TRENDS IN THE CHARACTERISTICS OF ALLERGENIC POLLEN IN CENTRAL EUROPE BASED ON THE EXAMPLE OF SZEGED, HUNGARY

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REZUMAT. Schimbările climatice pot influența caracteristicile de polenizare ale diferiților taxoni, în moduri variate. Scopul lucrării a fost să analizeze un spectru larg al datelor despre polenul din aer (19 taxoni) pentru aglomerația Szeget din sudul Ungariei pentru perioada cuprinsă între 1997 şi 2007. În fapt, tendințele din sezonului de polenizare cu date de la început şi sfârşit, precum şi tendințele ale numărului anual total de polen şi cantitatea anuală de polen au fost calculate pentru fiecare categorie.

Cuvinte cheie: schimbări climatice, polen, taxon,.

ABSTRACT. Climate change may, however, influence the pollination characteristics of different taxa in a variety of ways. The aim of paper was to analyse a comprehensive spectrum of airborne pollen data (19 plant taxa) for the Szeged agglomeration in Southern Hungary, for the period between 1997 and 2007. 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.

Keywords: climate change, pollen, taxon.

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).

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. 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). 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, $W \cdot m^{-2}$), relative humidity (RH, %), wind speed (WS, $m \cdot s^{-1}$) and rainfall (R, mm). They were collected in a meteorological station located in the inner city area of Szeged.

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).

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 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 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 and 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 (Table 1). 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.

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	**[1]TAPC by linear trend**	**[2]TAPC via daily linear trend**	**[3]APP**	**[4]Pollination season**		
				Start	**End**	**Duration**
Alnus	–207	–214	–59*	18	16	–2
[5]*Ambrosia*	**229**	**–1170**	**230**	**14***	**–9**	**–22**
Artemisia	–61	–60	–133	–4	15	19
Betula	–60	–60	0	–1	2	3
Cannabis	47	47*	–4	8	36**	28
Chenopodiaceae	–175	–175**	–9	–2	3	5
Juglans	253	253***	30*	–8	–7	1
Morus	400	400***	44	–7	–4	3
Pinus	–194	–194***	–20	–2	–1	0
Plantago	91	91**	3	–23**	19	4
Platanus	271	271**	48	–7	–3	4
[5]Poaceae	**176**	**176**	**43**	**–1**	**17***	**27*****
[5]*Populus*	**2981****	**2981*****	**610****	**–2**	**3**	**4**
Quercus	236	236*	25	4	9	5
Rumex	–505	–505***	–45	–11**	3	15
Taxus	697*	678***	59	–4	29***	32
Tilia	–65	–65*	–1	–4	–1	3
Ulmus	–160	–160***	–12	5	–13	–18
[a]*Urtica*	**1183***	**1183*****	**25**	**–13****	**18****	**31*****

[1] **TAPC by linear trend:** change in the total annual pollen count calculated by using linear trends.
[2] **TAPC via daily linear trend:** change in the total annual pollen count calculated by using daily linear trends.
[3] **APP:** change in the annual peak pollen concentration calculated by using linear trends.
[4] **Pollination season:** change of start, end and duration of the pollinations season calculated by using linear trends.
[5] **Bold:** taxa with the highest pollen levels.
* A tendency of trend at the 10% probability level.

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 icrease of T 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 2. 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. 1). 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 2-3).

Table 2. **Association measure ([a]AM) 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	[a]AM							[b]MAM
	T_{min}	T_{max}	*T*	*R*	*TR*	*RH*	*WS*	
Alnus	0.718*	0.775*	0.742*	0.313	-0.028	-0.620*	-0.455	0.992
[c]*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
[c]Poaceae	**-0.088**	**-0.649***	**-0.816***	**0.826***	**-0.057**	**0.309**	**0.643***	**0.959**
[c]*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
[c]*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}).

[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).

