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TRENDS IN THE CHARACTERISTICS OF ALLERGENIC POLLEN IN SZEGED, HUNGARY

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Summary: The aim of the study is to analyse trends of the pollination season with its start and end dates, as well as trends of annual total pollen count and annual peak pollen concentration for Szeged, Hungary. The data set covers an 11-year period (1999-2007) and includes one of the largest spectra, with 19 taxa, as well as five meteorological variables. After performing Mann-Kendall tests, the annual cycles of slopes of daily pollen concentration trends and annual cycles of slopes of daily climate variable trends are calculated. Representing the strength of their relationship an association measure was introduced. Total annual pollen count calculated by linear trends and annual peak pollen concentrations indicate a small number of trends, while total annual pollen count calculated by daily linear trends show significant trends (71% of them positive) for almost all taxa. However, phenological characteristics are free of significant changes except for *Urtica*. We received that the association measure performs well when comparing it to the climate change related forces. Furthermore, significant changes in pollen characteristics are also in accordance with the risk and expansion potential due to the climate change.

Key words: pollen, pollination season, trend, climate change, respiratory allergy

1. INTRODUCTION

The warming of the climate system is obvious, as is now evident from observations of increases in global average air and ocean temperatures, the widespread melting of snow and ice and rising global average sea level. Observational evidence shows that many natural systems are being affected by regional climate changes, particularly temperature increases. In terrestrial ecosystems, earlier timing of spring events and poleward and upward shifts in plant ranges are with very high confidence linked to recent warming. There is medium confidence that other effects of regional climate change on natural and human environments are emerging. They include effects of temperature increases on change in land use and parameters (start and end dates, as well as the length of the pollen season, daily peak pollen level, the incidence of peak day and the total annual pollen count) of allergenic pollen in Northern Hemisphere high and mid-latitudes (IPCC 2007).

Recent changes of the aforementioned pollen characteristics have been reported considering earlier onset (Jäger et al. 1996, Emberlin et al. 1997, Emberlin et al. 2002, Clot 2003, Teranishi et al. 2006, Emberlin et al. 2007a, Stach et al. 2007, Frei 2008, Frei and Gassner 2008), earlier end date (Jäger et al. 1996, Stach et al. 2007, Recio et al. 2010), longer pollen season (Stach et al. 2007), an increase in the daily peak pollen counts (Jäger et al. 1996, Frei 2008, Frei and Gassner 2008, Recio et al. 2010), earlier incidence of peak day (Jäger et al. 1996, Stach et al. 2007) and higher annual pollen concentration (Jäger et al. 1991, Jäger et al. 1996, Damialis et al. 2007, Frei 2008, Frei and Gassner 2008, Cristofori et al. 2010, Recio et al. 2010). However, for certain taxa, either no trends are experienced (Jäger et al. 1996, Frenguelli et al. 2002, Emberlin et al. 2007b) or being sensitive against warming an opposite change in pollen parameters is observed (Latorre and Belmonte 2004, Ridolo et al. 2007, Jato et al. 2009). Predominant changes in timing-related pollen parameters are due to higher temperatures associated with global warming, while those in quantity-related pollen characteristics are in association with both higher temperatures and change in land use (urbanisation and giving up or modifying cultivation) (Frei and Gassner 2008).

Over the last three decades, parallel to the global warming, an increasing effect of aeroallergens on allergic patients has been observed which may imply a greater likelihood of the development of allergic respiratory diseases in sensitized subjects (Damialis et al. 2007, Stach et al. 2007). Together with the aforementioned changes in pollen production and timing further factors may contribute to the development of respiratory diseases, including both indoor and ambient air pollution, as well as reduced exposure to microbial stimulation (Frei and Gassner 2008). Furthermore, chemical air pollutants increase exposure to the allergens, their concentration and/or biological allergenic activity (Just et al. 2007).

Pollen analyses rarely produce a comprehensive picture on quantity- and timing-related pollen parameters of all taxa that occur in a region studied. Many studies consider just one taxon (Emberlin et al. 2002, Latorre and Belmonte 2004, Tedeschini et al. 2006, Emberlin et al. 2007a, Stach et al. 2007, Jato et al. 2009, Recio et al. 2010), or at most a small number of taxa (up to four taxa e.g. Jäger et al. 1991, Emberlin et al. 2007b, Ridolo et al. 2007, Frei and Gassner 2008, García-Mozo et al. 2010). Altogether three studies, namely Clot (2003, 25 plant taxa), Damialis et al. (2007, 16 plant taxa) and Cristofori et al. (2010, 63 plant taxa) analysed a comprehensive spectrum of the regional pollen flora. An overall analysis of pollen characteristics for a given source area provides a more reliable picture of the local pollen trends for each taxon considered in accordance with their different optimum environmental conditions.

