Carpathian Journal of Earth and Environmental Sciences, February 2015, Vol. 10, No. 1, p. 183 - 193

PLANTS AND PAST WEATHER: A STUDY FOR ATMOSPERIC POLLEN CONCENTRATIONS OF AMBROSIA, POACEAE AND POPULUS

István MATYASOVSZKY[1], László MAKRA[2], Zoltán CSÉPE[2], Zoltán SÜMEGHY[1], Áron József DEÁK[3], Elemér PÁL-MOLNÁR[4] & Gábor TUSNÁDY[5]

[1]*Department of Meteorology, Eötvös Loránd University, HU-1117 Budapest, Pázmány Péter st. 1/A, Hungary; E-mail: matya@ludens.elte.hu*

[2]*Department of Climatology and Landscape Ecology, University of Szeged, HU-6722 Szeged, Egyetem u. 2, Hungary; corresponding author: L. Makra, e-mail: makra@geo.u-szeged.hu, Tel: +36 62 544 856, Fax: +36 62 544 624*

[3]*Department of Physical Geography and Geoinformatics, University of Szeged, HU-6722 Szeged, Egyetem u. 2, Hungary; E-mail: aron@geo.u-szeged.hu*

[4]*Department of Mineralogy, Geochemistry and Petrology, University of Szeged, HU-6701 Szeged, P.O.B. 653, Hungary; E-mail: palm@geo.u-szeged.hu;*

[5]*Mathematical Institute of the Hungarian Academy of Sciences, HU-1364 Budapest, P.O.B 127, Hungary, E-mail: tusnady.gabor@renyi.mta.hu*

Abstract: After extreme dry (wet) summers or years, pollen production of different taxa may decrease (increase) substantially. Accordingly, studying effects of current and past meteorological conditions on current pollen concentrations for different taxa has of major importance. The purpose of this study is separating the weight of current and past weather conditions influencing current pollen productions of four taxa. Two procedures, namely multiple correlations and factor analysis with special transformation are used. The 11-year (1997-2007) data sets include daily pollen counts of *Ambrosia* (ragweed), Poaceae (grasses) and *Populus* (poplar), as well as daily values of 4 climate variables (temperature, relative humidity, global solar flux and precipitation). Multiple correlations of daily pollen counts with simultaneous values of daily meteorological variables do not show annual course for *Ambrosia*, but do show definite trends for *Populus* and Poaceae. Results received using the two methods revealed characteristic similarities. For all the four taxa, the continental rainfall peak and additional local showers in the growing season can strengthen the weight of the current meteorological elements. However, due to the precipitation, big amount of water can be stored in the soil contributing to the effect of the past climate elements during dry periods. Higher climate sensitivity (especially water sensitivity) of the herbaceous taxa (*Ambrosia* and Poaceae) can be definitely established compared to the arboreal *Populus*. Separation of the weight of the current and past weather conditions for different taxa involves practical importance both for health care and agricultural production.

Keywords: pollen, respiratory allergy, current weather, past weather, multiple correlations, factor analysis with special transformation

1. INTRODUCTION

Allergic diseases have become one of the most important health issues worldwide (Bocking et al., 2012; D'Amato et al., 2013). Sensitization and allergic diseases increase with socioeconomic status and living in large cities (Langen et al., 2013). Allergy and asthma, especially those associated with ragweed pollen, have been prevailing in Hungary (Kazinczi et al., 2008; Páldy et al., 2010). Recently, 20% of the Hungarian population suffers from pollen allergy and 60-90% of them are sensitized with ragweed pollen (Harsányi, 2009). In 1998-1999, according to skin prick tests, 83.7% of the patients were sensitive to ragweed pollen in Szeged, Hungary (Kadocsa & Juhász, 2002).

