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Trends in the characteristics of allergenic pollen circulation in central Europe based on the example of Szeged, Hungary

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ABSTRACT

The aim of the study is to analyse trends of the pollination season with its start and end dates, as well as trends of the annual total pollen count and annual peak pollen concentration for the Szeged agglomeration in Southern Hungary. The data set covers an 11-year period (1999–2009) and includes one of the largest spectra, with 19 taxa, as well as seven meteorological variables (minimum-, maximum- and mean temperature, total radiation, relative humidity, rainfall and wind speed). For highly skewed data, such as the annual total number of pollen counts or annual peak pollen concentrations, the Mann–Kendall test has a substantially greater predictive power than the *t*-test. After performing Mann–Kendall tests, the annual cycles of daily slopes of pollen concentration trends and annual cycles of daily slopes of climate variable trends are calculated. This kind of trend analysis is a novel approach as it provides information on annual cycles of trends. In order to represent the strength of their relationships an association measure (AM) and a multiple association measure (MAM) are introduced. Based on climate sensitivity, the individual taxa are sorted into three categories. The results obtained for the pollen quantity and phenological characteristics are compared with two novel climate change related categories, namely risk and expansion potential due to the climate change for each taxon. The total annual pollen count and annual peak pollen concentrations indicate a small number of changes when using ordinary linear trends, while the total annual pollen count calculated via daily linear trends show significant trends (70% of them positive) for almost all taxa. However, except for Poaceae and *Urtica*, there is no significant change in the duration of the pollination season. The association measure performs well compared to the climate change related forces. Furthermore, remarkable changes in pollen season characteristics are also in accordance with the risk and expansion potential due to climate change.

1. Introduction

Today, few dispute that the earth's ecosystem is experiencing a global warming. This is apparent from the observations of increases in the global average air and ocean temperatures, the widespread melting of snow and ice and the rising global average sea level. The observational evidence tells us that many natural systems are being affected by regional climate changes (e.g. rising temperatures). In terrestrial ecosystems, the earlier timing of spring events and poleward and upward shifts in plant ranges are with very high confidence linked to recent warming. There is a fair chance that other effects of regional climate change on natural and human environments are also emerging. These include the 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 counts, the prevalence of peak day and the total annual pollen count) of allergenic pollen in the high and mid-latitudes of the Northern Hemisphere (IPCC, 2007).

Recent changes in the above-mentioned pollen season characteristics were reported concerning an earlier onset (Jäger et al., 1996; Emberlin et al., 1997, 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), a 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), an earlier incidence of peak day (Jäger et al., 1996; Stach et al., 2007) and higher annual pollen concentrations (Jäger et al., 1991, 1996;

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Frei, 2008; Damialis et al., 2007; Frei and Gassner, 2008; Cristofori et al., 2010; Recio et al., 2010). However, for certain taxa, either no trends are observed (Jäger et al., 1996; Frenguelli et al., 2002; Emberlin et al., 2007b) or, being sensitive to warming, an opposite change in pollen season parameters is seen (Latorre and Belmonte, 2004; Jato et al., 2009). Predominant changes in timing-related pollen season parameters are due to higher temperatures associated with global warming, while those for quantity-related pollen season characteristics are associated with both higher temperatures and changes in land use (urbanisation and abandoning or modifying cultivation) (Frei and Gassner, 2008). According to experimental warming results (e.g. Ziska and Caulfield, 2000), warming itself increases plant biomass leading to an increased flowering production and pollen production. However, this relationship does not apply in a warmer continental climate where the general lack of water together with a warming event can cause a biomass decrease, since closed grasslands are opened, steppes can become semi-deserts and woodlands can change to wooded steppes or steppes.

Over the past three decades, in parallel with 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 problems in sensitised subjects (Damialis et al., 2007; Stach et al., 2007). Together with the above-mentioned changes in pollen production and timing, further factors including indoor and ambient air pollution may contribute to the development of respiratory complaints and a reduced exposure to microbial stimulation (Frei and Gassner, 2008). Furthermore, interactions of pollen with air pollution seem to modify the properties of both allergens and pollen, so that sensitised patients become more easily sensitised (D'Amato, 2011).

Pollen circulation analyses rarely produce a comprehensive picture on quantity and timing-related pollen season parameters of all taxa that occur in a given region. Many studies consider just one taxon (Emberlin et al., 2002, 2007a; Latorre and Belmonte, 2004; Tedeschini et al., 2006; Stach et al., 2007; Jato et al., 2009; Recio et al., 2010), or a small number of taxa (e.g. Jäger et al., 1991; Emberlin et al., 2007b; Frei and Gassner, 2008; García-Mozo et al., 2010). To our knowledge, only three studies analysed a comprehensive spectrum of the regional pollen flora (Clot, 2003; Damialis et al., 2007; Cristofori et al., 2010) with 25, 16 and 23 plant taxa, respectively.