The knowledge of important dates of the pollination season, as well as parameters of the pollen production are very important since they make patients suffering from pollen induced respiratory diseases prepare in time for the unfavourable conditions. Climate change may, however, influence the pollination characteristics of different taxa diversely. The aim of our study is to analyse a comprehensive spectrum of airborne pollen data (19 plant taxa) for the Szeged agglomeration in Southern Hungary. Namely, trends of the pollination season with its start and end dates, as well as trends of annual total pollen count and annual peak pollen concentration are calculated for each taxon considered. After performing Mann-Kendall tests, the annual cycles of slopes of daily pollen concentration trends and annual cycles of slopes of daily climate variable trends are calculated and their association is analysed. This kind of trend analysis is a novel approach, providing information on annual cycles of trends. Results received for the pollen characteristics are compared with two novel climate change related categories, namely risk and expansion potential due to the climate change for each taxon.

2. MATERIALS AND METHODS

2.1. Location and data

Szeged (46.25°N, 20.10°E), the largest settlement in South-eastern Hungary is located at the confluence of the rivers Tisza and Maros. The area is characterised by an extensive flat landscape of the Great Hungarian Plain with an elevation of 79 m asl. The city is the centre of the Szeged region with 203,000 inhabitants. The climate of Szeged belongs to Köppen's Ca type (warm temperate climate) with relatively mild and short winters and hot summers (Köppen 1931). The pollen content of the air was measured using a 7-day recording "Hirst-type" volumetric trap (Hirst 1952). The air sampler is located on top of the building of the Faculty of Arts at the University of Szeged some 20 m above the ground surface (Makra et al. 2010). Daily meteorological variables include the mean temperature (T, °C), mean global solar radiation (GSR, Wm^{-2}), mean relative humidity (RH, %), mean wind speed (WS, ms^{-1}) and precipitation total (P, mm). They were collected in a monitoring station located in the inner city area of Szeged.

The database consists of daily mean pollen counts (pollen grains·m^{-3} of air) of altogether 24 taxa over the 11-year period 1997-2007. Due to incomplete data sets five taxa were omitted. The 19 taxa retained for further consideration with their Latin (English) names are as follows: *Alnus* (alder), *Ambrosia* (ragweed), *Artemisia* (mugwort), *Betula* (birch), *Cannabis* (hemp), Chenopodiaceae (goosefoots), *Juglans* (walnut), *Morus* (mulberry), *Pinus* (pine), *Plantago* (plantain), *Platanus* (platan), Poaceae (grasses), *Populus* (poplar), *Quercus* (oak), *Rumex* (dock), *Taxus* (yew), *Tilia* (linden), *Ulmus* (elm) and *Urtica* (nettle). Missing values in the data sets, not exceeding a one week term for any taxa, were estimated by interpolating on either sides of the gap (Damialis et al. 2007). The number of daily missing values runs less than 5% of the total pollen data. The 19 taxa considered produce 93.2% of the total pollen amount for the given period. Taxa with the highest pollen levels include *Ambrosia* (32.3%), Poaceae (10.5%), *Populus* (9.6%) and *Urtica* (9.1%), making up altogether 61.5% of the total pollen.

Considering the most frequent taxa, *Ambrosia* species appear both in the urban environment and in the countryside. Ragweed occurs especially frequently west of Szeged city. The ruling north-western winds can easily transport its pollen into the city. Since in the sandy region, north-west of Szeged, stubble-stripping is not necessary for ground-clearance due to the mechanical properties of sandy soils, *Ambrosia* can cover large areas. Owing to highway buildings around Szeged, several farmlands have been abandoned that also favoured the expansion of *Ambrosia*. Poaceae species represent a substantial ratio in the city, while *Urtica* and *Ulmus* have a high frequency in the floodplain forest undergrowth of the Tisza River, as well as in those of the Tisza and Maros Rivers, respectively. *Urtica* also occurs in neglected lawns of the city area. On the contrary, *Betula* has no natural habitat in the Szeged region; all individuals in the public places have been planted.

The remaining species occur sparsely. *Alnus* species are only found in the Botanical Garden of Szeged. The pollen of *Artemisia, Cannabis,* Chenopodiaceae and *Rumex* can come from neglected areas of both the city and its surroundings, as well as from stubbles. *Juglans, Pinus, Platanus, Taxus* and *Tilia* species are planted exclusively in public places and gardens; they have no natural habitats in the Szeged region.

However, since the 1960s *Pinus* species have been extensively planted in the sandy regions north-west of Szeged in the frame of an afforestation programme. Their pollen can easily reach Szeged through the north-western winds. *Morus* is planted in boulevards and in public places. *Plantago* species occur in natural lawns of both the city and its surroundings. Natural and domesticated species of *Populus* are characteristic in the sallow and poplar floodplain forests along the Tisza and Maros rivers, forming continuous green corridors there. Furthermore, these species are frequently planted into public places and beyond the city along public roads as forest belts. *Quercus* species are planted along the embankment surrounding the city, as well as north of the city (Horváth et al. 1995, Parker and Malone 2004).

The pollen season is defined by its start and end dates. For the start (end) of the season we used the first (last) date on which 1 pollen grain·m^{-3} of air is recorded and at least 5 consecutive (preceding) days also show 1 or more pollen grains·m^{-3} (Galán et al. 2001). In the case of a given pollen type, the longest pollen season during the 11-year period was considered for each year.