The release of allergenic pollens depends both on phyto-physiological status of the given taxon and meteorological conditions. There is a vast amount of literature dealing with the relationship between daily allergenic pollen concentrations and simultaneous weather conditions (Bartková-Ščevková, 2003;

Kasprzyk, 2008; Veriankaitė et al., 2011; Prtenjak et al., 2012). The current pollen concentration is, however, affected not only by current weather conditions but also by effects of the antecedent meteorological conditions during a period. Taxa with short pollen seasons have longer period of past weather conditions between the last and the forthcoming pollen seasons and vice versa.

The influence of past weather conditions on certain phenological phases of different taxa have been investigated in several studies. Emberlin & Norris-Hill (1991) found that annual differences in the cumulative Urticaceae pollen concentration were primarily due to weather conditions in the period of pollen formation and only secondarily due to weather conditions in the pollen release season. Furthermore, relative humidity, temperature, wind speed and rainfall were most important in daily variations but their relative importance varied between years. Spieksma et al., (1995) found that the air temperature during the preceding 40 days has a decisive influence on the start date of the *Betula* pollen season. Munuera Giner et al., (1999) related daily *Artemisia* pollen concentrations to the rainfall and global solar flux in the preceding weeks. They found that once pollination had begun, meteorological factors (excluding wind direction) did not seem to influence pollen concentrations significantly. Linderholm (2006) found that the timing of spring events in mid- to high-latitude plants, such as budding, leafing and flowering, is mainly regulated by temperatures after the dormancy is released. For breaking dormancy, chilling temperatures (temperatures that break dormancy) accelerate bud growth from the state of quiescence (i.e. when dormancy is broken) to the state of burst (Hänninen et al., 1993; Chuine, 2000). Namely, the more chilling temperatures are received, the less forcing temperatures (temperatures that force growth during spring when dormancy has been released) are subsequently needed to reach budburst (Chuine, 2000). Therefore, higher winter and early spring temperatures can produce a later onset of bud burst and pollen release. Emberlin et al., (1997) found a trend to earlier *Betula* pollen seasons that was related to an increase in cumulative temperatures over 5.5°C in January, February and March. Furthermore, they detected a significant positive relationship between the start dates of the *Corylus* pollen season and temperatures in October suggesting that lower temperatures in October result in an earlier onset, and vice versa (Emberlin et al., 2007). They found a significant negative association between onset and December temperatures indicating that higher December temperatures will produce an earlier onset of *Corylus* flowering and vice versa (Emberlin et al., 2007).

Although, several studies have been published to explore the relationship between meteorological conditions and pollen loads, as well as past weather conditions and certain phenological phases of different taxa, neither of them was aimed to distinguish between the effect of current and past weather on current pollen concentrations. The purpose of this paper is to separate the weight of the current and past climate conditions in determining the pollen concentrations of *Ambrosia,* Poaceae and *Populus* for the Szeged region in Southern Hungary applying two procedures, namely multiple correlation and factor analysis with special transformation.

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, namely Pannonian 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 spore 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).

Time dependent daily pollen concentrations are influenced by numerous underlying processes. They include (1) genetic attributes, (2) soil type including location specific nutrient availability, (3) meteorological conditions in the root zone, (4) land use changes, (5) current and preceding weather variables, (6) the height of the planetary boundary layer (PBL) and the ventilation coefficient, (7) long-range pollen transport, (8) resuspenson of the pollen grains, (9) disruption of the pollen grains, and (10) pollen grains as condensation nuclei.

Since some of the above parameters are either constant for a given taxon (1), or can be neglected (4), or not available (3, 6) or are hard to model (2, 8, 9) or difficult to consider their effect when assessing the target variable (7, 10), they are omitted from further consideration. However, daily values of the current and preceding weather variables [mean temperature, (T°C); relative humidity (RH%), global solar radiation (GSR, Wm^{-2}) and precipitation amount (Pmm) influencing daily pollen concentrations were used in the study. They were collected in a meteorological station located in the inner city area of Szeged (Fig. 1).