A knowledge of the key dates of the pollination season and of the main parameters that describe pollen production are useful as people suffering from pollen-induced respiratory complaints can be informed in time about the unfavourable conditions. Climate change may, however, influence the pollination characteristics of different taxa in a variety of ways. The aim of our study was to analyse a comprehensive spectrum of airborne pollen data (19 plant taxa) for the Szeged agglomeration in Southern Hungary. In effect, the trends of the pollination season with its start and end dates, as well as trends of annual total pollen count and annual peak pollen counts were calculated 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 (Fig. 1). The area is characterised by an extensive flat landscape of the Great Hungarian Plain with an elevation of 79 m above sea level. 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) (Fig. 1). The air sampler is located on top of the building of the Faculty of Arts at the University of Szeged approximately 20 m above the ground surface (Makra et al., 2010). Meteorological variables include daily values of minimum (T_{min}, °C), maximum (T_{max}, °C) and mean temperature (T, °C), total radiation (TR, W m^{-2}), relative humidity (RH, %), wind speed (WS, m s^{-1}) and rainfall (R, mm). They were collected in a meteorological station located in the inner city area of Szeged (Fig. 1).

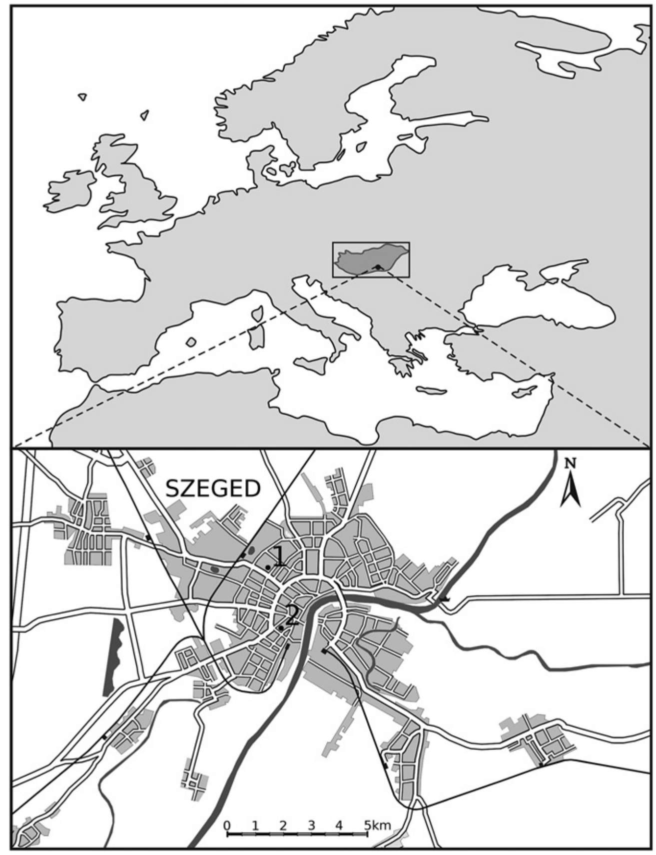

Fig. 1. Location of Europe including Hungary (upper panel) and the urban web of Szeged with the positions of the data sources (lower panel). 1: meteorological station; 2: aerobiological station. The distance between the aerobiological and the meteorological station is 2 km.

The data set consists of daily pollen counts (per m^3 of air) of 19 taxa taken over the period 1997–2007. With their Latin (English) names they are: *Alnus* (alder), *Ambrosia* (ragweed), *Artemisia* (mugwort), *Betula* (birch), *Cannabis* (hemp), Chenopodiaceae (goosefoots), *Juglans* (walnut), *Morus* (mulberry), *Pinus* (pine), *Plantago* (plantain), *Platanus* (plane), Poaceae (grasses), *Populus* (poplar), *Quercus* (oak), *Rumex* (dock), *Taxus* (yew), *Tilia* (linden), *Ulmus* (elm) and *Urtica* (nettle). Missing values in the data sets never exceeded one week for any taxon and were estimated by linearly interpolating on either side of the gap (Damialis et al., 2007).

As regards the taxa with the highest pollen concentrations, the *Ambrosia* genus has only one species, namely *Ambrosia artemisiifolia* (Common Ragweed) in the Szeged region. This appears both in the urban environment and in the countryside. Ragweed occurs especially frequently west of the city. The ruling north-western winds can easily transport pollen into the city. Since in the sandy region, northwest of Szeged, stubble stripping is not necessary for ground-clearance due to the mechanical properties of sandy soils, *Ambrosia* can spread unchecked. Owing to newly-built motorways around Szeged, several farmland areas have been left untouched for a long time that also favour the expansion of *Ambrosia*. Several species of Poaceae family, namely *Agropyron repens* (Common Couch), *Poa trivialis* (Rough Meadow-grass), as well as *Poa bulbosa* (Bulbous Meadow-grass) over untouched areas, along with *Poa angustifolia* (Narrow-leaved Meadow-grass) and *Alopecurus pratensis* (Meadow Foxtail) in floodplains, and along the dyke surrounding the Szeged region represent a substantial proportion in the city. For the *Populus* genus, natural species of *Populus alba* (White Poplar) and *Populus canescens* (Grey Poplar), as well as cultivated poplars such as I-273 Poplar and *Populus x euroamericana* (Canadian Poplar) and its variants are the most frequent in the city. At the same time, *Urtica* genus with its single species of *Urtica dioica* (Common Nettle) in Szeged region occurs with high frequency in the floodplain forest underwood of the Tisza and Maros Rivers, road-, and channel-sides and in locust-tree plantations around the city. *Urtica* also occurs in neglected grassy areas of the city space.