2.2. Methods

Linear trend analysis is a common way for estimating trends in the data. The existence of trends is examined generally by the *t*-test based on the estimated slopes and their variances. This technique, however, can be used only for data distributed nearly normally. Data having probability distributions far from normality can be tested against monotone trends by nonparametric tests such as the Mann-Kendall (MK) test. For highly skewed data, such as the annual total number of pollen counts or annual peak pollen concentration, the latter technique has substantially higher power than the *t*-test (Önöz and Bayazit 2003). Therefore, this method is used here, although the slopes are also calculated.

Frequently, trends might have too complex forms to be well-approximated by global linear fits, thus nonparametric methods should be preferred. Nonparametric methods require some smoothness of the trends to be estimated. Each version of these techniques results in linear combinations of observations lying within an interval around the points where trends are estimated. The size of this interval is controlled by a quantity called bandwidth. There are several versions of such estimators but local linear fittings using weighted local regression (WLR) have nice properties. They possess high statistical efficiency (Fan 1993) and are design adaptive (Fan 1992). Further, they automatically correct edge effects at boundaries of data sets (Fan and Gijbels 1992). The choice of the bandwidths has a crucial role in the accuracy when estimating the trends. A large bandwidth delivers small variances with large biases of the estimates, while a small bandwidth results in large variances with small biases. Thus, an optimal bandwidth producing relatively small variances and small biases needs to be found. Such a bandwidth minimizes the expected mean squared error of estimates. A technique proposed by Francisco-Fernández and Vilar-Fernández (2004) is used to estimate bandwidths, because the method provides autoregressive (AR) models to describe the autocorrelations of the underlying data sets, too. These AR models will be important in Sections 3.2 and 3.3. Note that the local linear fits become globally linear with infinite bandwidths.

3. RESULTS

3.1. Pollination season, annual total pollen count and annual peak concentration

In the order of descending strength of the significance based on the MK test *Populus, Taxus* and *Urtica* show a significant increase of the annual total pollen count (Table 1). Concerning the annual peak pollen concentration the similar order of taxa are *Populus, Alnus* and *Juglans*. *Populus* and *Juglans* are characterised by growing, while *Alnus* with declining peak concentrations. Only Poaceae and *Urtica* show significant rising of the duration of the pollination season. The most substantial changes emerge in the behaviour of *Urtica*, because both the annual total pollen count and the duration (with significantly earlier start and later end) of the pollination season are strongly increasing. *Populus* does not have any change concerning its pollination season, however both the annual total pollen count and annual peak pollen concentration increase significantly. The majority of test statistics for the pollination season is not statistically significant, nevertheless the beginning seems to occur earlier and the end tends to happen later thus extending the duration of this period.

Table 1 Change of total annual pollen count (TAPC) (pollen grains·m^{-3}/10 years), annual peak pollen concentration (APP) (pollen grains·m^{-3} / 10 years), start, end and duration of the pollination season (days / 10 years) calculated by linear trends. Significant values for the Mann-Kendall test are denoted by **bold** (1%), ***bold italic*** (5%) and light-faced (10%) letters.

Taxa	TAPC	APP	Pollination season		
			Start	End	Duration
Alnus	*-207*	*-59*	*18*	*16*	*-2*
Ambrosia	*229*	*230*	14	*-9*	*-22*
Artemisia	*-61*	*-133*	*-4*	*15*	*19*
Betula	*-60*	*0*	*-1*	*2*	*3*
Cannabis	*47*	*-4*	*8*	*36*	*28*
Chenopodiaceae	*-175*	*-9*	*-2*	*3*	*5*
Juglans	*253*	30	*-8*	*-7*	*1*
Morus	*400*	*44*	*-7*	*-4*	*3*
Pinus	*-194*	*-20*	*-2*	*-1*	*0*
Plantago	*91*	*3*	***-23***	*19*	*4*
Platanus	*271*	*48*	*-7*	*-3*	*4*
Poaceae	*176*	*43*	*-1*	17	**27**
Populus	***2981***	***610***	*-2*	*3*	*4*
Quercus	*236*	*25*	*4*	*9*	*5*
Rumex	*-505*	*-45*	***-11***	*3*	*15*
Taxus	697	*59*	*-4*	**29**	*32*
Tilia	*-65*	*-1*	*-4*	*-1*	*3*
Ulmus	*-160*	*-12*	*5*	*-13*	*-18*
Urtica	1183	*25*	***-13***	*18*	**31**

Note that only a few trends have been detected significant as compared to the total number of tests performed, which is however not surprising as the interannual variability (variance) of the characteristics examined is quite high and the length of data sets is quite short. In order to get a deeper insight into the tendencies of pollen concentrations a detailed trend analysis is introduced on a daily basis.