[c]**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,** *italic*), 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.*

4. CONCLUSIONS

Recent warming may help to extend habitats of herbaceous and arboreal plants producing allergenic pollen that contributes to the increase of pollen levels and exacerbation of their adverse effects, hence may contribute to the rise in pollen sensitivity and respiratory admissions due to pollen-related allergy problems.

Note that this study is the first attempt to show the climate sensitivity of the main allergenic species groups of vegetation. Two climate change-related forces were introduced, where the risk potential concentrates on the local survival capability, specifying what will happen with the species in their present habitats, while the expansion potential concentrates on the moving capability of the species and the landscape-level response.

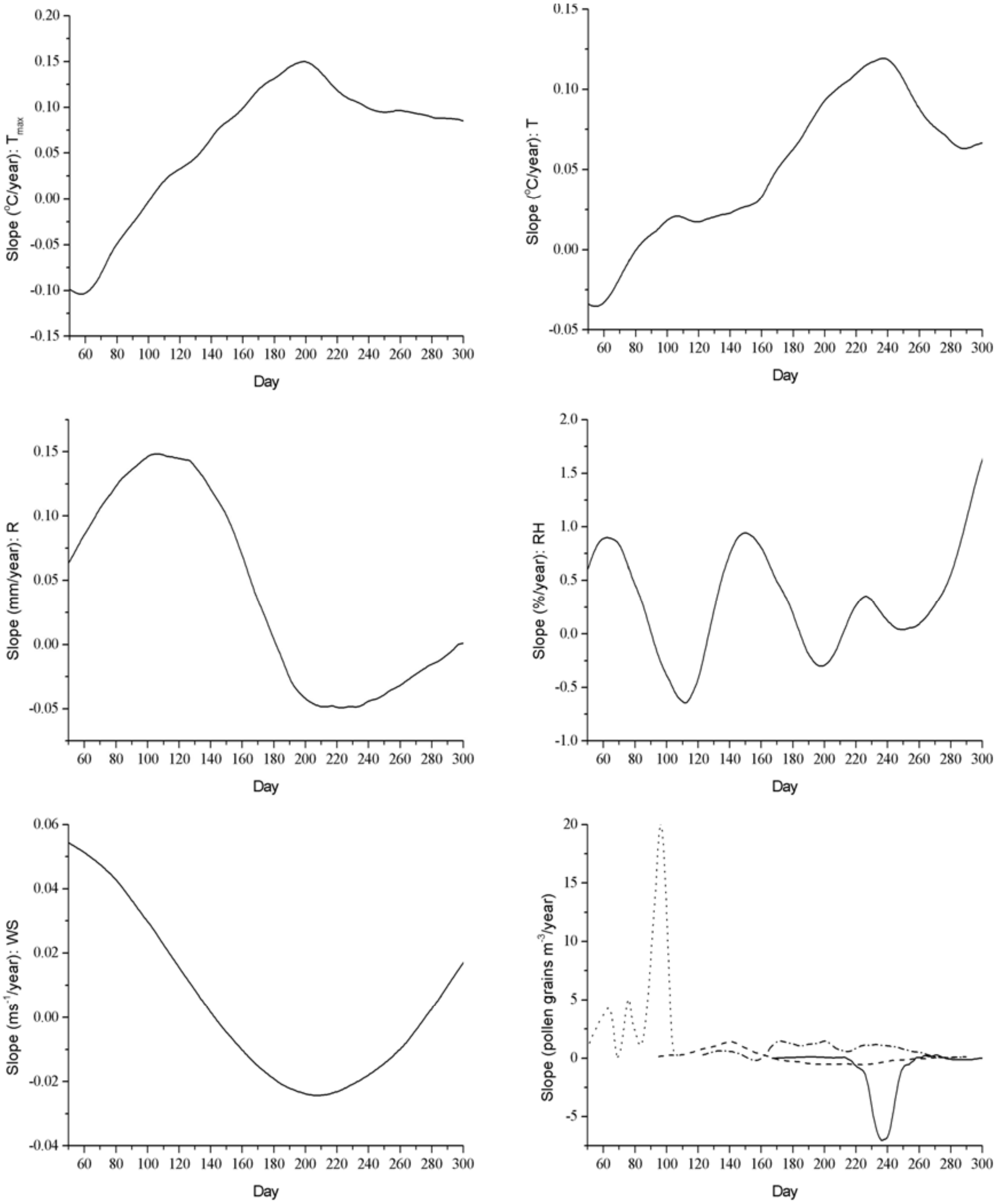

Fig. 1. Annual cycles of the slopes of daily linear trends for maximum temperature (T_{max}), mean temperature (T), rainfall total (R), relative humidity (RH) and wind speed (WS) for *Ambrosia* (solid), Poaceae (dash), *Populus* (dot) and *Urtica* (dash dot) .

The scale of the two forces is thus different. Expansion potentials were determined using risk potentials based on the ecological indicators of the species pool; hence, these forces have a strong connection. These latter two plant-associated forces include (a) an intra-taxonic species change, (b) a higher range of species coming from the surroundings of the Carpathian basin, (c) the transformation of abiotic features of habitats, (d) the moving capability of species and (e) the rescue effect of habitats due to special microclimates.

The MAM values are not always in close agreement with the risk and expansion potentials, but do closely follow them for certain taxa. MAMs use only the climate sensitivity of the taxa for a given time period, area and species pool. Furthermore, the risk and expansion potentials are useful for detecting regional changes over longer time periods (centuries, millennia), while MAMs can be used for detecting local changes over shorter periods (decades).