The remaining species seldom occur here. *Alnus* species are only found in the Botanical Gardens of Szeged. Pollen of *Artemisia, Cannabis,* Chenopodiaceae and *Rumex* can come from neglected areas of both the city and its surroundings, as well as from stubble pastures. *Juglans, Pinus, Platanus, Taxus* and *Tilia* species have been 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 within the framework of an afforestation programme. Their pollen can easily reach Szeged via north-western winds. *Morus* is planted along avenues and in public places. *Plantago* species occur in natural grassy areas of both the city and its surroundings. Natural and domesticated species of *Populus* are characteristic in the shallow and poplar floodplain woods along the Tisza and Maros rivers forming continuous green corridors there. Furthermore, these species are frequently planted in public places and outside the city along public roads as wooded 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). For a given pollen type, the longest pollen season during the 11-year period was considered for each year.

2.2. Methods

A common way of estimating trends in data is linear trend analysis. The existence of trends is examined generally by the *t*-test based on the estimated slopes and their variances. This test, however, may be used for normally distributed data. Data having probability distributions far from the normal one can be tested against monotone trends by using nonparametric tests such as the Mann–Kendall (MK) test. For skewed data, such as the annual peak pollen counts, this latter technique has significantly higher power than the *t*-test (Önöz and Bayazit, 2003). Therefore, this method is used here, although the slopes have also been calculated.

It may happen that some trends might have overly complex forms to be well approximated by global linear fits, so nonparametric methods are preferable. Nonparametric methods assume some smoothness of trends to be estimated. Each version of these techniques results in linear combinations of observations lying within an interval around the points where the trends are estimated. The size of this interval is controlled by a parameter called the bandwidth. There are several versions of such estimators, but local linear fittings have nice properties. They possess high statistical efficiency (Fan, 1993), automatically correct edge effects at boundaries of data sets (Fan and Gijbels, 1992) and are design adaptive (Fan, 1992). When estimating the trends, the choice of the bandwidths has a crucial role in the overall accuracy. A large bandwidth provides 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 has to be found. Such a bandwidth minimises the expected mean squared error of estimates. A technique proposed by Francisco-Fernández and Vilar-Fernández (2004) is used here to estimate bandwidths because the method also furnishes autoregressive (AR) models to describe autocorrelations of the underlying data sets. These AR models will be outlined in Sections 3.2 and 3.3. Note that the local linear fits become globally linear with infinite bandwidths.

We introduced a multiple association measure (MAM) that describes how well the annual cycle of the slope of a pollen concentration trend can be represented by a linear combination of annual cycles of slopes of climate variable trends. MAM varies between zero and one, approaching one with increasing accuracy of this above-mentioned representation (Meyer, 2001). All classifications are subjective; however, the individual taxa are grouped into three categories according to climate sensitivity defined by MAM values.

In order to evaluate the response of plants to climate change, two categories were introduced. Risk due to the expected climate change in the Carpathian basin (Bartholy et al., 2008) describes the endangerment of the species of different taxa in their present habitats, indicating survival potential of the species with 3 categories. Non-endangered taxa (*) can survive the anticipated climate change for the Carpathian basin since they comprise species for warmer and drier conditions, whereas climatically endangered taxa (***) have no species in the present flora for the awaited new conditions. In the first case, change of species within a taxon in a certain landscape could help the adaptation of the taxon to global warming, while in the latter case the lack of warm-tolerant species can lead to the disappearance of a given taxon. The wider the tolerance range and the more species (especially warm and dry-tolerant species) a taxon has, the less exposed it is to climate change. 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 tells us the capability of the species to move in the landscape and survive or to expand in their distribution area with their adaptation. This feature is described by five categories as a wide range of response is expected due to the different climate tolerance of the species pool of taxa (Deák, 2010). The categories are defined using a flora database provided by Horváth et al. (1995).

3. Results

3.1. Trends on an annual basis

The number of daily missing values amounts to less than 5% of the total pollen data. The 19 taxa studied made up 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%), which together account for 61.5% of the total pollen production.

Total annual pollen concentrations, as well as start date, end date and the duration of the pollen season revealed only a few overall trends. In the order of decreasing level of significance based on the MK test, *Populus, Taxus* and *Urtica* display a significant increase in the total annual pollen count (TAPC) (Table 1). As for the

Table 1
Change in the 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 using linear trends. Significant values for the Mann–Kendall test are denoted by *** (1%), ** (5%) and * (10%).

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*****

Bold: taxa with the highest pollen levels.
* A tendency of trend at the 10% probability level.

annual peak pollen counts (APP) (Table 1), taxa in decreasing order are: *Populus, Alnus* and *Juglans*. *Populus* and *Juglans* have growing peak pollen counts, while *Alnus* has declining peak concentrations. Only Poaceae and *Urtica* show a significant increase in the duration of the pollination season. The most significant changes emerge in the behaviour of *Urtica*, because both the total annual 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, but both the total annual pollen count and annual peak pollen counts are definitely rising. Although the majority of test statistics for the pollination season is not statistically significant, the start seems to occur earlier and the end tends to happen later, thus extending the period of pollination.

Note that only a few trends have been clearly identified for all pollen season characteristics compared to the total number of tests performed. This is not surprising as the interannual variability (variance) of the characteristics studied is quite high and the size of the data sets is quite small. A 10-element data set is the shortest for which the MK test may be used (e.g. Önöz and Bayazit, 2003). Having 11-element data sets, the MK test can be performed, although the critical values of MK test statistics for rejecting the null-hypothesis of no trend are rather high because the data sets are small. In order to gain a deeper insight into the general trends in pollen concentrations, a detailed trend analysis on a daily basis will be presented below.