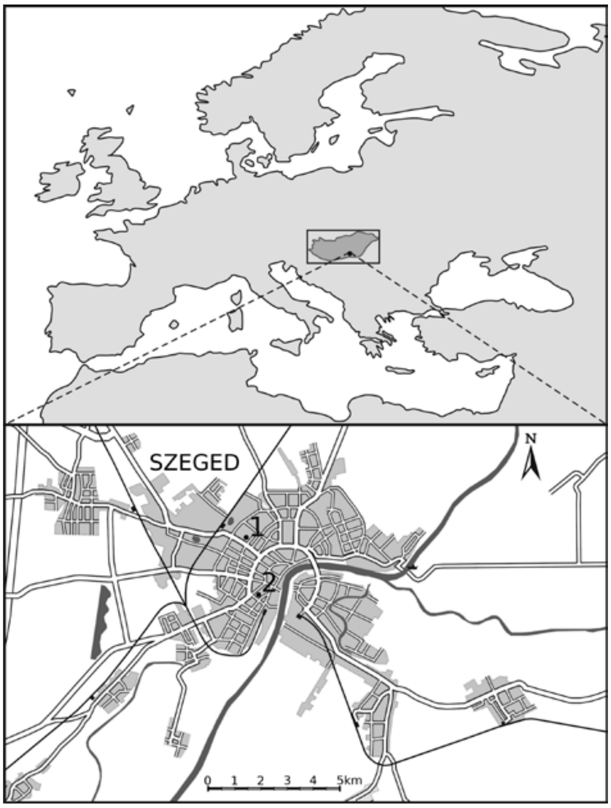


Figure 1. Location of Europe with Hungary (upper panel) and the urban web of Szeged with the positions of the data sources (lower panel). 1: meteorological monitoring station; 2: aerobiological station

These elements were used since they indicate the highest impact on pollen production (Galán et al., 2000; Bartková-Ščevková, 2003; Štefanič et al., 2005; Kasprzyk, 2008; Makra & Matyasovszky, 2011). The data set consists of daily pollen counts (average daily pollen count per cubic meter of air) of 3 taxa taken over the 11-year period 1997-2007. With their Latin (English) names they are: *Ambrosia* (ragweed), Poaceae (grasses) and *Populus* (poplar) that account for (32.6%), (10.4%) and (9.2%) of the total pollen production in Szeged, for the given period respectively. At the same time, they altogether include 52.2% of the total pollen load (Table 1).

Ragweed is a highly prevalent taxon not only in the Szeged area but over the Pannonian Plain in the Carpathian Basin, as well. They occur in stubble fields, especially in sand landscapes and in abandoned places around settlements. The increase of mean temperature for the warm-tolerant *Ambrosia*, especially in summer time (August) leads to a limit for pollen production. In this period, in order to preserving water it decreases pollen production. This genus can adapt well to dry and hot conditions. If more fallows and abandoned human habitats appear in the landscape, its further increase is awaited especially on sand soils. Higher potential distribution of *Ambrosia* is anticipated due to its 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 (Makra et al., 2011; Deák et al., 2013).

Table 1. Plant habits and phenological pollen season characteristics

Taxa	Plant habit	*pollen level	Pollen season		
			Start	End	Length, day
Ambrosia	H	32.6	Jul 15	Oct 15	93
Poaceae	H	10.4	Apr 16	Oct 11	180
Populus	AD	9.2	Feb 27	Apr 20	53

*: in percentage of the total pollen dispersion;
AD: arboreal deciduous, H: herbaceous;

Both elder fallows and natural grasslands are characterized by a huge coverage of grasses, so fallow regeneration in the Szeged region led to the extension of grass covered areas. Poaceae can produce high biomass in years with higher than usual rainfall, which is in accordance with their higher pollen production. At the same time, increased mean and maximum temperatures can cause water-shortage in the driest summer period also for grasses, meaning a serious limiting factor. So they preserve water instead of producing pollen. Poaceae show high climate sensitivity. However, the species-pool of this family is the widest in Hungary among the four taxa analysed in the study, so there will be other species to substitute the actual grasses and even species from both the Mediterranean and continental areas can reach the Carpathian Basin in the future (Deák, 2011; Makra et al., 2011; Deák et al., 2013).

