# NEW CLIMATE CHANGE RELATED FORCES IN CENTRAL EUROPE ON THE EXAMPLE OF ALLERGENIC TAXA

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## Abstract

The aim of the study is to analyse trends of the pollination season with its duration, 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 (1997-2007) including 19 taxa and seven daily climate variables. Trend analysis is performed on both annual and daily bases. The latter approach provides information on annual cycles of trends. The strength of the relationship between the annual cycle of the slope of a pollen concentration trend and the annual cycles of slopes of climate variable trends is quantified by an association measure and a multiple association measure. Individual taxa are sorted into three categories according to their climate sensitivities. These are compared with two novel climate change related indicators, namely risk potential and expansion potential due to the climate change. 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 measures perform well when compared to the climate change related forces. Remarkable changes in pollen season characteristics are also in accordance with the risk potential and expansion potential due to climate change.

Keywords:
pollen, pollen season, trend, ecological indicator, climate change, respiratory allergy,

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## 1. Introduction

Recently, the earth's ecosystem is experiencing a global warming. Climate change is responsible for the observed northward and uphill distribution shifts of many European plant species. By the late 21st century, distributions of European plant species are projected to have shifted several hundred kilometres to the north; forests are likely to have contracted in the south and expanded in the north. The rate of change will exceed the ability of many species to adapt. Concerning plant phenology, the timing of seasonal events in plants is changing across Europe due to changes in climate conditions. Between 1971 and 2000, the average advance of spring and summer was 2.5 days per decade. The pollen season starts on average 10 days earlier and is longer than 50 years ago *(Feehan et al. 2009)*.

A recent warming is associated with an earlier onset *(Frei 2008; Rodriguez-Rajo et al. 2011)*, an earlier end date *(Stach et al. 2007; Recio et al. 2010)*, a longer pollen season *(Stach et al. 2007; Ariano et al. 2010)*, an increase in the total annual pollen load *(Cristofori et al. 2010; Ariano et al. 2010)*, furthermore an increase of patient number sensitized to pollen throughout the year *(Ariano et al. 2010)*.

The scope of the studies is generally limited to only one taxon *(Alcázar et al. 2011; Peternel et al. 2006)*, or a very small number of taxa *(García-Mozo et al. 2010; Kaminski and Glod 2011; Rodriguez-Rajo et al. 2011)*. A comprehensive spectrum of the regional pollen flora was only analysed in three studies, namely in *Clot* (*2003,* 25 plant taxa), *Damialis et al. (2007,* 16 plant taxa) and *Cristofori et al. (2010,* 63 plant taxa), respectively. An overall analysis of pollen season characteristics for a given source area provides a more reliable picture of the climate sensitivity for each taxon studied based on their different optimum environmental conditions.

Precognition of pollen season characteristics is important for those people suffering from pollen-induced respiratory diseases, who can prepare in due time for days of extreme high pollen load. At the same time, climate change can affect pollen characteristics of different taxa diversely. The object of this paper is to study an extended spectrum of airborne pollen characteristics (19 plant taxa) for Szeged region in Southern Hungary. Trends of both quantity-related and phenological pollen season characteristics are calculated for each taxon. Furthermore, a multiple association measure (MAM) is introduced 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

In addition, two novel climate change related forces, namely risk potential (RP) and expansion potential (EP) due to the climate change are also introduced and these forces are evaluated 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). The 19 taxa studied 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%), which together account for 61.5% of the total pollen production.

As regards the taxa with the highest pollen concentrations, *Ambrosia* genus has only one species, namely *Ambrosia artemisiifolia* (Common Ragweed) in Szeged region that 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, furthermore *Poa angustifolia* (Narrow-leaved Meadow-grass) and *Alopecurus pratensis* (Meadow Foxtail) in floodplain, and along the dyke surrounding Szeged region represent a substantial proportion in the city. Along the urban lakesides *Phragmites australis* (Common Reed) is the most frequent Poaceae. Furthermore, on short grass steppes of sand, loess and saline areas *Festuca pseudovina* and *Festuca rupicola* also occur. For *Populus* genus, natural species of *Populus alba* (White Poplar) and *Populus canescens* (Grey Poplar) are the most frequent in the city and are characteristic in floodplain forests along the Tisza and Maros Rivers. In addition, cultivated poplars such as I-273 Poplar and *Populus x euroamericana* (Canadian Poplar) and its variants are frequently planted in urban parklands, public places, as well as along roads in peripheries. At the same time, *Urtica* genus with its only species of *Urtica dioica* (Common Nettle) in Szeged region has a 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 area.

The remaining species seldom occur here. *Alnus* species are only found in the Botanical Garden 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

### 2.2.1. Trend analysis

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 the Mann-Kendall (MK) 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 (Fan 1993). 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. A technique proposed by *Francisco-Fernández and Vilar-Fernández (2004)* is used here for the purpose. Note that the local linear fits become globally linear with infinite bandwidths.

