ACTA CLIMATOLOGICA ET CHOROLOGICA
Universitatis Szegediensis, Tomus 44-45, 2011, 51-63

TEMPERATURE AND PRECIPITATION TRENDS IN AGGTELEK KARST (HUNGARY) BETWEEN 1958 AND 2008

E TANÁCS

Department of Climatology and Landscape Ecology, University of Szeged, P.O.Box 653, 6701 Szeged, Hungary
E-mail: nadragulya@geo.u-szeged.hu

Summary: The study examines the temperature and precipitation data series of Jósvafő meteorological station (situated in the Aggtelek Karst region) in the period between 1958 and 2008 and analyses the characteristics of droughts and humid periods based on the Standard Precipitation Index. The results were interpreted on the basis of earlier forest historical investigations and forest structure analysis of nearby Haragistya-Lófej forest reserve as well as the ecological characteristics of the main tree species of the area. Annual mean temperature shows an increase from the mid-1980's while there is no detectable tendency in annual precipitation sums. After the droughts of the 1980's and 1990's, the 2000's show the presence of both extremities, sometimes shortly following each other. Ellenberg's Climate Quotient shows the transitional nature of the area (between oak- and beech-dominated forests), slightly favouring oak. However a small increase in the dominance of beech and the retreat of sessile oak is shown by historical records (and recently the evidence of deadwood) throughout the examined period. This emphasizes the modifying effect of earlier management activity and the role of local site characteristics, which strongly influence the reaction of species to changes in the climate and thus the dominance conditions.

Key words: climate change, Standard Precipitation Index, species dominance, forest reserve, Aggtelek Karst

1. INTRODUCTION

Forests are especially vulnerable to climate change, due to the longevity of trees. Through its impact on forest growth, climate change will affect both long-term wood supply and carbon sequestration in trees, forest soils and wood products (Kramer and Mohren 2001). Hungary being situated on the climatic boundary between forests and forest steppe vegetation there are concerns that many of our current forest areas would in the future be unable to fulfil their functions with the present species composition (see e.g. Mátyás 2008, Czúcz et al. 2011). However, as the mentioned authors also emphasize, this is a complex issue. On a smaller scale the forests of ecotones are not (only) affected by changes in annual means of climatic variables like precipitation sums or temperature, but by interannual climate variations (Bugmann and Pfister 2000). The 'edge' of the climatically determined range of tree species depends on the occurrences of shorter unfavourable (e.g. extremely dry) periods which cause significant damage in many individuals. The effect of drought on the vegetation is often postponed (Csóka et al. 2007); besides its direct effects on the plants, it is also a major factor in the outbreaks of forest pests (Csóka et al. 2007, Mátyás 2008). On the other hand the effect of these can be modified by the soil conditions (Gärtner et al. 2008). Efficient local adaptation and mitigation measures are only possible if the local trends and characteristics of the change are revealed. It is also yet unclear how the different species would react to the changes, which is especially important in the case of economically significant species like beech (*Fagus sylvatica*) or sessile oak (*Quercus petraea agg.*) (Rennenberg et al. 2004, Ammer et al. 2005).

Aggtelek Karst is one of the southern foothill regions of the Carpathians (Fig. 1). It is a highly diverse transitional area where continental, alpine and Mediterranean species occur together within short distances (Varga et al. 1998), which makes it especially sensitive to change. Karstic habitats are in many cases quite extreme due to erosion from previous management, further increasing this vulnerability. This makes the area suitable as an indicator of the effect of climatic change. Research in Haragistya-Lófej forest reserve suggests a recent shift in the tree species composition (Tanács et al. 2007, Tanács et al. 2010) but the reasons could be anthropogenic as well as natural, since the studied reserve had been heavily managed for centuries until its designation in 1993. In this paper I review what is known about the area's climate and analyse the trends of some ecologically important climatic variables in the vicinity of Haragistya-Lófej forest reserve between 1958 and 2008. Finally I would discuss the results with regard to the two main tree species of the area and their ecological characteristics.