3.2. Trends on a daily basis

MK tests are performed and slopes of linear trends are estimated for every particular day of each pollination season using 11 pollen concentration data corresponding to the 11 years. This kind of trend analysis provides information on annual cycles of trends. In the absence of trend on every day of the pollination season the MK test values are distributed normally with expectation zero and variance unit. Therefore, deciding on the existence of trend is identical with the problem of deciding whether the annual mean of daily MK test values correspond to the expectation zero. The classical *t*-test is simplified as the variance is known (unit), but modified according to the autocorrelations among the consecutive MK test values. First order autoregressive (AR(1)) models are used to describe these autocorrelations as mentioned in Section 2.2. Averaging daily slopes over the pollination seasons gives rates of the change of total annual pollen counts. Table 2 shows that only 5 out of the 19 taxa do not exhibit significant change. However, it can happen that the pollination season consists of time intervals with both positive and negative trends, and this is why the mean of MK test values are close to zero. This possibility is examined by the following way (Fig. 1a-b).

Table 2 Change of total annual pollen count (TAPC) (pollen grains·m^{-3}/10 years) calculated from daily linear trends. Significant values for the modified *t*-test performed with daily Mann-Kendall test values are denoted by **bold** (1%), ***bold italic*** (5%) and light-faced (10%) letters.

Taxa	TAPC
Alnus	*-214*
Ambrosia	*-1170*
Artemisia	*-60*
Betula	*-60*
Cannabis	47
Chenopodiaceae	***-175***
Juglans	**253**
Morus	**400**
Pinus	**-194**
Plantago	***91***
Platanus	***271***
Poaceae	*176*
Populus	**2981**
Quercus	236
Rumex	**-505**
Taxus	**678**
Tilia	-65
Ulmus	**-160**
Urtica	**1183**

Evidently, the daily MK test statistics exhibit big variability. In order to estimate the annual cycles of daily trends, daily MK test values are smoothed with the nonparametric regression technique outlined in Section 2.2. In the absence of trend for every day the estimated bandwidth would be extremely large (practically infinite) producing a line close to zero, because the local linear approximation to the annual cycle of the trend becomes globally linear. However, well-defined finite bandwidth has been obtained for each taxon indicating trends even for *Alnus, Ambrosia, Artemesia, Betula* and Poaceae.

3.3. Relationships with climate variables

MK tests are performed and slopes of linear trends are estimated for every particular day of the entire year using 11 data corresponding to the 11 years for each climate variable. Averaging daily MK test values show significant (even at 0.1% probability level) growth of global solar radiation, relative humidity and wind speed. In contrast, temperature and precipitation do not exhibit overall trends at any reasonable significance level. However, the smoothing of daily MK test values indicates stages of positive and negative trends within the year for these latter two variables.

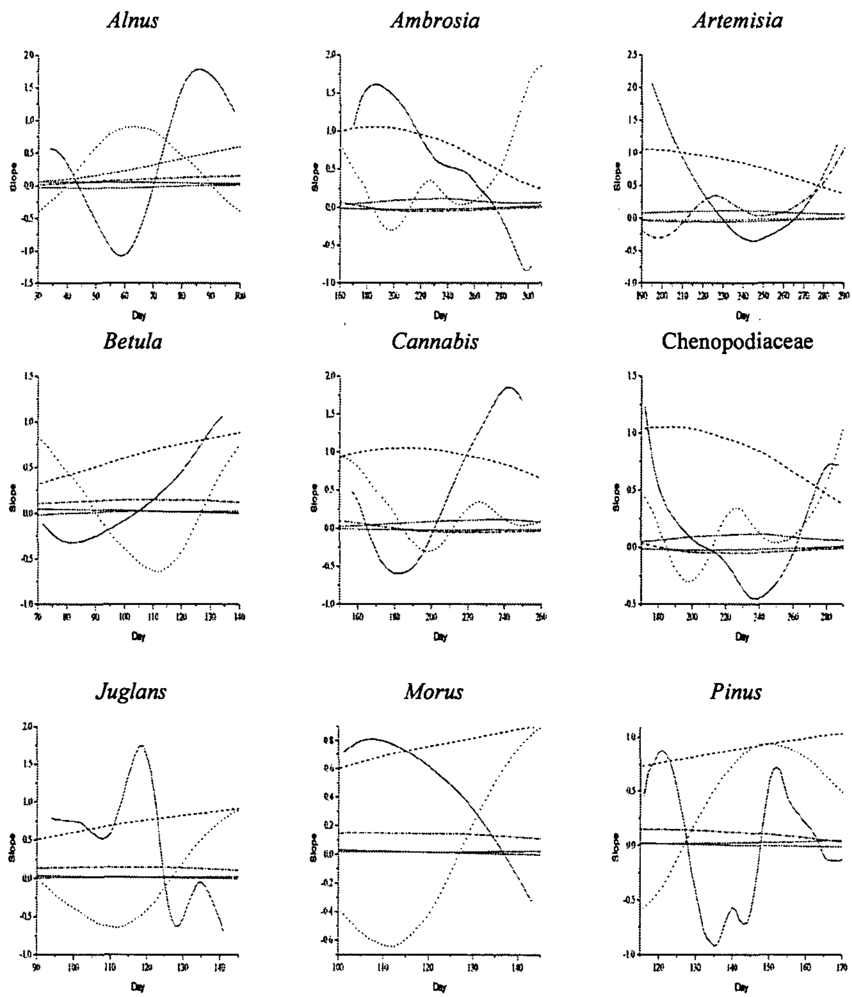

Fig. 1a Annual cycles of slopes of global solar flux (10 Wm^{-2}/year, dash), relative humidity (%/year, dot), precipitation (mm/year, dash dot), temperature (°C/year, short dot), wind speed (ms^{-1}/year, short dash) and pollen concentration (pollen grain·m^{-3}/year, solid) of the 19 taxa examined