### 2.2.2. Taxon-specific ecological indicators as a basis for introducing new climate change related forces

In order to evaluate the response of plants to climate change, two indicators were introduced: risk due to the climate change (RP) and expansion potential due to the climate change (EP). Both indicators were determined for a specific taxonomic group (genus, family) of the most allergenic plants. The species-pool of the Hungarian vegetation was collected according to the Flora Database of Hungary *(Horváth et al. 1995)*. The above mentioned two new terms were determined on the basis of four main ecological indicators of the taxa examined, collected from this database. The selected parameters were: temperature requirement due to Zólyomi (TZ-value) *(Zólyomi and Précsényi 1964)*, temperature requirement due to Soó (TS-value) *(Soó 1964-1980)*, heat supply of species interpreted with the climate of the vegetation belts due to Borhidi (TB-value) *(Borhidi 1995)*, as well as degree of continentality and climate extremity tolerance according to the distribution of species due to Borhidi (CB-value) *(Borhidi 1995)*. Substitution of species within a taxon and habitat-shifts were also considered (*Table 1*). In order to calculate the new climate change related forces, besides the above-mentioned ecological indicators, local effects of the awaited changes predicted by recent climate models were also considered. These models count with a 2°C increase in annual temperature, higher mean temperature and lower rainfall total in the summer season and a more extreme rainfall distribution throughout the year for a 100-year time scale until the end of the century *(Láng et al. 2007; Czúcz 2009)*.

*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 pollen season (days / 10 years) calculated by using linear trends. Significant values on annual basis are denoted by *** (1%), ** (5%) and * (10%). Significant values on daily basis are denoted by +++ (1%), ++ (5%) and + (10%).*

| Taxa | Mean total annual pollen counts | TAPC | APP | Pollen season | | |
|---|---|---|---|---|---|---|
| | | | | Start | End | Duration |
| *Alnus* | 505 | -214 | -59* | 18 | 16 | -2 |
| [a]***Ambrosia*** | 7826 | **-1170** | **230** | **14*** | **-9** | **-22** |
| *Artemisia* | 772 | -61 | -133 | -4 | 15 | 19 |
| *Betula* | 901 | -60 | 0 | -1 | 2 | 3 |
| *Cannabis* | 432 | 47 + | -4 | 8 | 36** | 28 |
| Chenopodiaceae | 854 | -175 ++ | -9 | -2 | 3 | 5 |
| *Juglans* | 284 | 253 +++ | 30* | -8 | -7 | 1 |
| *Morus* | 667 | 400 +++ | 44 | -7 | -4 | 3 |
| *Pinus* | 500 | -194 +++ | -20 | -2 | -1 | 0 |
| *Plantago* | 409 | 91 ++ | 3 | -23** | -19 | 4 |
| *Platanus* | 400 | 271 ++ | 48 | -7 | -3 | 4 |
| [a]**Poaceae** | 2552 | **176** | **43** | **-10** | **17*** | **27***** |
| [a]***Populus*** | 2322 | **2981** +++** | **610**** | **-2** | **3** | **4** |
| *Quercus* | 423 | 236 + | 25 | 4 | 9 | 5 |
| *Rumex* | 462 | -505 +++ | -45 | -11** | 3 | 15 |
| *Taxus* | 572 | 697* +++ | 59 | -4 | 29*** | 32 |
| *Tilia* | 225 | -65 + | -1 | -4 | -1 | 3 |
| *Ulmus* | 260 | -160 +++ | -12 | 5 | -13 | -18 |
| [a]***Urtica*** | 2200 | **1183* +++** | **25** | **-13**** | **18**** | **31***** |

[a]***Bold:*** *taxa with the highest pollen levels*

### 2.2.3. Risk potential (RP) and expansion potential (EP) as new forces due to climate change

RP 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 climate change since they contain species for warmer and drier conditions, whereas the climatically endangered taxa (***) have no species in the present flora for the awaited changed conditions. In the first case, change of species within a taxon in a certain landscape could help adaptation of the taxon to the global warming, whereas in the latter case the lack of warm-tolerant species can lead to the disappearance of a given taxon. The wider tolerance-range (the more values) and the more species (especially warm and dry-tolerant species) a taxon has, the less exposure to climate change it has.

Moderately endangered taxa (**) could survive partly in their places, but populations of some species may decrease regionally.

Three variables must be considered for a given taxon: (1) the number of species within a taxon, (2) the value-range of the ecological indicators of the species within a taxon and (3) the number of warm- and dry-tolerant species within a taxon (this is the most important factor). For example, grasses (Poaceae) have a lot of species [see: (1)] with a wide value-range of the ecological indicators of their species [see: (2)], and many of them are warm-tolerant [see: (3)], so they will have enough species to adapt to the changes. However, the answer of species can be different to the climate change (all three categories of RP can occur for Poaceae). If a taxon contains mainly warm- and dry-tolerant species (e.g. *Ambrosia, Juglans* and *Platanus*) less species need adaptation, decreasing RP due to the climate change (*). If a taxon has only a few species and neither of them favours warmer and drier conditions, RP of extinction is significantly high (***) (e.g. *Betula* and *Alnus*) *(Table 1).*