2. MATERIAL AND METHODS

2.1. The study area

Gömör-Torna Karst is one of the southern foothill regions of the Carpathians. It is located in the northeast of Hungary, divided by the Hungarian-Slovakian border (the Hungarian side is called Aggtelek Karst) (Fig. 1). The area was placed under protection on both sides, its largest cave, the Baradla-Domica system being designated a UNESCO World Heritage Site in 1995. Aggtelek Karst mainly consists of a series of karst plateaus, elevated to a different extent. Their height above sea level varies between 400-600 m, while the valleys separating them are situated at about 200 m asl. The surface of the plateaus is dry; the vegetation's only source of water is precipitation. Because of its height and the nearby mountainous regions it is one of the coldest areas in Hungary. According to Trewartha's classification its climate is humid continental with a long summer and a strong mountainous influence (Fig. 2).

Several more or less detailed descriptions of the area's climate can be found in different publications (Jakucs 1975, Ujvárosy 1998, Maucha 2000). Maucha (1998) published a book about the water balance of the Aggtelek Karst area, including the daily temperature and precipitation data from 1958 until 1993 as well as the water yields of some springs. Some calculations were carried out concerning the probabilities of high precipitation days and certain annual precipitation sums, but apart from that none of the above studied the temporal changes of the variables.

In the different descriptions the average mean annual temperature values vary between 8.5°C and 9.1°C. The hottest month is July with an average mean monthly temperature of 19.2°C, the coldest is January (-2.8°C). The area is characterised by a long winter, the last frosty days usually occur at the end of April (Ujvárosy 1998).

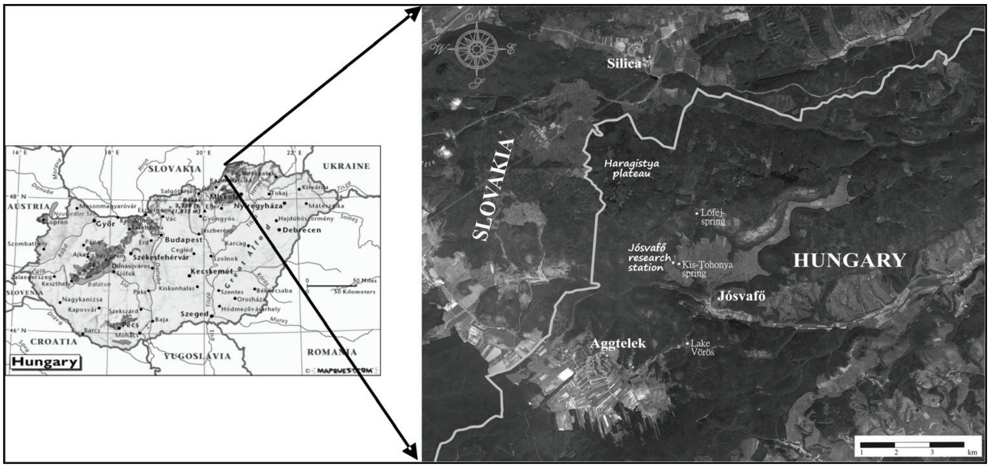


Fig. 1 The study area

The different mean annual precipitation values provided by the different authors vary depending on the period they used for the calculations (Table 1). It is interesting that after 1950, as the examined dataset gets longer (or is related to a later period), the mean values get lower. On the other hand Jakucs (1975) examined an earlier dataset and gave a mean value of 612 mm for the period 1901-1950. He stated that the precipitation in this area was less than in other similar regions in Hungary due to the surrounding higher mountains.

The driest months are February and March, the most humid June and July. There is a second precipitation maximum in November, which is a sign of sub-Mediterranean influence.

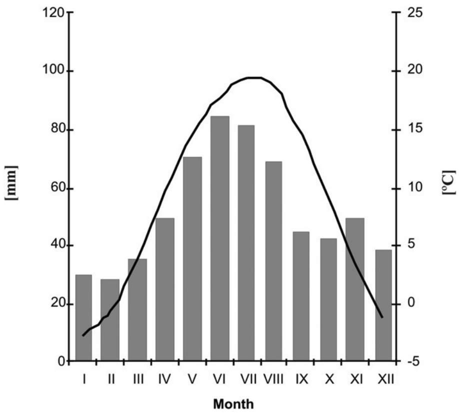


Fig. 2 Average mean monthly precipitation (columns) and temperature (line) at Jósvafő research station in the period 1958-2008

Table 1 Mean annual precipitation according to different authors

Author	Period	Mean annual precipitation (mm)
Jakucs (1975)	1901-1950	612
Ujvárosy (1998)	1940-1970	680
Maucha (2000)	1940-1998	648
The author's calculations based on data from Maucha (1998) and the Hungarian Meteorological Service	**1958-2008**	**620**

