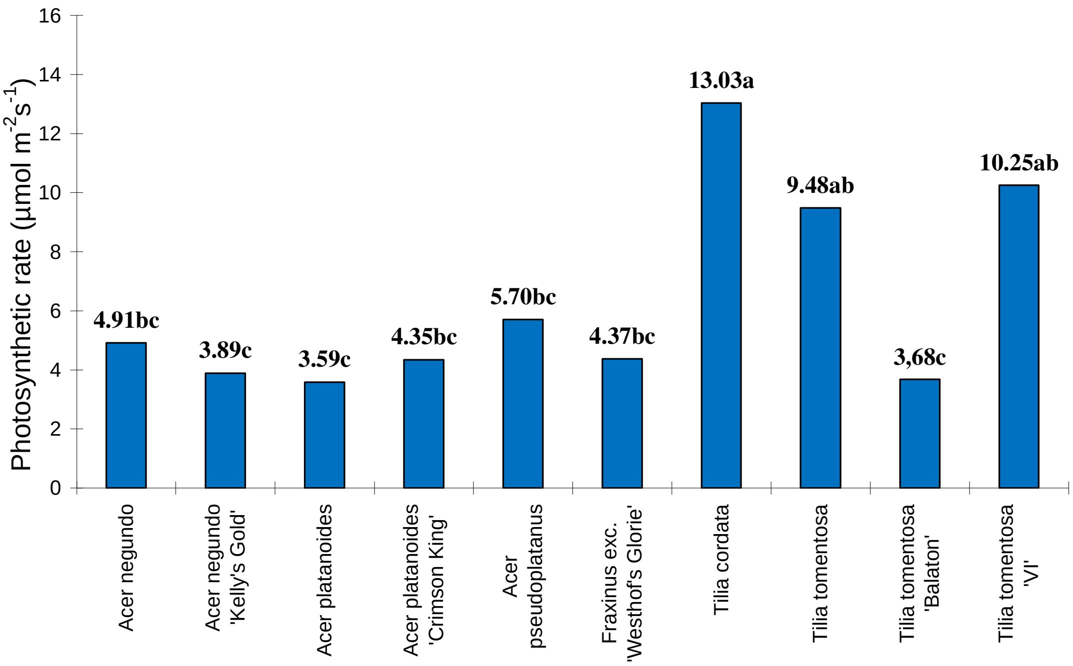

Figure 5. *Photosynthetic rate (µmol m^{-2} s^{-1}) with the mean values of the measured plant. Different letters mean significant differences according to Tukey post hoc test ($p<0.05$).*

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Table 4 summarizes the regression analysis results: the bivariate correlation between the photosynthetic rate and the explaining variables such as stomatal conductance, leaf surface temperature and PAR, the estimated parameters, the *t* values of the estimated parameters, the tolerance of the model variables, the *F* value of the ANOVA model test with its degrees of freedom and the variance explained by the model.

Table 4. *Regression diagnostics of the model of the photosynthetic rate of the leaves (mmol m^{-2} s^{-1})*

Model		Corr. R^2	Parameters		*t*	Toler-ance	*F* with df	Variance explained by the model
Dependent variable	**Explaining variables**							
Photosynthetic rate	constant		p_0	-8.332	-2.609*	-	(3;112) 39.80 ***	0.516***
	stomatal conductance	0.619**	p_1	24.753	5.32***	0.731		
	leaf surface temperature	0.570**	p_2	0.469	2.82**	0.617		
	PAR	0.519**	p_3	0.002	3.172**	0.715		

*p <0.05; **p <0.01; ***p<0.001

The correlation of net CO_2 assimilation rate of leaves showed significant correlation to stomatal conductance, leaf surface and PAR (*Table 4*). Though the estimated parameters are all significant together with the explained variance of the model (0.516), the latter value is the lowest compared to the other regression models which implies that other factors, like species or genus treats might be involved in correspondence to Endres et al. (2009) and Fini et al. (2010).