3.2. Trends on a daily basis

MK tests are performed and linear trends are estimated for each particular day of each pollination season of all 19 taxa considered using 11-element pollen concentration data sets corresponding to the 11-year study period. This kind of trend analysis provides information on the annual cycles of trends. In the absence of a trend for each day of the pollination season, the MK test values are distributed normally with zero expectation and unit variance. Therefore, deciding on the existence of a trend is identical with the problem of deciding whether the annual mean of daily MK test values corresponds to the expectation zero. The classical *t*-test has been simplified as the variance is known (unit), but modified based on 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 values of daily slopes of linear trends over the pollination seasons gives rates of change of the total annual pollen counts. Table 2 tells us that at the 5% level there are 11 taxa with significant trends out of the 19 examined, and of these 11 just 7 show increasing trends. 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 do not provide overall trends for 5 (10% level) or 8 (5% level) taxa. This possibility is examined below.

Needless to say, the daily MK test statistics have a big variability. Therefore, daily MK test values were smoothed using the nonparametric regression technique outlined in Section 2.2. In the absence of a trend for each day the estimated bandwidth is extremely large (practically infinite), producing a line close to zero because the local linear approximation to the annual cycle of the daily trends becomes globally linear. Hence, well-defined finite bandwidths obtained for each taxon indicate trends even for *Alnus, Ambrosia, Artemisia, Betula* and Poaceae, the 5 taxa not exhibiting overall trends on yearly basis even at a 10% significance level.

3.3. Relationships between climate variables

MK tests were performed and linear trends were estimated for each particular day of the entire year using 11 data sets, corresponding to the 11 years for each climate variable. Averaging daily MK test values reveals a significant (even at 0.1% probability level) growth of total radiation, relative humidity and wind speed. In contrast, minimum-, maximum- and mean temperature as well as rainfall do not exhibit any noticeable overall trend at any reasonable level. However, the smoothing of daily MK test values indicates stages of positive and negative trends within the year for these latter two variables. Including minimum and maximum temperatures resolves a paradox, namely the annual increase of total radiation does not involve the annual increase of mean temperature. The reason is that the period of the intra-annual increase of *T*

Table 2
Change in the 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 *** (1%), ** (5%) and * (10%).

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*****

Bold: taxa with the highest pollen levels.
* A tendency of trend at the 10% probability level.

coincides with the highest increase of TR within the year. If T_{max} is considered instead of *T*, the above result is even more pronounced as T_{max} changes more sharply than *T* within the year. This is because the increase in TR affects T_{max} (early afternoon) rather than T_{min} (at dawn, early morning).

We examined whether there were any associations between the annual cycles of daily slopes of pollen concentration trends and those of climate variables trends. Here an association measure (AM) is used to characterise these relationships by calculating the correlations between the annual cycles of slopes obtained by the nonparametric trend estimation procedure of Section 2.2. This quantity will not be labelled as a correlation because a correlation is defined for random variables, but now similarities between deterministic functions (annual cycles) have to be quantified. Values for this parameter are tabulated in Table 3. The last column contains an overall measure called multiple association measure (MAM) characterising how well the annual cycle of the slope of a pollen concentration trend can be represented by a linear combination of annual cycles of slopes of climate variable trends. MAM varies between zero and unit approaching the unit under increasing accuracy of this above-mentioned representation. Technically, MAM is calculated as a multiple correlation between a random variable and a number of other random variables, but again it should not be considered as a correlation. AM and MAM are based on elementary considerations of linear algebra; see e.g. Section 5.15 in Meyer (2001).

The association between the annual cycles of the daily slopes of pollen concentration trends and those of climate variables trends is only analysed in detail for those of the 19 taxa that comprise the highest total annual pollen counts for the 11-year period, namely for *Ambrosia* (32.3%), Poaceae (10.5%), *Populus* (9.6%) and *Urtica* (9.1%) (Fig. 2). The highest increase in the mean temperature, especially in summer time (August), represents a limit for pollen production of *Ambrosia*. In this period, the loss of water can be a problem for the plant, so to save water it reduces its pollen production. This is why AM is negative for *T*. Poaceae can produce a high biomass in years with higher than usual rainfall, which is in accordance with its higher pollen production. Significant habitat changes, grassland-zone shifts (Deák, 2010) can also influence their pollen production as wetter communities (dominated by *Molinia* or *Alopecurus*) with a higher biomass can appear on former drier places due to exceptionally high rainfall. However, increased mean and maximum temperatures can lead to a water-shortage in the driest summer period for grasses, meaning a serious limiting factor for pollination. So they preserve water instead of producing pollen. For *Populus*, though its MAM is high in itself, that this is relatively low is in accordance with the non-important associations between the climate elements and pollen counts. The pollen production of *Urtica* is encouraged by increasing maximum temperatures, and this is why its pollination begins earlier and lasts longer (Tables 3 and 4).

4. Discussion and conclusions

Climate change can modify the pollen season characteristics of different taxa in diverse ways and can exert a substantial influence on habitat regions. The present study analyses a comprehensive spectrum of the pollen flora in the Szeged region. In our best knowledge, only three previous studies (Clot, 2003; Damialis et al., 2007; Cristofori et al., 2010) analysed 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 trends of pollen concentration data for each taxon and those of all seven climate variables are calculated on a daily basis. This kind of trend analysis provides information on annual cycles of daily slopes of trends.