2.2. The dataset

The analysis is based on data from the meteorological station of Jósvafő, situated on a lower karst plateau at a latitude of 48°29'43"N and longitude of 20°32'10"E 270 m above sea level. 5 types of data were used:

- for the period 1958-1993 daily temperature and precipitation data published by Maucha (1998)
- for the period 1994-2000 only monthly precipitation and temperature data were available (courtesy of the Hungarian Meteorological Service)
- for the period 2001-2008 daily temperature and precipitation data from the daily weather report of the Hungarian Meteorological Service
- The daily discharge of two springs (Kis-Tohonya and Lófej) from January 1961 and 1965 respectively until December 1993 from the work of Maucha (1998)
- The water levels of Lake Vörös from 2004 to 2008 – data provided by the Directorate of Aggtelek National Park, extended by own measurements

The daily weather reports always relate to 7 am and contain data from the previous 24 hours: the minimum and maximum air temperature and the amount of precipitation. Daily mean temperatures for the period 2001-2008 were therefore calculated based on these two available values.

3. METHODS OF ANALYSIS

3.1. Climatic variables and Ellenberg's Climate Quotient

We used PASW Statistics 18 software for the analysis. Daily data were aggregated and monthly mean temperature was calculated as well as precipitation sums. There is no information about missing data from the period 1958-1993. In 1995, 1996 and 1997 some monthly means and yearly precipitation sums could not be directly calculated, these were replaced with the help of data from the nearby Silica station (Slovakia). After applying seasonal adjustment a linear trend was fitted on the adjusted data to see if there is a significant change over time and spectral analysis was carried out to trace further cycles. Makra's test (Makra et al. 2002, Makra et al. 2005) was applied on the annual precipitation sum and mean temperature data in order to identify sub-periods of which the means were significantly different from the overall mean. Ellenberg's Climate Quotient, a variable suitable to demonstrate the interplay of temperature and precipitation from the ecological point of view was calculated for each year with the following formula: mean July temperature/annual precipitation*1000 (Ellenberg 1988).

3.2. Drought

We studied the occurrence and length of drought and humid periods using the Standard Precipitation Index (McKee et al. 1993). The values of the SPI index are in fact standard deviation values (Table 2) calculated for a period defined by the user according to the time frames of the process to be studied. The main advantage of SPI is its simplicity: only monthly precipitation data are required for its calculation. Although it ignores temperature Hayes et al. (1999) found that the SPI identified the onset and severity of drought earlier than the widely used Palmer's Drought Severity Index (PDSI) (Palmer 1965).

Table 2 The meaning of SPI values

SPI value	Category
>2	Extremely wet
1.5 - 1.99	Very wet
1 - 1.49	Moderately wet
(-0.99) - 0.9	Normal
(-1) - (-1.49)	Moderately dry
(-1.5) - (-1.99)	Very dry
< (-2)	Extremely dry

In this study we first chose to examine the 3-month SPI, commonly used for agricultural predictions (Hayes et al. 1999). However, in order to specify the period related to the karst water supply, we compared the discharges of two springs (Lófej and Kis-Tohonya) and the water levels of one lake (Lake Vörös) with the SPI values calculated for periods of different lengths (Fig. 3). Since the distribution of the water data was not normal, we used Spearman's rank correlation for the comparison.

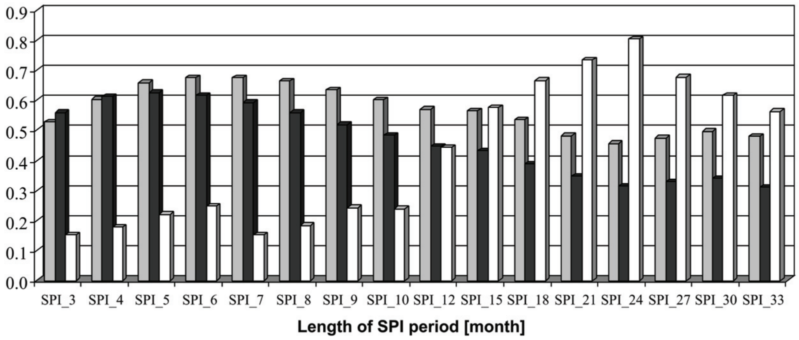


Fig. 3 Spearman's rho correlations between the discharge (or water level, in the case of Lake Vörös) and the values of SPI calculated for different periods (grey: Kis-Tohonya-spring, dark grey: Lófej-spring, white: Lake Vörös)