Of course, the results and conclusions were stated for only one sampling point. The results presented above will form the basis of further studies that will examine the climate change-related reasons for the modifications in vegetation dynamics, the phenology of flowering and pollen production as well.

Table 3. **Climate change related forces and significance of the different pollen season characteristics for each individual taxon**

Taxa	**[1]RP**	**[2]EP**	**[3]MAM**	**[4]TAPC by linear trend**	**[5]APP**	**[6]Pollination season**			**[7]TAPC via daily linear trend**
						onset	**end**	**duration**	
Alnus	***	-2	+++		(-10)				
[8]*Ambrosia*	*	**2**	+			**(+10)**			
Artemisia	*	2	+++						
Betula	***	-2	+++						
Cannabis	*	0	+++				+5		(+10)
Chenopodiaceae	* **(few taxa)	1	+++						-5
Juglans	*	2	++		(+10)				+1
Morus	**	-1	+++						+1
Pinus	**	-1	+++						-1
Plantago	* **(few taxa)	1	++			-5			+5
Platanus	*	2	++						+5
[8]Poaceae	* ****(few taxa)** *****(few taxa)**	**1**	+++				**(+10)**	**+1**	
[8]*Populus*	* ****(few taxa)**	**1**	+	**+5**	**+5**				**+1**
Quercus	* **(few taxa)	1	++						(+10)
Rumex	* **(few taxa)	1	+++			-5			-1
Taxus	***	-2	+++	(+10)			+1		+1
Tilia	* **(few taxa)	1	+++						(-10)
Ulmus	* **(few taxa)	1	++						-1
[8]*Urtica*	* ****(few taxa)**	**1**	+	**(+10)**		**-5**	**+5**	**+1**	**+1**

[1] **Risk Potential 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: unaffected by global warming; 1: for some species there is an area-increase, while for some others an 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 an area-decrease is expected;
(The effect of global warming is indifferent to or mostly favourable for families and a genus grouped 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.)

[3] **MAM (multiple association measure):** + low sensitivity; ++ medium sensitivity; +++ high sensitivity;

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

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

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

[7] **TAPC via daily linear trend:** change in the total annual pollen count calculated by using daily linear trends;

[4, 5, 6, 7]: ± 1, ± 5: a significant increasing/decreasing trend at the 1%, 5% probability levels; (± 10): a tendency of trend at the 10% probability level;

[8] **Bold:** taxa with the highest pollen levels;

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