It was found in descending order that on a yearly basis *Populus*, *Taxus* and *Urtica* show a significant increase of the annual total

Table 3
Association measure (AM[a]) between the annual cycles of the daily slopes of pollen concentration trends and the annual cycles of the daily slopes of climate variables trends.

Taxa	T_{min}	T_{max}	T	R	TR	RH	WS	MAM[b]
Alnus	0.718*	0.775*	0.742*	0.313	−0.028	−0.620*	−0.455	0.992
Ambrosia	**0.100**	**0.207**	**−0.641***	**0.398**	**0.049**	**0.087**	**0.223**	**0.827**
Artemisia	−0.249	0.676*	−0.486	0.140	−0.004	−0.230	−0.049	0.998
Betula	−0.689*	−0.192	−0.544*	−0.663*	−0.006	0.542*	0.070	0.973
Cannabis	0.602*	−0.559*	0.763*	−0.531*	−0.152	0.106	−0.147	0.993
Chenopodiaceae	0.071	0.306	−0.869*	0.644*	0.047	0.112	0.307	0.965
Juglans	0.271	−0.392	−0.466	0.613*	−0.129	−0.726*	0.452	0.925
Morus	0.329	−0.668*	−0.874*	0.821*	−0.216	−0.893*	0.684*	0.978
Pinus	0.093	0.144	0.241	−0.269	−0.160	−0.294	−0.079	0.963
Plantago	0.183	−0.642*	−0.093	0.337	−0.131	0.371	0.490	0.947
Platanus	0.308	−0.265	−0.354	0.368	−0.020	−0.576*	0.328	0.948
Poaceae	**−0.088**	**−0.649***	**−0.816***	**0.826***	**−0.057**	**0.309**	**0.643***	**0.959**
Populus	**0.361**	**0.358**	**0.395**	**0.407**	**−0.093**	**−0.378**	**−0.349**	**0.869**
Quercus	−0.046	0.165	0.360	0.616*	−0.076	−0.640*	−0.062	0.911
Rumex	−0.093	−0.026	0.450	−0.244	−0.060	−0.365	−0.087	0.979
Taxus	0.618*	0.305	0.428	0.446	0.010	0.009	−0.264	0.985
Tilia	0.284	−0.378	−0.171	0.327	0.062	−0.106	0.428	0.973
Ulmus	0.381	0.565*	0.462	0.063	−0.069	−0.766*	−0.256	0.934
Urtica	**−0.467**	**0.612***	**0.451**	**−0.396**	**0.076**	**−0.580***	**−0.705***	**0.827**

T_{min}: minimum temperature (°C), T_{max}: maximum temperature (°C), T: mean temperature (°C), R: rainfall (mm), TR: total radiation (W m^{-2}), RH: relative humidity (%), WS: wind speed (m s^{-1}).
Bold: taxa with the highest pollen levels.
*AM > |0.5| indicates a strong association.
The above association is analysed in detail only for *Ambrosia*, Poaceae, *Populus* and *Urtica* (bold), representing the highest total annual pollen counts for the 11-year period examined. (1) high sensitivity: MAM > 0.950, 11 taxa; *Artemisia, Cannabis, Alnus, Taxus, Rumex, Morus, Betula, Tilia*, Chenopodiaceae, *Pinus* and Poaceae; (2) medium sensitivity: 0.900 < MAM ≤ 0.950, 5 taxa; *Platanus, Plantago, Ulmus, Juglans* and *Quercus;* (3) indifferent: MAM ≤ 0.900, 3 taxa; *Populus, Ambrosia and Urtica*.
[a] AM (association measure): reflects the strength of the relationship between the annual cycle of the daily slopes of pollen concentration trends and the annual cycles of the daily slopes of climate variables trends for each individual taxon.
[b] MAM (multiple association measure): describes how well the annual cycle of the slope of a pollen concentration trend can be represented by a linear combination of annual cycles of slopes of climate variable trends. MAM varies between zero and one, approaching one with increasing accuracy of this above-mentioned representation (Meyer, 2001).