Water use efficiency (WUE) of leaves

Calculating the water use efficiency (WUE) significant differences were found between genera and species (*Fig. 6*). The leaves of *Tilia* species with high photosynthetic activity and high transpiration rate (*Fig. 4* and *Fig. 5*) showed intermediate water use efficiency. According to our measurement *Acer negundo* and *Acer negundo* ‘Kelly’s Gold’ have the lowest water use efficiency, here the low net CO_2 assimilation was accompanied with high transpiration rate (*Fig. 4* and *Fig. 5*). *Acer platanoides* showed the highest WUE.

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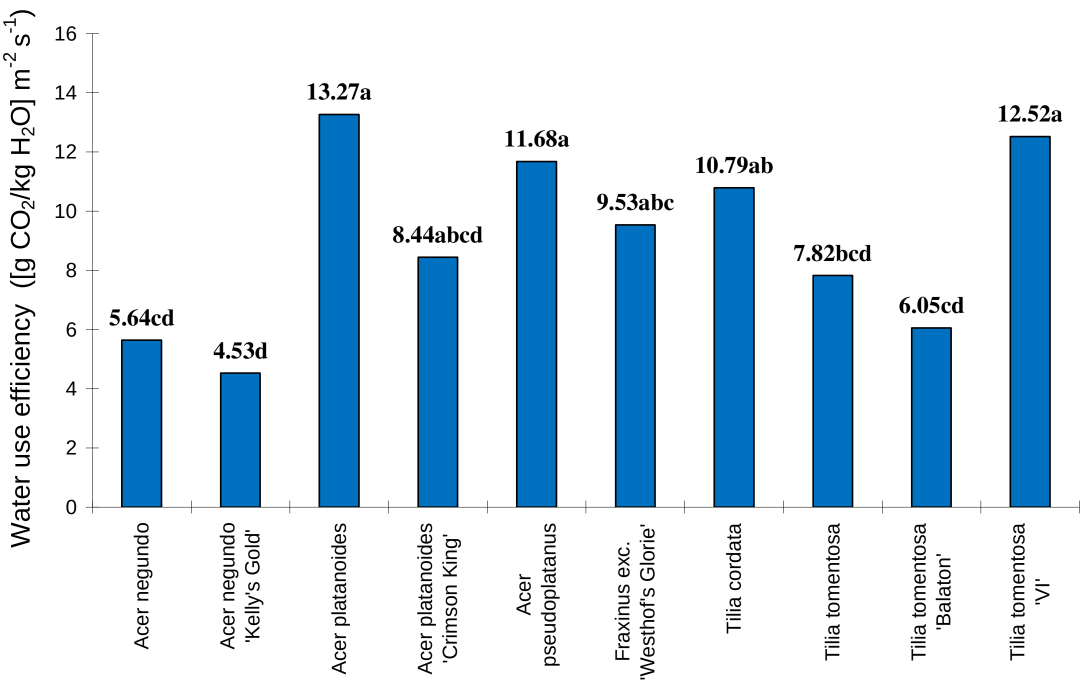

Figure 6. *Water use efficiency of leaves on the investigated plants ([g CO_2/kg H_2O] m^{-2} s^{-1}). Different letters mean significant differences according to Games-Howell post hoc test ($p<0.05$).*

Conclusions

There are considerable differences found in net photosynthetic rate and transpiration rate in leaves of different species and genera. As a consequence, these plants have different capacity of environmental benefits.

We showed that transpiration rate was strongly influenced by leaf temperature and stomatal conductance. Since these variables are altering during the day and the vegetation period, an accurate comparison of genera, species or cultivars would be needed under the same environmental conditions.

Further on, for an exact evaluation of the CO_2 assimilation capacity of the urban tree canopy and green space systems we should follow the daily and also the annual course of the activity of the leaves. To follow this course and to compare the species, varieties and site conditions more precisely, measurements should be carried out after the leaves have completely developed, through all day and in different periods of the year.

Only leaves exposed to direct sunlight were measured so far, which are playing the main role in photosynthesis, however, more shaded leaves also exploit some sunlight which implies that measuring them would raise new aspects and questions.

Our study confirmed that the stomatal conductance influences the transpiration rate and CO_2 assimilation rate strongly. By observing the daily and annual alteration of stomatal conductance we could get a more accurate aspect about the photosynthesis and the water use of each tree and about their environmental value.

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