EP shows the capability of the species to move in the landscape, so this term measures the rescue effect. If a taxon belongs to several categories of RP due to the climate change, these categories can be grouped into different classes on the basis of field experiments. As a result, this feature is described with 5 classes as a wide range of responses are awaited due to the different climate-tolerance of the species-pool of taxa. These classes are as follows. (0): Taxa non-influenced by global warming. They could survive and their distribution area will remain about the same. (1): Taxa non-influenced by global warming, but for some species area-increase and for some others area-decrease is possible. They can rather survive the changes through moving in the landscape, but their expansion is limited although possible. (2): Taxa significantly influenced by global warming. For some species area-increase is expected. They show the best adaptation to the climate change as they will not just survive but can spread well in the landscape. (-1): For some species regional area-decrease is possible. They can survive in a few places, their spread in the landscape is limited and area-decrease is awaited. (-2): Taxa significantly influenced by global warming. For the majority of species area-decrease is expected. They have the smallest adaptation capability; they will gradually disappear and even the rescue effect in some refugees is doubtful (Table 1).

The above-mentioned five categories can be useful not only to evaluate the future distribution of allergenic species groups but they can also help to reveal the possible changes in endangered plant groups and invasive species (nature conservation aspect), as well as the spread of weeds (agricultural aspect).

### 2.2.4. Multiple association measure (MAM) as a newly introduced measure and its association with RP and EP

Beside RP and EP as climate change related forces, a multiple association measure (MAM) was also introduced 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 (Table 3). However, the multiple association measures (MAMs) do not necessarily harmonize with RP and EP for given taxa. EPs were determined using RPs based on the ecological indicators of the species-pool; hence, these forces are in strong association. These latter two plant associated forces count (a) with the intra-taxonic species change, (b) with a higher range of species (species in and around the Carpathian-basin), (c) with transformation of abiotic features of habitats, (d) with the moving capability of species and (e) with the rescue effect of habitats due to special microclimates. While, MAMs consider climate sensitivity of the taxa for a given time period, area and their species-pool only. Furthermore, RP and EP are suitable to detect regional changes for longer (centuries, millennia) time periods, whereas MAMs can be used for observing local changes for shorter (decades) periods (Table 1, 3, 4).

## 3. Results

### 3.1. Trend analysis

Only a few trends have been clearly identified compared to the total number of MK tests performed (Table 2). It is not surprising as the interannual variability of the characteristics studied is quite high, while the size of the data sets is quite small. Therefore, MK tests are performed and linear trends are estimated for each particular day of each pollen 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 pollen 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 for the purpose 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. Averaging values of daily slopes of linear trends over the pollen seasons gives rates of change of the total annual pollen counts (Table 2). Note that trend analysis on daily basis detects much more significant trends of total annual pollen counts (TAPC) than trend analysis on annual basis.

*Table 2. The values of the ecological indicators and the climate change related forces for the most common allergenic taxa for Hungary*

| Taxa | TZ-value | TS-value | TB-value | CB-value | Risk potential due to climate change (RP) | Expansion potential due to climate change (EP) |
|---|---|---|---|---|---|---|
| *Alnus* | 2, 3, 6 | 1, 2 | 3, 4, 5 | 4 | *** | -2 |
| [3]***Ambrosia*** | **0** | **0** | **8** | **6** | * | **2** |
| *Artemisia* | 5, 6, 7, | 2, 3, 4, 5 | 6, 7, 8, 9 | 5, 6, 7, 8, 9 | * | 2 |
| *Betula* | 3 | 1, 2 | 3, 4 | 3, 4 | *** | -2 |
| *Cannabis* | 5 | 0 | 7 | 7 | * | 0 |
| Chenopodiaceae | 0, 5, 6, 7 | 0, 2, 3, 4, 5 | 5, 6, 7, 8, 9 | 0, 2, 3, 4, 5, 6, 7, 8, 9 | *<br>**(few taxa) | 1 |
| *Juglans* | 5 | 4 | 8 | 2, 5 | * | 2 |
| *Morus* | – | – | 7 | 5 | ** | -1 |
| *Pinus* | 3 | 1, 2, 4 | 4, 8 | 4, 7 | ** | -1 |
| *Plantago* | 5, 6, 7 | 0, 2, 3, 4 | 5, 6, 7, 8 | 0, 1, 3, 6, 7, 8 | *<br>**(few taxa) | 1 |
| *Platanus* | 5, 6, 7 | 4 | 6, 7, 8, 9 | 6 | * | 2 |
| [3]**Poaceae** | **0, 3, 4, 5, 6, 7** | **0, 2, 3, 4, 5** | **3, 4, 5, 6, 7, 8, 9** | **2, 3, 4, 5, 6, 7, 8, 9** | *<br>**(few taxa)<br>***(few taxa) | **1** |
| [3]***Populus*** | **3, 5** | **3, 4** | **5, 7, 8** | **5, 6, 7** | *<br>**(few taxa) | **1** |
| *Quercus* | 5, 6 | 3, 4 | 6, 7, 8 | 4, 5, 6, 7 | *<br>**(few taxa) | 1 |
| *Rumex* | 0, 5 | 0, 2, 3, 4 | 4, 5, 6, 7, 8 | 2, 3, 5, 6, 7, 8 | *<br>**(few taxa) | 1 |
| *Taxus* | 5 | 2 | 5 | 2 | *** | -2 |
| *Tilia* | 5, 6 | 3, 4 | 5, 7 | 2, 4, 7 | *<br>**(few taxa) | 1 |
| *Ulmus* | 5 | 2, 3, 4 | 5, 6, 7 | 3, 5, 6 | *<br>**(few taxa) | 1 |
| [3]***Urtica*** | **5, 6** | **0, 4** | **6, 7** | **4, 6** | *<br>**(few taxa) | **1** |