Populus indicate a wide climate tolerance since both wet and dry tolerant species are represented in the landscape from the floodplains to the bare sand. *Populus* (both wild and cultivated types) were planted widely especially in the sand lands, west from Szeged city, as well as in the floodplains, too. 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 have grown up, they are in mature state, so they can pollinate on high level. The warmer and moderately humid weather in the spring also favours their pollination (Deák, 2011; Makra et al., 2011; Deák et al., 2013).

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.

Daily values of mean temperature, relative humidity, global solar flux and precipitation amount were labelled as current meteorological conditions for the pollen season of a given taxon, while they were considered as past meteorological conditions for the period starting from the first pollen-free day following the previous pollen season to the last pollen-free day preceding the actual pollen season.

2.2. Regression

Linear regressions are used in our present study as follows. The explaining variables are divided into two parts and the daily pollen concentrations are regressed separately against these two groups of meteorological variables for every day of the pollen season. The first group includes daily values of T, RH, GSR and P. The second group consists of cumulative T, RH, GSR and P, which are defined as follows. Let *D* be the duration of the pollen season of a given taxon, and let *d* be the duration of the period from the first pollen-free day following the previous pollen season to the last pollen-free day preceding the actual pollen season. On the *i*th day of an actual pollen season, values of the meteorological variables are accumulated from $(i-d+j)$ th day to $(i-1)$ th day corresponding to accumulation lengths $d-j$ for $i=1,...,D$. The linear regression is carried out for every day of the pollen season ($i=1,...,D$) with every accumulation length $d-j$ ($j=0,...,d-1$). For instance, Poaceae exhibits a pollen season in Szeged from April 16 to October 12 (Table 1), and thus *D*=180 and *d*=186 days. Adjusted multiple correlations (e.g. Draper & Smith, 1981) for both groups of explaining variables are calculated for every day of the pollen season and every accumulation length in the past. The procedure outlined here is applied to the above-mentioned 4 taxa.

2.3. Factor analysis with special transformation

Factor analysis identifies linear relationships among examined variables and thus helps to reduce the dimensionality of the initial database without substantial loss of information. Factor analysis was applied to our initial datasets consisting of 9 correlated variables (8 explanatory variables including 4 meteorological variables characterizing the weather of actual days and the same 4 meteorological variables characterizing the weather of antecedent days, as well as 1 resultant variable including actual daily pollen concentrations of the given taxa) in order to transform the original variables into fewer uncorrelated variables. These new variables, called factors, can be viewed as latent variables explaining the joint behaviour of the past and current meteorological elements as well as the current pollen concentration. The number of retained factors can be determined by different criteria. The most common and widely accepted one is to specify a least percentage (80%) of the total variance of the original variables that has to be explained (Jolliffe, 1993) by the factors. After performing the factor analysis a special transformation of the retained factors was made to discover to what degree the above-mentioned explanatory variables affect the resultant variable and to give a rank of their influence (Jahn & Vahle, 1968). When performing factor analysis on the standardized variables, factor loadings are correlation coefficients between the factors and the original variables. Consequently, if the resultant variable is strongly correlated with a factor and an explanatory variable is highly correlated with this factor, then the explanatory variable is also highly correlated with the resultant variable. Hence, it is advisable to combine all the factors together with the resultant variable into one new factor. It is effective to do so that only one factor has big contribution to the resultant variable and the remaining factors are uncorrelated with the resultant variable. This latter procedure is called special transformation (Jahn & Vahle, 1968).