Lófej-spring has the lowest correlation values; the maximum is at the 5-month SPI. Kis-Tohonya is similar, but it shows the highest correlation with the 6- and 7-month SPI values. The water levels of Lake Vörös seem to have a rather stronger relationship with the precipitation trends of a longer period; the maximum is at the 24-month SPI. Based on these results, besides the 3-month SPI index, we chose to also examine the 6-month SPI values because the karst water supplies seem to depend on the precipitation trend of the previous 5-7 months and the 24-month SPI values because karst lakes seem to be most affected by these.

The 50 years time series was divided into 5 ten-year periods and we examined the number, average length and maximum magnitude of the dry and humid periods.

4. RESULTS

4.1. Temperature

According to our dataset the average annual mean temperature of the period between 1958 and 2008 is 8.9°C.

Makra's test identified one period with a significantly lower mean, which basically divides the dataset in 3 different parts (Fig. 4). The first period from 1958 to 1974 is characterised by an annual mean temperature of 8.9°C including both warmer and colder years. From the year 1974 a colder period started with an average of 8.4°C and the annual mean temperature never exceeded 9.3°C. The change was caused by cooler summers. The test marked the end of this period in 1992; the mean of the last 16 years is 9.6°C. The higher mean covers an increase in both the maximum and minimum values: while in some years (1995, 2007) the annual mean temperatures exceeded 10°C and almost reached 11°C there were no really cold years (annual mean under 8°C) and from 1998 there were hardly any values under 9°C. There is an apparent warming trend from the beginning of the 1980's.

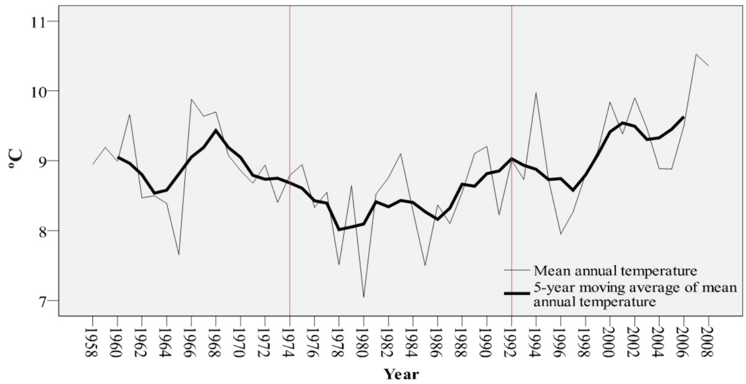


Fig. 4 Annual mean temperatures (1958-2008)

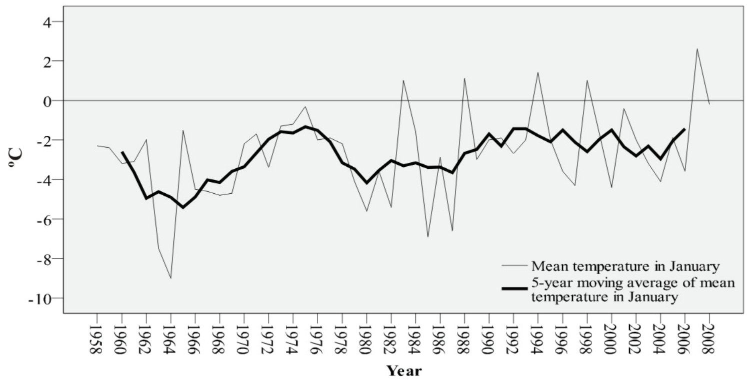


Fig. 5 Mean monthly temperatures in January (1958-2008)