***TZ-value: temperature requirement due to Zólyomi (Zólyomi and Précsényi 1964; Horváth et al. 1995):***

***TS-value: temperature requirement due to Soó (Soó 1964-1980; Horváth et al. 1995):***

***TB-value: heat supply of species interpreted with the climate of the vegetation belts due to Borhidi (Borhidi 1995; Horváth et al. 1995):***

***CB-value: degree of continentality and climate extremity tolerance in association to the distribution of species due to Borhidi (Borhidi 1995; Horváth et al. 1995):***

[1] ***Risk Potential due to climate change (RP):***

** non-endangered taxa; ** moderately endangered taxa (population of some species may decrease regionally); *** endangered taxa;*

[2] ***Expansion Potential due to climate change (EP):*** *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] ***Bold:*** *taxa with the highest pollen levels;*

Needless to say, the daily MK test statistics have a big variability. Therefore, daily MK test values are smoothed with the nonparametric regression technique outlined in Section 2.2.1. 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 every taxon indicate trends even for *Alnus, Ambrosia, Artemisia, Betula* and Poaceae, the 5 taxa not exhibiting overall trends on yearly basis at even 10% significance level. The nonparametric regression technique was used also to estimate annual cycles of the slopes of daily trends.

*Alnus* and *Betula* occur around Szeged with very little populations (especially *Alnus*). According to the tolerance range of these taxa, increasing temperature and drying climate do not favour them, so their decreasing pollen trend is not surprising as *Alnus glutinosa* – the only representative of this taxon appearing just in few bogs in the Great Hungarian Plain and parks in Szeged – and *Betula pendula* (planted in parks) like a wetter, more humid, equalized climate. Due to their low occurrences, the decrease of their pollen counts cannot be significant in the trends.

*Pinus* show a clear decreasing trend as a result of non-suitable choice of species, as foresters and gardeners plant non-warm-tolerant *Pinus* species in many cases. In the forest plantations of Kiskunság sand-ridge the co-plantation of *Pinus sylvestris* favouring a wetter, cooler climate and the more warm-tolerant sub-Mediterranean *Pinus nigra* is common. The increasing temperature and the lack of water especially in summer does not suit for *Pinus sylvestris*, hence a substantial decrease of TAPC for *Pinus* can only be partially compensated by an increase of pollen counts of *Pinus nigra*.

Total annual pollen counts for *Tilia* show a slight decreasing tendency. This species is not widely represented in the forests of the Great Hungarian Plain, but it is quite common in the parks and gardens of Szeged city. Among its species *Tilia platyphyllos* are planted many times that stands the warmer and drier climate less compared to *Tilia cordata* and *Tilia tomentosa*, which are more warm-tolerant, especially the latter species. *Tilia tomentosa* is awaited to show a remarkable spread in the future if warming will be continued as it is a sub-Mediterranean plant. *Tilia tomentosa* is represented along the Illyrian-Dacical pincers, being a route for sub-Mediterranean species approaching the Carpathian-basin from the south. In this way, its nearest appearance to Szeged can be found in Mecsek and Fruska Gora mountains, or in the southern slopes of the mountains of Partium, as well as the sand-ridge of Nyírség

The lack of humidity and the increasing temperatures can be a limiting factor for *Ulmus* too, as a notable decrease in its annual pollen counts was observed. Stocks of its most common species, *Ulmus minor* grow in dry places without shading trees like oak; they appear several times alone alongside roads and channels. This species together with *Ulmus laevis* can be found in the hardwood floodplain forests, as well. These taxa can also occur in parks, where *Ulmus glabra* is rarely planted. In dry places the lack of shading trees, while in floodplains the absence of floods and the lower level of the summer groundwater can limit their pollination.

Change of TAPC for *Artemisia,* Chenopodiaceae and *Rumex* calculated on yearly basis is not significant. However, Chenopodiaceae and *Rumex* show remarkable decreasing trends when calculating on daily basis that are due to changes in land use. These plants are typical species of young fallows, which appeared after the change of political system at the beginning of 1990s, especially in sand landscapes. However, due to spontaneous regeneration facilitated by grazing and mowing, these new stocks began to disappear as these sand fallows turned into sand steppe grasslands *(Deák 2010)* and only the populations associated with natural habitats or settlements remained. At the same time, the abandonment of arable lands have decreased during the last 10 years, as the extension of fallows was reduced by in-buildings and forest plantations, respectively. Strong decrease of *Rumex* can be explained by the drier years resulting in the lack of inland waters as *Rumex* species are typical plants of inland water affected arable lands situated in depressions.