Factor analysis with special transformation is used in the study as follows. The first 5 variables of the above mentioned 9 variables include daily pollen levels and daily values of T, RH, GSR and P during the pollen season of a given taxon for every year. The remaining 4 variables (cumulative T, RH, GSR and P) are defined as in section 2.2, and factor analysis with special transformation is carried out for every day of the pollen season with every accumulation length in the past for each taxon, as in the case of the linear regression procedure of section 2.2.

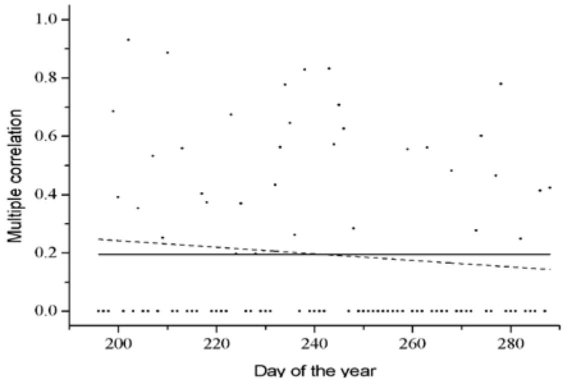
3. RESULTS AND DISCUSSION

Multiple correlations of daily pollen counts of the four taxa on the daily values of the meteorological variables are determined (Fig. 2). As only 11 years are available for the analysis and hence the sample size is very small, for every day the estimated multiple correlations have big variances. In order to remove this big variability, polynomials as a function of days are fitted to the daily multiple correlation values. The optimal order of polynomials is determined by Akaike's criterion (Akaike, 1974) and the significance of *t*-values corresponding to the estimated coefficients in polynomials is checked.

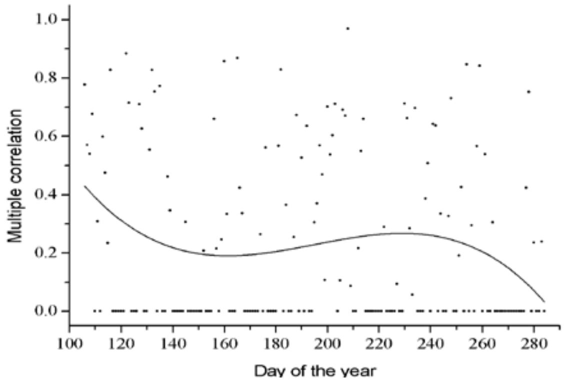
It can be concluded that multiple correlations are quite modest and do not necessarily exhibit annual cycles during the pollen seasons of the four taxa (Fig. 2). The correlation has an inclination for decrease from the beginning to the end of the pollen season for *Ambrosia* (dashed line), which is however not statistically significant at reasonable significance levels (somewhat larger than 10%) based on *t*-test, so that correlations should be considered constant (solid line). In contrast, the correlations for *Populus* provide a clear decreasing trend (statistically significant at a 3.5% level). Correlations for Poaceae can be best approximated by a third order polynomial (at a significance level of 1%) showing the highest multiple correlations at the beginning of the pollen season. A local minimum and maximum can be observed around day 159 and day 230, respectively. The lowest multiple correlations occur at the end of the pollen season (Fig. 2).

The difference between the multiple correlations (factor loadings) of daily pollen counts on the current values of daily meteorological variables and on the cumulative values of daily meteorological variables as a function of the day of the year and of the accumulation length are calculated and presented in figure 3. If the above difference is positive (negative), it indicates that the influence of the current meteorological variables on daily pollen counts is higher (lower) than the influence of the past meteorological variables.