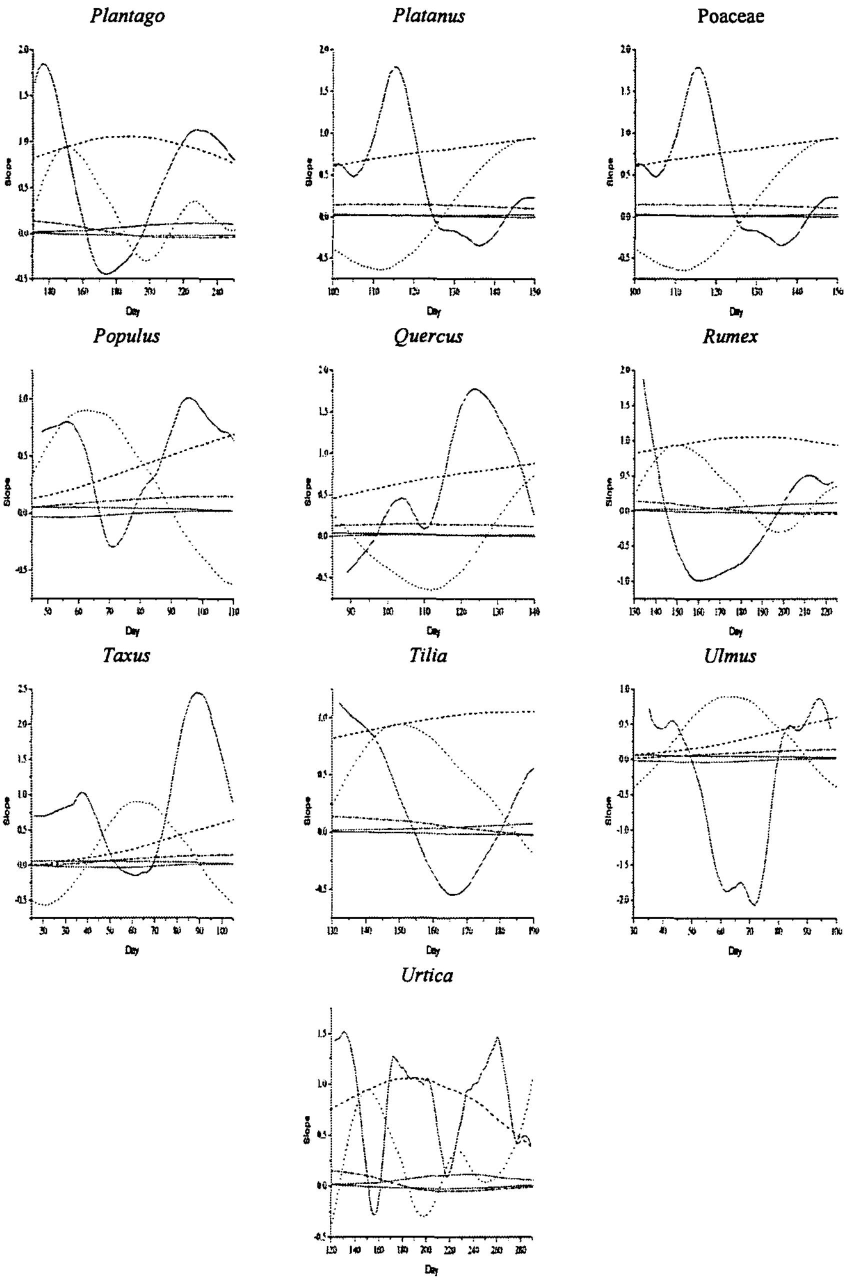

Fig. 1b Annual cycles of slopes of global solar flux (10 Wm^{-2}/year, dash), relative humidity (%/year, dot), precipitation (mm/year, dash dot), temperature (°C/year, short dot), wind speed (ms^{-1}/year, short dash) and pollen concentration (pollen grain·m^{-3}/year, solid) of the 19 taxa examined

The question now is how the annual cycles of slopes of pollen concentration trends and annual cycles of slopes of climate variable trends are related. An association measure is used to characterise these relationships calculating the correlations between the annual cycles of slopes obtained by the nonparametric trend estimation procedure of Section 2.2. This quantity, hereafter, will not be labelled correlation because a correlation is defined for random variables, but now similarities between deterministic functions (annual cycles) have to be quantified. This quantity is tabulated in Table 3.