In contrast, TAPC of *Plantago* show a clear increase, which can also be explained by the above-mentioned regeneration processes of fallows. *Plantago* species (especially *P. media* and *P. lanceolata*) are typical plants of old fallows regenerating into sand steppe grasslands, but also occur frequently in urban grasslands. It is typical that weeds of *Artemisia*, Chenopodiaceae and *Rumex* disappear in the later stages of fallow-succession as steppe species like *Plantago* appear especially in the treated (mown, grazed) fallows. The fallows of the sand-ridge around Szeged have reached the stage when *Plantago* became more frequent, so its significance is much higher, which refers to a stronger trend.

Duration of the pollen season of Poaceae is significantly increasing due to the warming climate, but TAPC exhibits no significant trend, which can also be in association with the regenerating fallows. The elder fallows are all characterized by a huge coverage of grasses, so fallow regeneration led to a slight extension of grasslands during the last 10 years. The Poaceae family contains different species which are dominating a several type of grassland habitats. Namely *Agropyron repens* (Common Couch), *Poa trivialis* (Rough Meadow-grass), *Cynodon dactylon* (Bermuda grass), *Bromus* species (Brome species), as well as *Poa bulbosa* (Bulbous Meadow-grass) and *Poa angustifolia* (Narrow-leaved Meadow-grass) are typical rather on weedy dry grasslands, while *Echinochloa crus-galli* (Cockspur) in wet weedy grasslands of the inland-water covered depressions incorporated into arable lands. Several natural grasslands remained around Szeged in both sand and loess and floodplain landscapes mainly associated with depressions. *Alopecurus pratensis* (Meadow Foxtail) is the main grass of floodplain meadows, which covers also the dykes around Szeged, whereas *Molinia hungarica* (Hungarian Purple Moor-grass) forms the rare *Molinia* fens situated in the groundwater's upwelling-zones of the depressions of Kiskunságian Sandland. *Agrostis stoloinfera* (Creeping Bent) is the main grass of the sandland-type saline meadows, whereas *Puccinellia limosa* (Common Saltmarsh Grass) forms the *Puccinellia* swards, a grassland with surface salt-accumualtion, appearing mainly in the Kiskunságian Sandlands. *Festuca* species (mainly *Festuca pseudovina* and *Festuca rupicola*) are dominating the sand, loess and short-grass alkali steppe grassland types, but in these habitats *Dactylis glomerata* (Cocksfoot) and *Botriochloa ischaemum* (Yellow Bluestern) are also common. Swamps, artificial lakes, oxbow lakes, channels are surrounded by *Phragmites communis* (Common Reed). Furthermore, cereals [wheat *(Triticum aestivum)*, maize *(Zea mays)* and barley *(Hordeum vulgare)*] also belong to Poacea, which cover a huge proportion of the landscape surrounding Szeged as arable lands are the most common habitats of all landscape types in this region.

*Populus* indicates a substantial increase of TAPC. This can be the result of its wide climate tolerance as both wet- (e.g. *P. nigra* and *P. canescens*) and dry-tolerant species are represented in the landscape. Especially *Populus alba* shows a great adaptation potential which lives in floodplains, sand lands and parks, as well. *Populus* (both wild and cultivated types) were planted widely in the sand lands west from Szeged and in the floodplains. Plantation of these species has not yet stopped during the last 10 years. Besides the locust-tree *(Robinia pseudo-acacia)* they are the most favoured trees for plantation of forests. The stocks planted in the last decades are in mature state, so they can pollinate on high level.

*Quercus* (mainly *Quercus robur*) was not planted so widely during the last 10 years, but in the 1960-1980s significant oak plantations appeared southeast from Szeged in the saved-side floodplains and in the active floodplain of river Maros. The stocks became more and more mature during the last decades, so they are on the level of their full pollination potential. As *Quercus robur* is a continental species with wide climate tolerance the increasing temperature can help its generative processes until a limit of available water.

Surprisingly, TAPC of *Taxus* showed an increase during the last 10 years. This species does not appear in natural communities around Szeged but is found just in parks and gardens. *Taxus baccata* – as a representative of this taxon in Szeged – is a Western European species favouring a more humid, equalized oceanic climate, which is warmer in the winter and springtime compared to the continental climate of Hungary. However, urban heat island of Szeged could influence its trend.

Highly significant increase was observed for TAPC and the duration of the pollen season of *Urtica*. *Urtica dioica*, the only representative of this species around Szeged, has a wide climate tolerance. It can be found both in dry and wet habitats. Under-use of urban habitats, huge plantation of locust-tree (Robinia pseudo-acacia) and increasing level of fallows also contributed to the expansion of their population. Their pollination is also promoted by increasing maximum temperatures facilitating an earlier start and later end of its pollen season.

Growing trends were observed for all warm-tolerant, non-endemic taxa. TAPC of *Cannabis* shows a slight increase. As this taxon is originated from South Asia, it is more warm-tolerant and hence increasing temperature could promote its pollination. Much stronger increase was observed for *Juglans*, *Platanus* (originating from the Mediterranean) and *Morus* (originating from East Asia) favouring a warm-temperate climate.