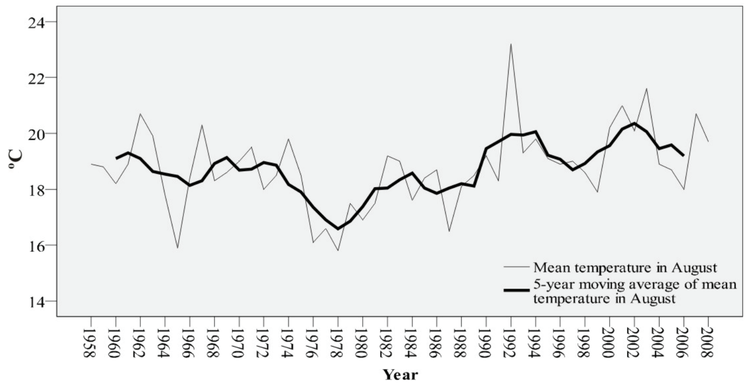


Fig. 6 Mean monthly temperatures in August (1958-2008)

There are two individual months with a significant linear trend: January and August. In both cases an increase seems to be occurring (Fig. 5, Fig. 6); the increase in January is almost continuous over the studied period (with higher averages in the first half of the

1970's) whereas in August the cooler period identified in the annual data appears and thus the warming trend seems to start in the second half of the 1970's.

4.2. Precipitation

In accordance with data from the literature a decrease could be expected in the mean annual precipitation in the Aggtelek area. Besides the authors presented in Table 1, Barančok (2001) also studied the climate of this area (based on data from Silice, Slovakia, approximately 6 km from Jósvafő meteorological station) and found that the annual mean precipitation in the period between 1981 and 1998 was 20-70 mm less than in the base period between 1931 and 1960. However our results show that there is no significant change based on the examined 50-year dataset (Fig. 7). One possible reason for this is that the datasets of the other authors (including Barančok) contained the data of a very humid period between 1947 and 1955 when the mean annual precipitation reached 760 mm whereas the measurements at Jósvafő meteorological station only started in 1958. This could mean that it was the middle of the 20th century which was uncharacteristically humid rather than the area recently becoming drier. It is also the lack of the occasional high-precipitation years (with an annual sum exceeding 750 mm) since the 1980's which could negatively influence the mean.

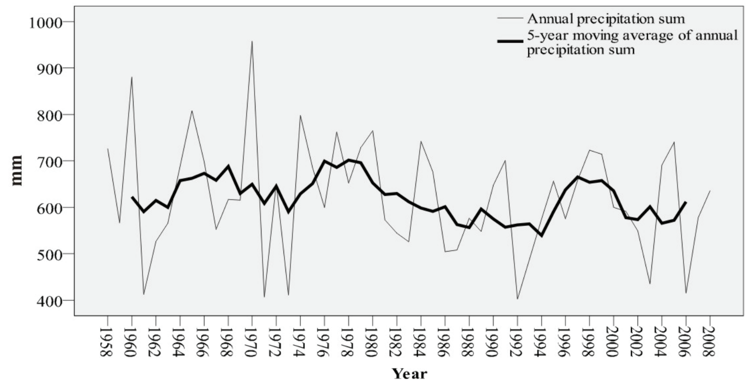


Fig. 7 Annual precipitation sums (1958-2008)

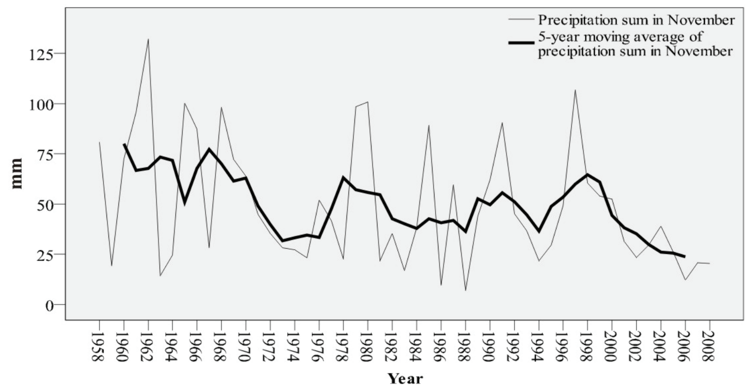


Fig. 8 Precipitation sums in November (1958-2008)

Fig. 7 shows no apparent changes in the length of dry spells, nor in the minimum values or their frequency. There is also an apparent decrease in the short-term fluctuation; the differentces between the sums of following years are smaller. Regarding single months, only the precipi-tation sums in November seem to have a downward trend (Fig. 8) probably caused by the low values of the 2000's.