An association between the annual cycles of slopes of pollen concentration trends and annual cycles of slopes of climate variable trends is considered strong (weak) if the measure is higher (lower) than 0.5. According to climate sensitivity, the individual taxa are counted into three categories; namely, (1) high sensitivity (annual cycles of slopes of pollen concentration trends are in strong association with annual cycles of slopes of four or five climate variable trends), (2) medium sensitivity (annual cycles of slopes of pollen concentration trends are in strong association with annual cycles of slopes of two or three climate variable trends), (3) indifferent (annual cycles of slopes of pollen concentration trends are in strong association with annual cycles of slopes of zero or one climate variable trends) (Table 3). According to this classification, *Alnus, Juglans Morus*, *Platanus,* Poaceae and *Taxus* have high sensitivity to climate; *Ambrosia, Betula, Cannabis,* Chenopodiaceae and *Tilia* indicate medium sensitivity; while *Artemisia, Pinus, Plantago, Populus, Quercus, Rumex, Ulmus* and *Urtica* are indifferent.

Table 3 Association measure between annual cycles of pollen concentration trends and annual cycles of climate variable trends

Taxa	Precipitation	Temperature	Global solar flux	Relative humidity	Wind speed
Alnus	0.603	0.910	0.725	-0.672	-0.725
Ambrosia	-0.203	0.210	0.974	-0.817	-0.910
Artemisia	0.093	-0.397	0.286	-0.259	-0.134
Betula	0.378	0.623	0.899	-0.157	-0.944
Cannabis	-0.825	0.731	-0.951	0.133	0.041
Chenopodiaceae	0.879	-0.956	-0.192	0.389	0.484
Juglans	0.651	-0.636	-0.553	-0.786	0.600
Morus	0.980	-0.745	-0.920	-0.987	0.939
Pinus	0.005	-0.075	-0.133	-0.381	0.143
Plantago	0.252	0.017	-0.779	0.289	0.498
Platanus	0.476	-0.523	-0.573	-0.720	0.599
Poaceae	0.839	-0.868	-0.621	-0.036	0.960
Populus	0.140	0.238	0.276	-0.544	-0.351
Quercus	0.012	0.465	0.749	0.181	-0.727
Rumex	-0.064	0.260	-0.586	-0.244	0.116
Taxus	0.482	0.785	0.600	-0.565	-0.614
Tilia	0.516	-0.372	-0.746	-0.029	0.644
Ulmus	-0.017	0.408	0.169	-0.876	-0.230
Urtica	0.056	0.007	-0.056	-0.531	0.115

The association between the annual cycles of slopes of total annual pollen count trends and the annual cycles of slopes of climate variable trends are only analysed in detail for those of the 19 taxa that comprise the highest total annual pollen counts for the examined 11 years, namely for *Ambrosia* (32.3%), Poaceae (10.5%), *Populus* (9.6%) and *Urtica* (9.1%) (Fig. 1a-b). For all taxa, the annual cycles of slopes of global solar flux trends and those of relative humidity trends are the most characteristic, while the annual cycles of slopes of the remaining meteorological variables are not substantial. *Ambrosia* and Poaceae indicate high climate sensitivity according to the above classification, while *Populus* and *Urtica* are indifferent in this respect (Table 3). For *Ambrosia*, the annual cycle of slopes of total annual pollen count trends indicates a clear decreasing tendency, presenting definite positive and negative associations with those of the global solar flux and relative humidity, respectively. For Poaceae, the annual cycle of slopes of the total annual pollen count shows a strong negative connection with that of the global solar flux and a disturbed and in this way non-important association with the annual cycle of slopes of relative humidity. Furthermore, for *Populus*, slopes of the total annual pollen count show a definite positive connection with those of the relative humidity, while the role of the global solar flux is not characteristic here. For *Urtica* a strong negative association can be observed between the slopes of the total annual pollen counts and those of the relative humidity (Fig. 1a-b; Table 3). The knowledge of the annual cycle of slopes of total pollen count trends in association with those of the meteorological parameters are important, since it draws the attention not only to potential changes of pollen characteristics within a given year but clearly reveals to a potential increase of pollen stress in the case of a given taxon for a given day of the year as an example of a potential short term climate change.

4. DISCUSSION AND CONCLUSIONS

Climate change can modify pollen characteristics of different taxa diversely and can exert a substantial influence on habitat regions. The present study analyses a comprehensive spectrum of the pollen flora in Szeged region. In our best knowledge, altogether three studies (Clot 2003, Damialis et al. 2007, Cristofori et al. 2010) have analysed the most comprehensive spectra of the regional pollen flora. The present study analyses one of the largest spectra with 19 taxa. Our study can be considered unique in the sense that we calculate trends of pollen concentration data for each taxon and those of all five climate variables on a daily basis. Hereby, this kind of trend analysis provides information on annual cycles of trends.

It was found that in descending order, *Populus, Taxus* and *Urtica* show a significant increase of the annual total pollen count. Furthermore, *Populus* and *Juglans* are characterised by the most important increase, while *Alnus* with the most substantial decrease of the annual peak pollen concentration. Only Poaceae and *Urtica* show a significant increase in the duration of the pollination season. In addition, 14 of the 19 taxa exhibit significant change of the total annual pollen count, while 9 of these 14 significant changes indicate increasing trends. Averaging daily Mann-Kendall tests, values indicate significant increasing trends of the global solar radiation, relative humidity and wind speed. However, temperature and precipitation do not exhibit significant trends. Nevertheless, smoothing of daily Mann-Kendall test values show stages of positive and negative trends within the year for these latter two variables. An association measure (AM) was introduced to characterise the strength of the relationship between the annual cycles of slopes of daily pollen concentration trends and annual cycles of slopes of daily climate variable trends. According to climate sensitivity, the individual taxa were sorted into three categories: (1) high sensitivity (characterised by *Alnus, Juglans Morus, Platanus,* Poaceae and *Taxus*), (2) medium sensitivity (including

Ambrosia, Betula, Cannabis, Chenopodiaceae and *Tilia*) and (3) indifferent (with *Artemisia, Pinus, Plantago, Populus, Quercus, Rumex, Ulmus* and *Urtica*).