*Ambrosia* (represented only with one species) show no significant trend as a moderate warming is favourable for this taxon, but the lack of available water during the hottest summer period can limit its pollination as the plant concentrates on preserving water and maintaining its vegetative life functions despite the generative. *Ambrosia* appears year by year in stubble fields, especially in sand landscapes and in abandoned places around settlements. The populations of young fallows represent just a smaller part of their population in the landscape.

### 3.2. Analysis of individual taxa based on MAM, RP and EP

*Alnus, Betula* and *Taxus* are endangered species according to their RP (***), as well as they are highly sensitive according to their MAM values (+++). This is because they favour a wetter, cooler and more equalized climate and they live on the edge of their distribution area in Hungary. Hence, global warming can affect them negatively, since they cannot stand warm and dry climate for longer time and they can extinct in several habitats and other competitors can be more successful.

*Ambrosia* is unaffected according to its MAM value. However, its higher potential increase is awaited due to its ecological indicator values and high climate-tolerance. Namely, this genus can adapt well to dry and hot conditions, but is highly influenced by future land use. If more fallows and abandoned human habitats appear in the landscape its further increase is awaited especially on sand soils.

*Artemisia* species are warm-tolerant so their EP is high: even Mediterranean and more continental species could appear in the Carpathian-basin. EP of agricultural weeds can be high on fallows that can appear fast in landscapes due to unfavourable weather conditions for farming. This is land use dependent since the last 10-year decrease in pollen dispersion can be explained by fallow-succession. A major part of *Artemisia* pollen samples are produced by *Artemisia santonicum*, a natural dominant species of *Artemisia short grass alkali steppes* – main habitats of saline grasslands formed on loess – that are characterized by near-to-surface salt-accumulation *(Deák 2010)*. These habitats and, in this way, this species are proved to be very climate-sensitive – in contrast with *Artemisia* weeds – as their out-leaching is remarkable, which is enhanced by the decrease of rainfall resulting in the decrease of salty groundwater-table. The ratio of *Artemisia santonicum* can be high in the samples since near to Szeged many of these habitats still exist.

*Cannabis* is a warm-tolerant species but cannot stand a major decrease of temperature, so is climate-sensitive to cold weather (Table 3). As cooling is not awaited it is not endangered by the expected climate change. Too high maximum temperatures, however, can be a limit for its pollen production as a result of water shortage (Table 4).

*Table 3. 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 | $T_{min}$ | $T_{max}$ | T | R | TR | RH | WS | [b]MAM |
|---|---|---|---|---|---|---|---|---|
| *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 ($W \cdot m^{-2}$), RH: relative humidity (%), WS: wind speed ($m \cdot s^{-1}$);*
*[a]AM: association measure;*
*[b]MAM: multiple association measure;*
*[c]**Bold:** taxa with the highest pollen levels;*
**AM > $|0.5|$ indicates a strong association;*

*Sensitivity classes*

*(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;*

*Table 4. 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]Pollen 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 | *<br>**(few taxa) | 1 | +++ | | | | | | -5 |
| *Juglans* | * | 2 | ++ | | (+10) | | | | +1 |
| *Morus* | ** | -1 | +++ | | | | | | +1 |
| *Pinus* | ** | -1 | +++ | | | | | | -1 |
| *Plantago* | *<br>**(few taxa) | 1 | ++ | | | -5 | | | +5 |
| *Platanus* | * | 2 | ++ | | | | | | +5 |
| [8]**Poaceae** | *****<br>****(few taxa)**<br>*****(few taxa)** | **1** | **+++** | | | | **(+10)** | **+1** | |
| [8]***Populus*** | *****<br>****(few taxa)** | **1** | **+** | **+5** | **+5** | | | | **+1** |
| *Quercus* | *<br>**(few taxa) | 1 | ++ | | | | | | (+10) |
| *Rumex* | *<br>**(few taxa) | 1 | +++ | | | -5 | | | -1 |
| *Taxus* | *** | -2 | +++ | (+10) | | | +1 | | +1 |
| *Tilia* | *<br>**(few taxa) | 1 | +++ | | | | | | (-10) |
| *Ulmus* | *<br>**(few taxa) | 1 | ++ | | | | | | -1 |
| [8]***Urtica*** | *****<br>****(few taxa)** | **1** | **+** | **(+10)** | | **-5** | **+5** | **+1** | **+1** |

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

[2] **Expansion Potential due to 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] **Pollen 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;

Chenopodiaceae family is highly influenced by land use (presence of fallows and their degree of regeneration). MAM indicates high sensitivity, but its response to climate change varies according to its species as it has a wide range of species-pool. Both increase and decrease of its species-pool are awaited. These plants frequently appear in areas affected by inland water around Szeged that can disappear due to a drying climate (Table 3). A decrease of its pollen counts can be explained also by changes in land use (Table 2).