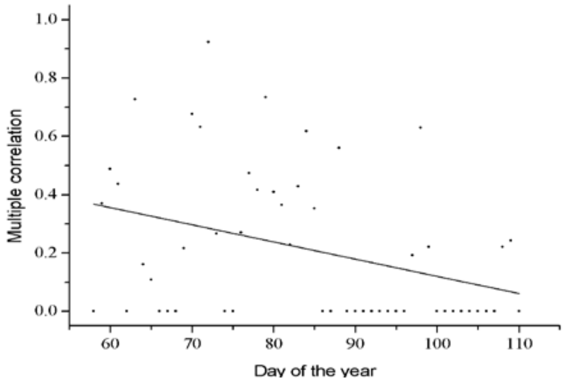
For *Ambrosia*, altogether 93 (number of days of the pollen season) x 272 (number of days from the first pollen-free day following the previous pollen season to the last pollen-free day preceding the actual pollen season) = 25,296 factor analyses, while for Poaceae and *Populus* 33,300 and 16,536 factor analyses with special transformations were carried out, respectively. Namely, in total 86,676 procedures were performed for every day of the pollen season with (1) every accumulation length for each taxon in the past, and another 86,676 procedures were carried out for every day of the pollen season with (2) every individual day for each taxon in the past. Hence, altogether 173,352 factor analyses with special transformations were performed. However, due to the smaller variability of the associations, only those for (1) are analysed in the study (Fig. 3a).



Ambrosia



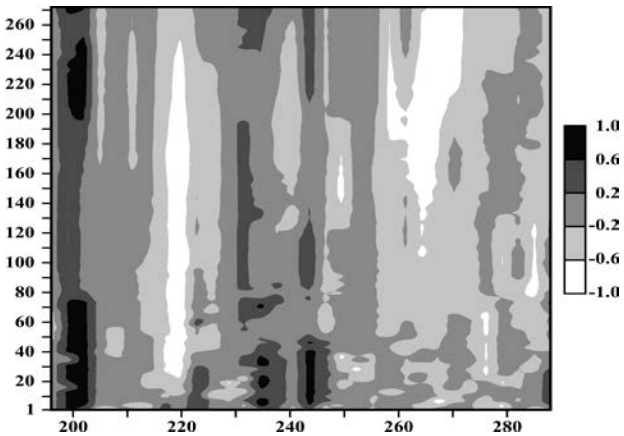
Poaceae



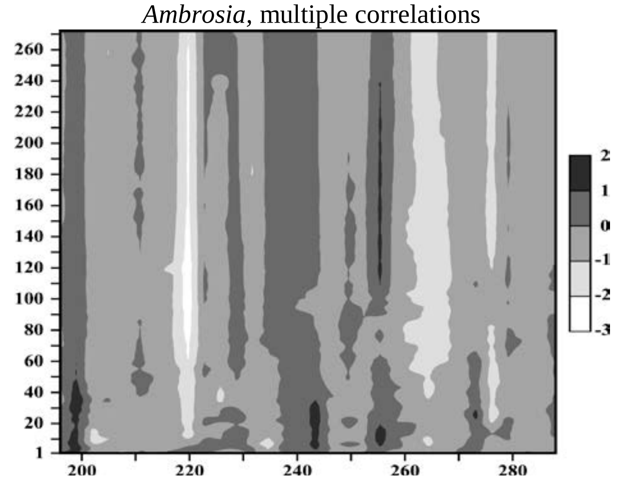
Populus

Figure 2. Multiple correlation of daily pollen counts on simultaneous values of daily meteorological variables as a function of the day of the year

Past weather may play a relevant role in the current development of plants and their phenological phases. For instance, after extreme dry (wet) summers or years pollen production of different taxa may decrease (increase) substantially (Láng, 1998; Haraszty, 2004). Accordingly, studying effects of current and past meteorological conditions on current pollen concentrations for different taxa has of major importance. In the study *Ambrosia*, Poaceae and *Populus* were selected due to their high or medium allergenicity in a four-score scale found in the Hungarian pollen index. Allergenicity of both *Ambrosia* and Poaceae is the highest indicated by score four, while that of *Populus* is medium indicated by score two] and to their more or less permanently high pollen concentrations. Another aspect of the selection was to analyze two herbaceous taxa (*Ambrosia* and Poaceae) and an arboreal deciduous taxon (*Populus*).