Furthermore, results received are evaluated by applying a new approach, namely trends for the pollen characteristics, as well as the association measure (AM) introduced representing the strength of the relationship between annual cycles of slopes of pollen concentration trends and annual cycles of slopes of climate variable trends are compared with two novel climate change related forces, namely risk and expansion potentials due to the climate change for each taxon.

Risk due to the climate change describes the endangerment of the species of different taxa. It indicates survival potential of the species with three categories in their present habitat. The non-endangered taxa (*) can survive the anticipated climate change for the Charpatian Basin as they comprise species for warmer and drier conditions, whereas the climatically endangered taxa (***) have no species in the present flora for the awaited changed conditions. At the same time, moderately endangered taxa (**) could survive partly in their place, but populations of some species may decrease regionally. The expansion potential (EP) due to the climate change shows the capability of the species to move in the landscape and rescue themselves or to increase their distribution area with their adaptation. This feature is described with five categories as a wide range of response is awaited due to the different climate-tolerance of the species-pool of taxa (Table 4). The categories have been defined using a flora database provided by Horváth et al. (1995).

Risk and expansion potential (EP) due to the climate change are compared to the AM for each taxon (Table 4). If there is no higher than one unit difference between the AM and the above two climate change related forces, then we say that the AM is in accordance with the risk and EP due to the climate change. Otherwise there is no correspondence between them. We received that 14 of the 19 taxa indicate risk due to the climate change, while 15 of the 19 taxa for EP agree well with their AM. Namely, this newly introduced measure performs well when comparing it to the climate change related forces (Table 4).

Considering pollen characteristics, change of total annual pollen count (TAPC) calculated by daily linear trends indicates the most significant values; namely, 9 positive of the 14 significant daily linear trends. On the contrary, for the pollination season only two significant trends were received, namely both for Poaceae and *Urtica* a definite increase were observed. Based on all pollen characteristics for all taxa, 17 of the 24 significant values were positive indicating a positive tendency in their trends. Next, the connection between the climate change related forces and the above significant pollen characteristics was examined separately for each taxon. An agreement is excepted if the tendencies are similar in each comparison. We received that 22 cases from the 24 significant changes in pollen characteristics were in accordance with the climate change related forces (Table 4).

Urtica, being principally a northern temperate belt origin taxon from the taiga to the Mediterrannean (Parker and Malone 2004), shows the most significant changes. The increase of its total annual pollen count (TAPC) calculated by both linear trend and daily linear trends was substantial. Furthermore, the duration (with significantly earlier start and latter end) of its pollination season is strongly increasing. This result is in accordance with its AM and the climate change related forces (Table 4).

Table 4 Climate change related forces and significance of the different pollen characteristics for the individual taxa

Taxa	**[1]Risk due to the climate change**	**[2]EP**	**[3]AM**	**[4]TAPC by linear trend**	**[5]APP**	**[6]Pollination season**			**[7]TAPC by daily linear trend**
						start	end	duration	
Alnus	***	-2	+++		-10				
Ambrosia	*(potential increase)	2	++						
Artemisia	*(potential increase)	2	+						
Betula	***	-2	++						
Cannabis	*	0	++						+10
Chenopodiaceae	*(potential increase) **(few taxa)	1	++						-5
Juglans	*(potential increase)	2	+++		+10				+1
Morus	*	0	+++						+1
Pinus	**	-1	+						-1
Plantago	*(potential increase) **(few taxa)	1	+						+5
Platanus	*(potential increase)	2	+++						+5
Poaceae	*(potential increase) **(few taxa) ***(few taxa)	1	+++					+1	
Populus	* **(few taxa)	1	+	+5	+5				+1
Quercus	* **(few taxa)	1	+						+10
Rumex	*(potential increase) **(few taxa)	1	+						-1
Taxus	***	-2	+++	+10					+1
Tilia	* **(few taxa)	1	++						-10
Ulmus	* **(few taxa)	1	+						-1
Urtica	* **(few taxa)	1	+	+10		-5	+5	+1	+1

[1]**Risk due to the climate change:** * non-endangered taxa; ** moderately endangered taxa (population of some species may decrease regionally); *** endangered taxa

[2]**Expansion Potential due to the climate change:** 0: non-influenced by global warming; 1: for some species area-increase, while for some others area-decrease is possible; 2: significantly influenced by global warming; for some species area-increase is awaited; -1: for some species regional area-decrease is possible; -2: significantly influenced by global warming; for the majority of species area-decrease is awaited;

(The effect of global warming is indifferent or mostly favourable for families and genus classified into categories 0, or 1 and 2, while for those listed into categories -1 and -2 changes are unfavourable. Taxa grouped into categories 0, 1 and -1 are not influenced substantially but those in categories 2 and -2 are significantly influenced by global warming.)