*Juglans,* being warm-tolerant, shows a potential increase due to warming and, according to MAM, has medium climate sensitivity. Rainfall is a major limiting factor for it. Global warming can help this species – as it happened in interglacial times – but a certain minimum rainfall is required; this species cannot be seen over the driest areas of the Mediterranean. However, it has still a larger EP in Hungary.

*Morus* is assigned to the moderately endangered category (**). Lack of rainfall and too high temperature are a barrier for their pollen production. Its AM and MAM values emphasize that decreasing rainfall can decrease their population intensely.

*Pinus* is endangered moderately according to RP (**) and rather decrease of their population is awaited. On the contrary, MAM shows much higher sensitivity (+++). It can be explained by its present species composition around Szeged, where *Pinus sylvestris* is still represented in a huge number in forests. This species cannot tolerate warming climate because it likes more humid, cooler conditions. However, change in species composition, plantation and appearance of Mediterranean species can make this genus more adaptive for awaited changes.

*Plantago, Quercus* and *Ulmus* have medium sensitivity (++) according to their MAM values and due to their diversified species-pool they can react well to climate change with intra-taxonic species changes. They can mainly stand warmer and somewhat drier conditions. According to their RP they are moderately endangered or not endangered, and for warm-tolerant, sub-Mediterranean or continental species further expansion can be awaited at the expense of present species. It can mostly be observed for genera *Ulmus* and *Quercus,* where more warm-tolerant species also exist in the landscape or around the Carpathian-basin.

A medium sensitivity indicated by MAM (++) is observed for *Platanus*. It stands warm climate, but a shortage of water can be a limiting factor. This species appears mainly in mountain valleys alongside streams in the Mediterranean, where a certain amount of water is available. It has a potential for expansion in Hungary but not in every landscapes.

*Poaceae* show high sensitivity according to MAM (+++) as the available water and high temperatures can mean limits for them and can cause regional decrease. However, the species-pool of this family is the widest among the studied plant groups, so there will be species to substitute the actual grasses and even species from the Mediterranean and the more continental areas can reach the Carpathian-basin in the future. This means a high risk for the present species, but intra-taxonic re-assemblage could happen. Shortage of water and too high temperatures can cause lower pollen production in natural grasslands and also in crops produced in arable lands. This is why certain species in certain time periods and places can suffer from climate change, but the change in species composition will give good chance for the survival of this family. Rather diverse response of this family is given in Table 4.

*Rumex* can give a wide response to climate change according to its species-pool. For some species extension, while for some others potential area decrease is awaited. Since *Rumex* species around Szeged live rather in semi-humid conditions favouring inland water covered areas (see *Rumex crispus*, the most common *Rumex* species around Szeged), climate change could affect them intensely due to water-shortage. *Rumex* in Szeged region is rather moderately endangered (**).

*Tilia* genus can give a wide range of response according to its species-pool. Potential increase, especially for *Tilia tomentosa*, is awaited in the Great Hungarian Plain, but this warm-tolerant species occurs just in the parks of Szeged. The existing species-pool is not favourable for the awaited climate changes. Especially *Tilia platyphyllos* characterized by high sensitivity according to its MAM (+++) will not stand the warming. *Tilia cordata* could survive better, but its natural stock is very small.

*Urtica* and *Populus have* a wide climate-tolerance, so 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 (**). *Urtica dioica* is not endangered according to its RP (*) and even population increase is awaited. For the extremely rare *Urtica kioviensis* living in boggy wetlands further major decrease is awaited in the Carpathian-basin. The better climate tolerance of *Populus* can be explained by wide adaptation of its different species (Table 3, 4).

## 4. Discussion and Conclusions

Climate change can modify the pollen season characteristics of different allergenic taxa in diverse ways and can exert a substantial influence on habitat regions. 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.

On a yearly basis only *Populus, Taxus* and *Urtica* show a significant increase of the annual total pollen count. *Populus* and *Juglans* display the most important increase, while *Alnus* exhibits the biggest decrease of the annual peak pollen counts. Poaceae and *Urtica* show a significant increase in the duration of the pollen season. Based on the 5% level, 11 of the 19 taxa indicated significant trends of the total annual pollen count, and 7 of these 11 trends is increasing on a daily basis (Table 2).

*Ambrosia* shows a decrease of daily pollen counts that can be explained by the lack of available water during the hottest summer period (Fig. 1). 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 is characterized by increasing and decreasing stages of its trend within the year. When warming is moderate and precipitation increases (till the middle of June) pollen concentrations are growing, but then decreasing during the rest of the pollen season due to the too intense warming and shortage of rainfall (Fig. 1). *Populus* displays a substantial increase in pollen count trends coinciding with the period of moderate warming and rainfall growth. More importantly, 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 pollen season *(Haraszty 2004)* (Table 2, 3, Fig. 1).

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 potential (RP) and expansion potential (EP) due to the climate change are compared to the MAM for each taxon (Table 3, 4). The association measure alone cannot contain or express the climate change related forces. However, all three taxa (*Ambrosia, Populus* and *Urtica*) having the lowest climate sensitivity (+) are non-endangered (*) and, except for *Ambrosia,* are characterized by a moderate EP. At the same time, for all endangered taxa (***) (even if just one species is endangered within a given taxon) MAMs indicate high sensitivity (+++). Accordingly, the association measures follow well the climate change related forces indicating that climate parameters are important elements of the environment for the taxa examined (Table 3, 4).