4.3. Ellenberg's Climate Quotient

According to Ellenberg (1988) this index corresponds to the climatic boundary between beech and oak dominated forests; above 30, the latter become dominant. Gálhidy et al. (2006) found that it corresponded well with the current occurrence of beech forests in Hungary. Fig. 9 shows the values of the quotient calculated for the study area; it clearly indicates that Aggtelek Karst is indeed a transi-tional area between the two types of forests, since the values fluctuate around 30 with a mean of 32.6. Whereas there is no clear trend of increase or decrease, the occasional lower values (under 25), which were common before, are missing since the late 1980's.

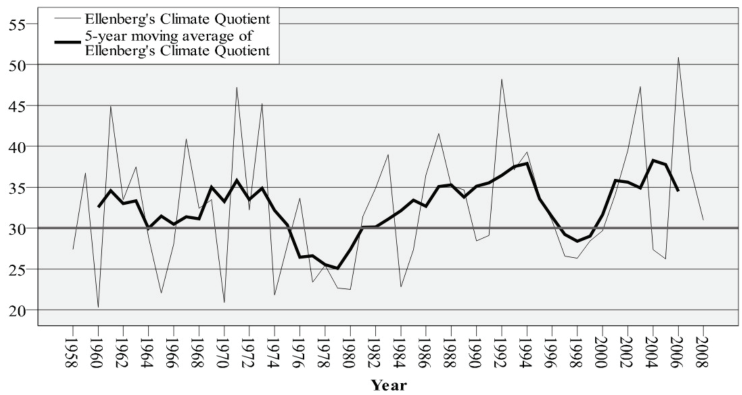


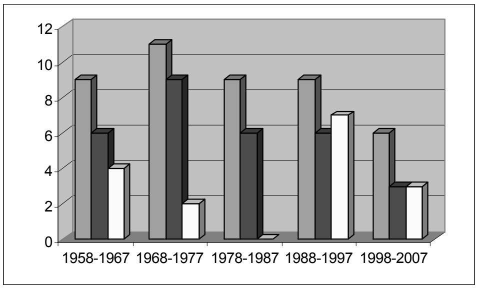
Fig. 9 Ellenberg's Climate Quotient (1958-2008)

4.4. SPI

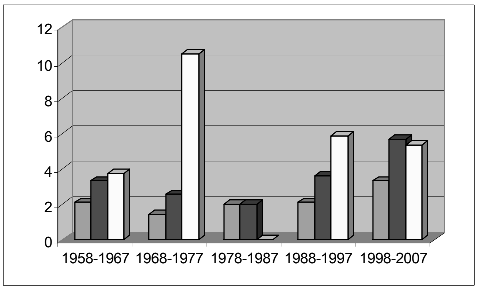
The number of dry spells (Fig. 10a) seems to be quite stable most of the time (around 6 times/10 years), it only increased from period I (1958-1967) to period II (1968-1977) and drought occurred less frequently in the last 10 years (1998-2007). The number of humid periods (Fig. 10d) differs in the case of all the 3 SPI indices used: 6-month humid periods (SPI6) are fairly stable, their number only decreased between 1988 and 1997. 3-month SPI (SPI3) first shows a sudden decrease compared to the first examined period, then a gradual increase and a slight decrease again in the last 10 years. According to the 24-month SPI (SPI24) the number of humid periods increased until the period of 1978-1987, and then came a dry spell between 1988 and 1997 and a slight improvement in the last 10 years.

The average length of dry periods (Fig. 10b) for the 3- and 6-month SPI show a small gradual decrease until period III (1978-1987) and then a stronger increase; drought in the last 10 years lasted on average for double the time than before. The average length of humid periods (Fig. 10e) in the case of the 6-month SPI has continuously decreased from period II (1967-1978). 6- and 24-month SPI behave similarly but show a slight increase in the last 10 years.