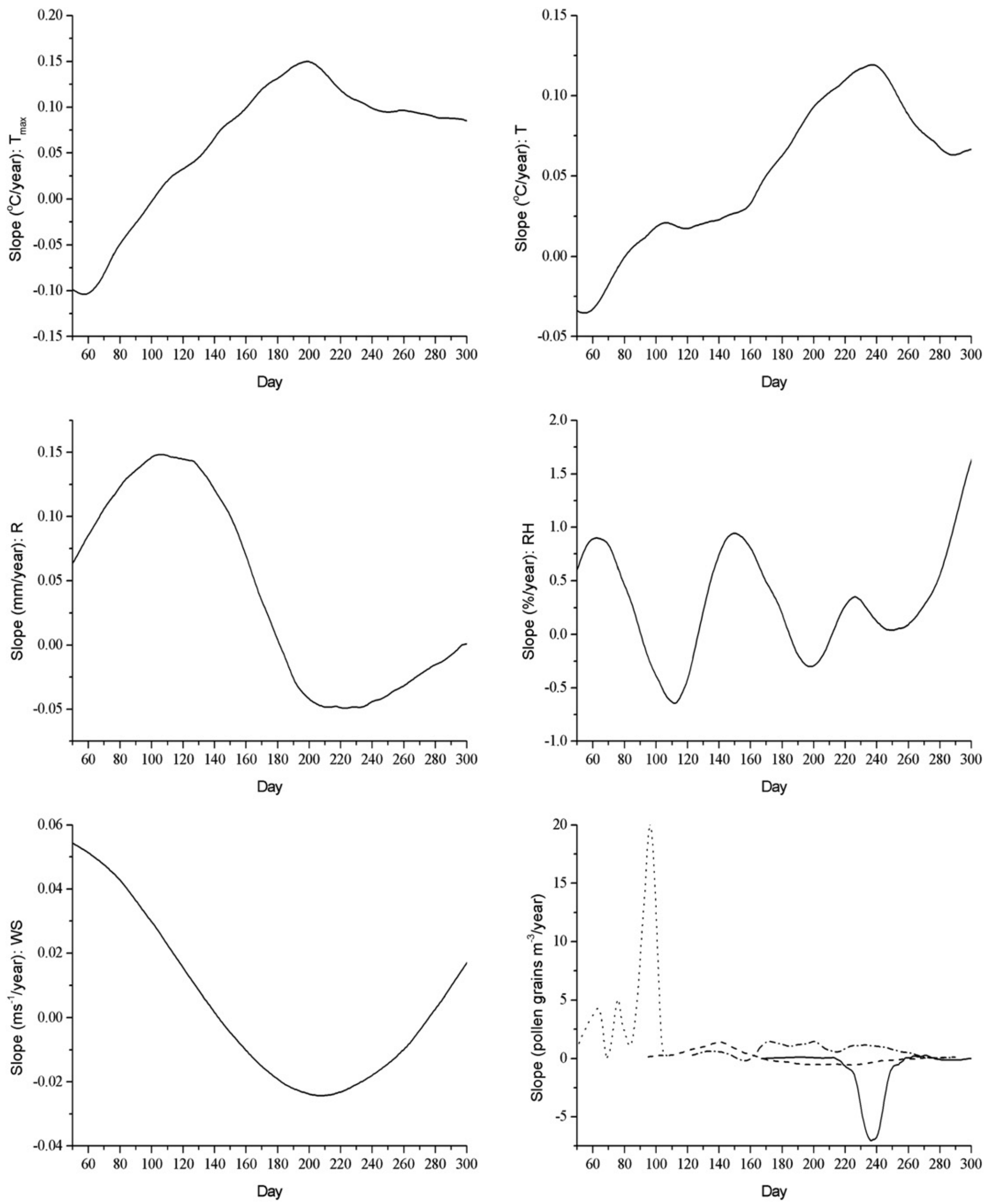

Fig. 2. Annual cycles of the slopes of daily linear trends for maximum temperature (T_{max}), mean temperature (T), rainfall total (R), relative humidity (RH), wind speed (WS) and for *Ambrosia* (solid), Poaceae (dash), *Populus* (dot) and *Urtica* (dash dot).

pollen count. Here *Populus* and *Juglans* display the most important increase, while *Alnus* exhibits the biggest decrease of the annual peak pollen counts. Only Poaceae and *Urtica* show a significant increase in the duration of the pollination season. Based on the 5% level, 11 of the 19 taxa indicated significant trends, and of these 11 just 7 showed increasing trends on a daily basis. Furthermore, considering all pollen season characteristics for all taxa, 21 out of the 30 significant values were positive (70%) (involving tendencies of trends at the 10% probability level) indicating an increase in their trends (Tables 1 and 2). Averaging the daily Mann–Kendall tests, the values indicate that there are significant increasing trends in the total radiation, relative humidity and wind speed. Yet, temperature and rainfall do not display any significant trends. Nevertheless, the smoothing of daily Mann–Kendall test values shows stages of positive and negative trends within the year for these latter two variables.

Pollen counts of *Ambrosia* show a slight increase according to ordinary linear trends (Table 1), as moderate warming is favourable for warm-tolerant *Ambrosia*. However, decreasing daily linear trends (Table 2; Fig. 2, the second half of August) can also be observed that can be explained by the lack of available water during the hottest summer period (Fig. 2, annual cycle of the slopes of daily linear trends for rainfall). A decrease in pollen counts can be accounted for by the disappearance of younger fallow areas – a former important habitat – due to their succession, grazing, moving, afforestation and in-building, as well as regular reaping. Poaceae show a growing but non-important trend connected with the regenerating fallow areas. The older fallow areas are characterised by grasses, resulting in the

Table 4
Climate change related forces and significance of the different pollen season characteristics for each individual taxon.