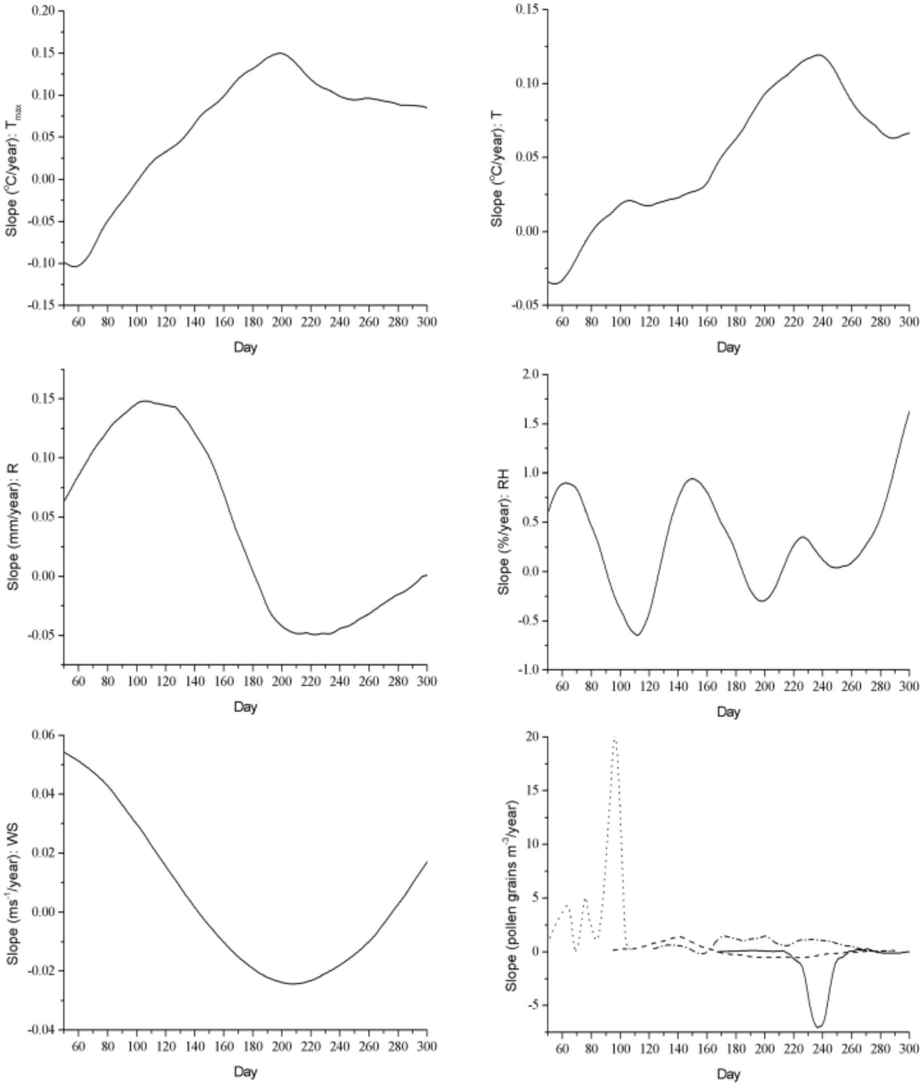

*Fig. 1. Annual cycles of the slopes of daily linear trends for the maximum temperature ($T_{max}$), mean temperature (T), rainfall total (R), relative humidity (RH) and wind speed (WS) for Ambrosia (solid), Poaceae (dash), Populus (dot) and Urtica (dash dot)*

Annual pollen counts display strong increasing trends for a number of taxa. Nevertheless, phenological characteristics (onset, end and duration of the pollen season) show changes only in 8 (10) out of 57 cases (19 taxa x 3 phenological characteristics) at 5% (10%) significance level. Here Poaceae and *Urtica* are the most important with notable changes of at least two characteristics. Our conclusions are in good agreement with those of several previous researches. For Thessaloniki (Greece), the total annual pollen counts, as well as daily peak pollen counts show significant increasing trends for the majority of taxa, but 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*), 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 pollen 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*).

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)*. We found increasing trends (at 5% significance level) in the total radiation, relative humidity and wind speed. Temperature and rainfall do not display overall significant trends, but smoothing of daily MK test values shows stages of positive and negative trends within the year for these latter two variables, too.

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, 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.

Acknowledgements

The authors would like to thank Gábor Motika (Environmental Conservancy Inspectorate, Szeged, Hungary) for providing meteorological data of Szeged and Miklós Juhász (University of Szeged) for providing daily pollen concentration data of Szeged. The European Union and the European Social Fund provided financial support for the project under the grant agreement no. TAMOP 4.2.1/B-09/1/KMR-2010-0003, TAMOP-4.2.1/B-09/1/KONV-2010-0005 and TÁMOP-4.2.2/B-10/1-2010-0012.

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