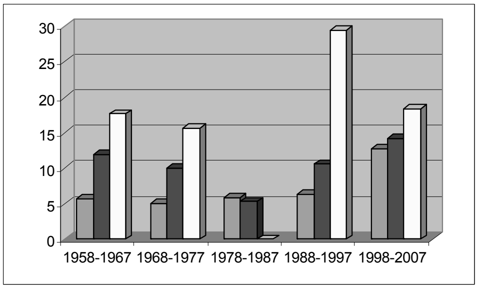
Drought



a) Number of dry spells

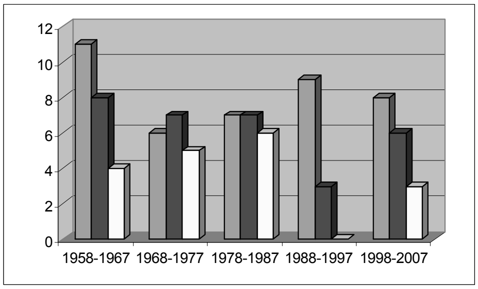


b) Average length of dry spells [month]

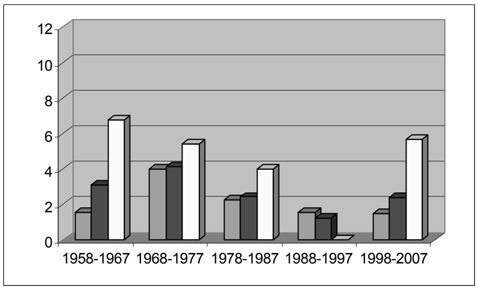


c) Maximum magnitude of drought

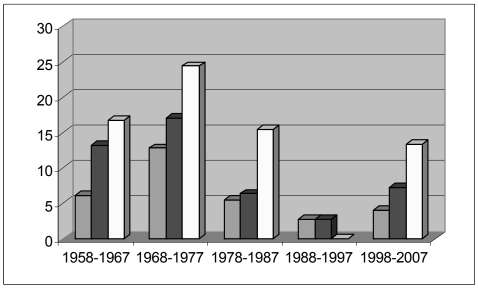
Humid periods



d) Number of humid periods



e) Average length of humid periods [month]



f) Maximum magnitude of humid periods

Fig. 10 Characteristics of dry and humid periods over the last 50 years
(grey: SPI3; dark grey: SPI6; white: SPI24)

The maximum magnitude of drought (Fig. 10c) in the case of the 3-month SPI was fairly stable in the first four examined periods and increased in the last 10 years. In the case of the 6-month SPI drought intensity first decreased, then increased from the period 1978-1987. Drought events based on the 24-month SPI seem to be more drastic; whereas there was no drought event occurring in the period 1978-1987, the next decade produced a very high maximum magnitude, which decreased a bit in the last decade but is still higher than before. All the 3 indices give the same results for the maximum magnitude of humid periods (Fig. 10f): after an initial increase they decreased continuously until the period 1988-1997 and produced a slight increase in the last 10 years.

The period between 1968 and 1977 included two of the driest years of the last 50 years and the wettest as well. These extremities are shown well by the drought index calculated for 24-month periods: both the highest average length of drought and the highest magnitude of humid periods occurred in this decade. The following ten years were fairly normal, without extremities. A really dry decade followed, lasting from 1988 till 1997 with very few humid periods and a high number of strong droughts. The last ten years brought a bit of relief but also another series of extremities. While the frequency of dry spells dropped, the magnitude of drought increased drastically, parallel with an increase in the average length and magnitude of the humid periods.

5. DISCUSSION

The most common tree species in the Aggtelek area is sessile oak (Quercus petraea agg.) and (considering the values of the Ellenberg climate index) the macroclimatic conditions seem to have been favourable for this species to be dominant in the last 50 years. However the oak decline beginning in the end of the 1970's reached this area as well and according to the forest inventory the proportion of sessile oak in the stands of the Haragistya plateau started to decrease at this time (Tanács et al. 2007). Several studies discussed the phenomenon (e.g. Jakucs 1984, Igmándy et al. 1984, 1986, Vajna 1989, Jakucs 1990, Berki 1993) and in the end it was agreed that the drivers behind it were complex and mainly related to the severe droughts in the 1980's (Führer 1998). According to Berki (1993)'s investigations in the Northern Mountain Ranges, sessile oak forests on dry sites were more affected, due to a latent lack of nitrogen in connection with the lack of water. Recent studies on the changes of species composition in such sites indicate that Turkey oak (*Quercus cerris*) is less affected by extreme periods (Mészáros et al. 2007) and also that sessile oak is in many places slowly being replaced with shade-tolerant species such as field maple (*Acer campestre*) or hornbeam (*Carpinus betulus*) and common ash (*Fraxinus excelsior*) (Kotroczó et al. 2007, Krakomperger et al. 2008, Mázsa et al. 2009, Misik és Kárász 2009). Our findings in Haragistya-Lófej forest reserve, based on the evidence of deadwood, also show a similar trend (Tanács et al. 2010). This can be explained by former management practices, which aimed to favour sessile oak. Recruitment of the species is also unfavourably affected by heavy browsing due to the ever increasing numbers of game.