Taxa	Risk due to the climate change[a]	EP[b]	MAM[c]	TAPC by linear trend[d]	APP[e]	Pollination season[f]			TAPC via daily linear trend[g]
						onset	end	duration	
Alnus	***	−2	+++		(−10)				
Ambrosia	*(potential increase)	**2**	**+**			**(+10)**			
Artemisia	*(potential increase)	2	+++						
Betula	***	−2	+++						
Cannabis	*	0	+++				+5		(+10)
Chenopodiaceae	*(potential increase) **(few taxa)	1	+++						−5
Juglans	*(potential increase)	2	++		(+10)				+1
Morus	**	−1	+++						+1
Pinus	**	−1	+++						−1
Plantago	*(potential increase) **(few taxa)	1	++			−5			+5
Platanus	*(potential increase)	2	++						+5
Poaceae	*(potential increase) **(few taxa) ***(few taxa)	**1**	**+++**				**(+10)**	**+1**	
Populus	* **(few taxa)	**1**	**+**	**+5**	**+5**				**+1**
Quercus	* **(few taxa)	1	++						(+10)
Rumex	*(potential increase) **(few taxa)	1	+++			−5			−1
Taxus	***	−2	+++	(+10)			+1		+1
Tilia	* **(few taxa)	1	+++						(−10)
Ulmus	* **(few taxa)	1	++						−1
Urtica	* **(few taxa)	**1**	**+**	**(+10)**		**−5**	**+5**	**+1**	**+1**

± 1, ± 5: a significant increasing/decreasing trend at the 1%, 5% probability levels; (± 10): a tendency of trend at the 10% probability level.
Bold: taxa with the highest pollen levels.
[a] **Risk due to climate change:** * non-endangered taxa; ** moderately endangered taxa (population of some species may decrease regionally); *** endangered taxa.
[b] **Expansion Potential due to the climate change:** 0: unaffected by global warming; 1: for some species there is an area-increase, while for some others area-decrease is possible; 2: significantly influenced by global warming; for some species area-increase is expected; −1: for some species regional area-decrease is possible; −2: significantly influenced by global warming; for the majority of species area-decrease is expected. (The effect of global warming is indifferent to or mostly favourable for families and a genus classified in categories 0, or 1 and 2, while for those placed into categories −1 and −2 the changes are unfavourable. Taxa grouped into categories 0, 1 and −1 are not substantially affected, but those in categories 2 and −2 are significantly affected by global warming.)
[c] **MAM (multiple association measure):** + low sensitivity; ++ medium sensitivity; +++ high sensitivity.
[d] **TAPC by linear trend:** change in the total annual pollen count calculated by using linear trends.
[e] **APP:** change in the annual peak pollen concentration calculated by using linear trends.
[f] **Pollination season:** change of start, end and duration of the pollinations season calculated by using linear trends.
[g] **TAPC via daily linear trend:** change in the total annual pollen count calculated by using daily linear trends.

extension of grass-covered areas. *Populus* displays a substantial increase in pollen count trends. This can be explained by wide climate tolerance of its species. Furthermore, the stocks planted during the last decades have grown up, so they can substantially pollinate. A noticeable increase in the annual pollen counts of *Urtica* can be accounted for by (1) under-use of urban habitats, (2) an increasing number of fallow areas, (3) huge plantations of locust trees *(Robinia pseudo-acacia)*, due to their nitrogen production, which contributes to the development of *Urtica*, as well as by (4) increasing maximum temperatures, facilitating an earlier start and later end of the pollination season (Haraszty, 2004) (Tables 1–3).

Based on an association measure (AM) – introduced to characterise the strength of the relationship between annual cycles of daily slopes of pollen concentration trends and those of climate variables trends – the individual taxa were placed into three categories according to their climate sensitivity defined by a multiple AM (MAM). These are: (1) high sensitivity: MAM > 0.950, involving 11 taxa (*Artemisia, Cannabis, Alnus, Taxus, Rumex, Morus, Betula, Tilia,* Chenopodiaceae, *Pinus* and Poaceae); (2) medium sensitivity: $0.900 <$ MAM ≤ 0.950, including 5 taxa (*Platanus, Plantago, Ulmus, Juglans* and *Quercus*); (3) low sensitivity: MAM ≤ 0.900, comprising 3 taxa (*Populus, Ambrosia* and *Urtica*) (Table 3).

Risk and expansion potential (EP) due to the climate change are compared to the AM for each taxon (Table 4). MAM alone does not completely contain or express the climate change related forces, but all three taxa (*Ambrosia, Populus* and *Urtica*) having the lowest climate sensitivity (+) are non-endangered (*) and, except for *Ambrosia,* are characterised by a moderate expansion potential (EP = 1). At the same time, for all endangered taxa (***) (even if just one species is endangered within a given taxon) MAM values indicate a high sensitivity (+++). Hence, MAM values go well the climate change related forces and tell us that climate parameters are important elements of the environmental conditions for the taxa examined (Tables 3 and 4).

Ambrosia has a low climate sensitivity (+) according to MAM (Tables 3 and 4). However, a higher potential increase is anticipated due to its bioclimatic indicator values and high climate tolerance. Namely, this genus can adapt well to dry and hot conditions. If more fallow areas and abandoned human habitats appear in the landscape, its further increase is expected, especially on sandy soils. Poaceae display a high sensitivity (+++) according to MAM, since a shortage of water and high temperatures can cause problems for them and cause a regional decrease. However, the species pool of this family is the widest among the studied taxa, so there will be species to replace the current grasses and even species from the Mediterranean and more continental areas might reach the Carpathian basin in the future. Of course, this could drive some of the present species out. *Urtica* and *Populus* have a wide climate tolerance; hence they are not climate-sensitive (+) according to MAM. Both genera could increase their population in the future. They are not endangered by global warming (*) or just certain species are moderately endangered (**). Climate tolerance of *Populus* can be accounted for by a wide adaptation of its different species (Tables 3 and 4).