[3]**Association Measure:** + indifferent; ++ medium sensitivity; +++ high sensitivity;

[4]**TAPC by linear trend:** change of total annual pollen count calculated by linear trends;

[5]**APP:** change of annual peak pollen concentration calculated by linear trends;

[6]**Pollination season:** change of start end and duration of the pollinations season calculated by linear trends;

[7]**TAPC by *daily linear trend:*** *change of total annual pollen count calculated by daily linear trends;*

[4,5,6,7]: ±1, ±5, ±10: significant increasing/decreasing trend for 1%, 5% and 10% probability levels;

According to our results annual pollen counts indicate strong increasing trends for a number of taxa. Nevertheless, phenological characteristics (onset, end and duration of the pollination season) are free of significant changes except for *Urtica*. Hence, the increasing trends in annual pollen levels can be explained by increasing diurnal pollen concentrations. Our conclusions are in accordance with those of several researchers. For Thessaloniki (Greece), total annual pollen levels, as well as daily peak pollen counts show significant increasing trends for the majority of taxa. At the same time, there were no any important changes for the phenological characteristics (Damialis et al. 2007). Considering the wider surroundings of Central Europe, for Zurich, Switzerland (Frei 2008, *Betula*; Frei and Gassner 2008, *Betula*), as well as for Vienna, Austria (Jäger et al. 1996, *Alnus, Corylus, Betula, Pinus* and *Ulmus*) the pollen counts for most of the pollen types have been increasing. Furthermore, for Zurich (Frei 2008, *Betula*), Poznań, Poland (Stach et al. 2007, *Artemisia*) and Vienna (Jäger et al. 1996, *Alnus, Corylus, Betula, Pinus* and *Ulmus*) the pollination season starts earlier, in addition the daily maximum pollen level increases (Frei 2008, *Betula*) and the days of peak pollen levels occur earlier (Stach et al. 2007, *Artemisia*).

While in our study only annual pollen counts indicate definite increasing trends and phenological characteristics do not change substantially, but for Switzerland, Austria and Poland both annual pollen levels increase remarkably and the pollination season starts substantially earlier. Note that arboreal plants appear to react stronger to the climate change than herbaceous plants (Clot 2003). We received significant increasing trends for global solar radiation, relative humidity and wind speed; while of the above-mentioned studies Frei (2008) reported a notable increasing trend for temperature. Several papers have reported evidence of ecological changes due to a potential climate change (Dose and Menzel 2004), like shifts in plant and animal phenology for the boreal and temperate zones of the northern hemisphere (Menzel and Fabian 1999). Phenological characteristics, like earlier start of the pollination season, are very simple bio-indicators to track climate changes (Ahas et al. 2002).

The knowledge of the annual cycle of slopes of total pollen count trends in association with those of the meteorological parameters trends are important, since it draws the attention not only to potential changes of pollen characteristics within a given year but clearly reveals to a potential increase of pollen stress in the case of a given taxon for a given day of the year as an example of a potential short term climate change.

Note, that all taxa examined in the study are families or genus involving a number of species. Accordingly, analysing pollen and phenological characteristics of a family or genus instead of a given species involves high variability of pollen data. An observed trend in the above characteristics incorporates variability of a given parameter for all species belonging to a given taxon. This variability is influenced by meteorological variables. An important positive role of global solar flux is stressed here, since its high values enhance pollen production (Valencia-Barrera et al. 2001, Kasprzyk and Walanus 2010).

As the ratio of local and medium-range transport in the total pollen level is higher than the ratio of long range transport (Makra et al. 2010), it is important to consider further factors of local pollen production for Szeged region. Besides meteorological variables, pollen levels are influenced also by agricultural and social factors (Makra et al. 2005) including urbanisation, so called "green meadow investments" (new investments over originally agricultural areas) and highway buildings. Land eutrophication facilitating higher pollen production is not characteristic over the agricultural area consisting of small private parcels for Szeged agglomeration. At the same time, as more important factors, large industrial areas were put on operation; housing estates as well as highways were built in the region during the study period. Stripping agricultural lands for building purposes involves the possibility for expanding neglected areas that contributes to the increase of habitat regions of weeds and hence to the increase of pollen production.

The results received indicate suggestions to public health services. The prevalence and severity of respiratory diseases has increased worldwide during the past three decades, especially in industrialised countries. This increase may be explained by changes in environmental factors (D'Amato et al. 2005), as well as by increasing levels of biological and chemical air pollutants. Furthermore, an interaction between pollen and chemical air pollutants in the atmosphere can also exacerbate respiratory allergy (Emberlin 1995). The observed changes in the pollen characteristics have important consequences. They provide substantial information for pollen-sensitive people, especially for prevention and pre-seasonal therapy purposes. They could also make possible to update input parameters for a more accurate pollen forecast.

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