According to Ellenberg (1988) European beech (*Fagus sylvatica*) should play a dominant role in most European temperate forests due to its high physiological tolerance and competitiveness. In the east, the north and at higher elevations its range is limited by winter and late spring frosts (Standovár és Kenderes 2003), while in the south and at lower elevations the major limiting factor is the lack of water. However its wood could not be used as building material before the late 19th century, therefore beech was artificially suppressed and sessile oak favoured in its sites (Csesznák 1985, Bartha 2001). Probably this is an important reason for the current debate (see Geßler et al. 2007) on how its range would be affected by climate change – its current distribution reflects anthropogenic impact rather than natural tolerance limits. On one hand ecophysiological experiments prove that the growth and competitiveness of young beech trees decreases as drought events become more frequent (Rennenberg et al. 2004), on the other hand some researchers found that the species tolerates drought much better than previously supposed (Peters 1997). Ammer et al. (2005) found that although the rate of growth of beech does indeed decrease in times of water stress, competitiveness does not.

The data from Jósvafő Research Station, situated 2 km south of Haragistya-Lófej forest reserve, at a slightly lower elevation suggest that although it is a transitional area the macroclimatic conditions in the last 30 years rather favoured the dominance of oak species. The Ellenberg Climate Quotient did not much decrease even in the cooler period at the end of the 1970's because the annual precipitation sums were also lower at this time. The frequent and strong drought events of the late 1980's and the 1990's should have caused a retreat of beech whereas the forest inventories show a small but constant increase in dominance, mainly where the bedrock is dolomite (Tanács et al. 2007). Our more recent results based on the species composition of dead wood and the spatial distribution of young trees show that beech seems to be spreading rather than retreating (Tanács et al. 2010) however it is only dominant in sites with favourable soil and microclimatic conditions, such as valleys, dolines and northern slopes. Czájlik et al. (2003) studied changes in the species composition of beech-dominated forests in Alsóhegy forest reserve (about 10 km to the west, also situated in Aggtelek Karst) between 1993 and 2003 and did not experience changes related to drought either.

The forecasts of different regional climate models for the Carpathian basin for the period 2071-2100 unambiguously predict an increase in temperature. There are different predictions concerning the annual precipitation sums, but increase is not very probable (Bartholy et al. 2008). The models also predict an increasing frequency of extreme events (Szépszó 2008), which could result in a growing importance of single disturbance events, such as droughts or windstorms. According to the bioclimatic distribution model of Czúcz et al. (2011) 56-99% of current zonal beech forests and 82-100% of sessile oak forests may be outside their present bioclimatic niche by 2050. However our experiences in Aggtelek Karst suggest that such results should be handled carefully. Since the current ranges and dominance conditions are not only defined by the ecophysiological characteristics of the different tree species, we might be in for some surprise concerning their behaviour in the future. It also draws attention to the fact that even in the case of stands near the xeric limit the site conditions (soil and microclimate) play an important role in the survival of the stands.

6. CONCLUSION

While annual mean temperature shows an increase from the mid-1980's there is no detectable tendency in annual precipitation sums. Ellenberg's Climate Quotient shows the transitional nature of the area (between oak- and beech-dominated forests), slightly favouring oak. After severe droughts and lack of humid periods in the 1980's and 1990's, the 2000's show the presence of both extremities, sometimes shortly following each other. Despite the conditions apparently favouring oak, a small increase in the dominance of beech and the retreat of sessile oak is shown by historical records (and recently the evidence of deadwood) throughout the examined period. While there are serious concerns about the future of economically important tree species in Hungary, these results emphasize the modifying effect of earlier forest management and the role of local site characteristics, which strongly influence the reaction of species to changes in the climate and thus the dominance conditions.

Acknowledgment: The research was funded partly by the Hungarian Scientific Research Fund (project no. OTKA/K77763) and partly by the European Union (co-financed by the European Regional Fund) in the project TÁMOP-4.2.1/B-09/1/KONV-2010-0005. I would like to express my thanks to Dr. László Makra for his help with Makra's test, and to the Hungarian Meteorological Service for providing the monthly data.

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