Annual pollen counts display strong increasing trends for a number of taxa. Nevertheless, phenological characteristics (onset, end and duration of the pollination season) show significant changes only in 10 out of 57 cases (19 taxa × 3 phenological characteristics) (17.5%). Here Poaceae and *Urtica* are the most important with notable changes of at least two characteristics. Hence, the increasing trends in annual pollen concentrations can be accounted for by increasing diurnal pollen concentrations. Our conclusions are in broad agreement with those of several research teams. For Thessaloniki (Greece), the total annual pollen counts, as well as daily peak pollen counts show significant increasing trends for the majority of taxa. At the same time, there are no important changes for the phenological characteristics (Damialis et al., 2007). Looking at a bigger region 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 concentrations for most of the pollen types have been increasing. Furthermore, for Zurich (Frei, 2008, *Betula*), Poznaň, Poland (Stach et al., 2007, *Artemisia*) and Vienna (Jäger et al., 1996, *Alnus, Corylus, Betula, Pinus* and *Ulmus*) the pollination season starts earlier, the daily maximum pollen concentration has increased (Frei, 2008, *Betula*) and the days of peak pollen counts occur earlier (Stach et al., 2007, *Artemisia*).

We compared the significance of long-term trends based on both quantity-related pollen season characteristics (TAPC on yearly and daily bases, as well as APP) and phenological characteristics (start, end and duration of the pollination season) of the taxa examined for Szeged (Hungary) (present paper) with those for Neuchâtel (Switzerland) (Clot, 2003) and Thessaloniki (Greece) (Damialis et al., 2007). Of the 19 taxa analysed in this study, only Taxus/Cupressaceae indicated the same notable increasing trend for all three locations. For Szeged and Thessaloniki there are 5 identical taxa indicating substantial positive trends, while another 4 taxa exhibit diverse trends at the two locations. For Hungary 6 out of 9 taxa indicating a substantial increase in daily linear trends of TAPC are woody plants, these being more sensitive to the climate change than grass and weeds (Clot, 2003; Damialis et al., 2007) (Table 5).

We found significant increasing trends for the total radiation, relative humidity and wind speed, while Frei (2008) reported a notable increasing trend for temperature. Several papers presented evidence for ecological changes due to a potential climate change (Dose and Menzel, 2004), such as shifts in plant and animal phenology for the boreal and temperate zones of the northern hemisphere (Menzel and Fabian, 1999). Phenological characteristics, like an earlier start of the pollination season, are very simple bio-indicators to help us track climate changes (Ahas et al., 2002).

Note that all taxa examined in the study are families or genera involving a number of species. Accordingly, analysing pollen season and phenological characteristics of a family or genus instead of given species involves a high variability of pollen season data. An observed trend in the above characteristics incorporates the variability of a given parameter for all species belonging to a given taxon, but this variability is influenced by meteorological variables. The important role of total radiation 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 concentration is higher than the ratio of long-range transport (Makra et al., 2010) other factors of local pollen production for Szeged region should also be considered. Besides meteorological variables, pollen concentrations are influenced as well by agricultural and social factors (Makra et al., 2005) including urbanisation,

Table 5
Comparison of the change in various pollen season characteristics for each taxon calculated by using linear trends between Hungary on one hand and Switzerland and Greece on the other.

Taxa	Plant habit[a]	TAPC by linear trend[b]			TAPC via daily linear trend[c]	APP			Pollination season								
									Start			End			Duration		
		1	2	3	1	1	2	3	1	2	3	1	2	3	1	2	3
Alnus	AD		+	+		(−)											
Ambrosia	**H**		+						(+)								
Artemisia	H		+											+			
Betula	AD																
Cannabis	H				(+)							+					
Chenopodiaceae	H			+	−									+			+
Juglans	AD				+	(+)											
Morus	AD				+												
Pinus	AE			+	−			+									
Plantago	H			+	+			+	−		−						+
Platanus	AD			+	+			+									
Poaceae	**H**			+				+				(+)			+		
Populus	**AD**	+		−	+	+		−						−			
Quercus	AD			+	(+)			+									
Rumex	H			+	−			+	−		+						−
Taxus	AE	(+)	+	+	+							+					
Tilia	AD				(−)												
Ulmus	AD		−		−												
Urtica	**H**	(+)		+	+				−			+			+		

Bold: taxa with the highest pollen levels in Szeged region.
Parameters significant at least at a 5% (10%) probability level are presented by their signs (in brackets). A negative slope of the linear trend indicates a shift to an earlier start or end of the pollen season, as well as a shorter duration or a lower daily peak pollen concentration.
1: Hungary (present paper); 2: Switzerland (Clot, 2003); 3: Greece (Damialis et al., 2007).
[a] AD: arboreal deciduous, AE: arboreal evergreen, H: herbaceous.
[b] TAPC by linear trend: change in the total annual pollen count calculated by using linear trends.
[c] TAPC by daily linear trend: change in the total annual pollen count calculated by using daily linear trends.

so-called "green meadow investments" (new investments in former agricultural areas) and newly-built motorways. Land eutrophication facilitating higher pollen production is not characteristic in an agricultural area consisting of small private plots for the Szeged agglomeration. A more important factor is that large industrial areas have come into use; housing estates as well as motorways were constructed in the region during the period investigated. Stripping agricultural lands for building purposes could mean an expansion of neglected areas that contributes to an increase of habitat regions of weeds and hence to an increase in pollen production.

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