Ambrosia, multiple correlations



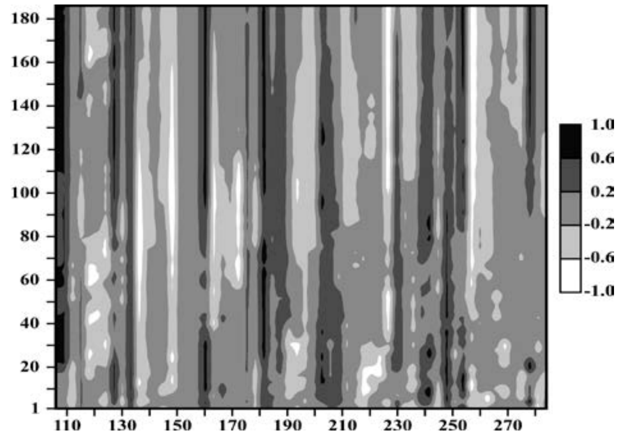
Ambrosia, factor loadings

Figure 3a. Difference between both the multiple correlations and factor loadings of daily pollen counts on current values of daily meteorological variables and on cumulative values of daily meteorological variables as a function of the day of the year (horizontal axis) and of the cumulation length (vertical axis)

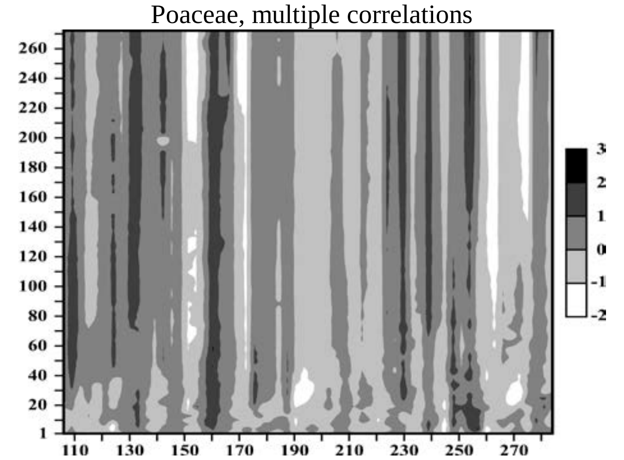
Multiple correlations of daily pollen counts on simultaneous values of daily meteorological variables have no significant dependence on the day of the year for *Ambrosia*. However, a clear decreasing tendency in the correlations for *Populus* can be explained as follows. The florescence of *Populus* starts earliest compared to the remaining three taxa. In late February – early March, the start of florescence strongly depends on the values of the meteorological elements, basically on temperature. At the same time, in the late pollen season the here-mentioned dependence gradually weakens that is confirmed by the absence of second florescence (Király, 2009).

Correlations for Poaceae are approximated by a third order polynomial of the day of the year. The phyto-physiological background of this association can be explained as follows. The reason of the high multiple correlations at the beginning of the pollen season in early April is due to the fill-up of the water storage of groundwater as a result of snow-melting and springtime precipitation, increasing daily mean temperatures, ceasing of night frosts and lengthening of daytimes (Láng, 1998; Haraszty, 2004). The here-mentioned components favour both photosynthetic and generative processes (e.g. pollen production). Due to the continental rainfall peak in summer time, pollen grains are washed out of the air; furthermore, owing to the higher cloud coverage, plants receive smaller amount of sunshine involving a decrease in photosynthesis that affects generative processes, as well. In this way, pollen production decreases in the first decade of June (Makra et al., 2011). Following the continental rainfall peak, the groundwater is restored and the cloud-coverage becomes lower again activating the metabolic processes. In May, the first mowing of grasses has been occurred, so due to the continental rainfall peak, grasses are capable of re-growing again. However, in view of the higher temperatures, evapotranspiration intensifies, but plants close their stomas in order to lose less water (Makra et al., 2011). Parallel to this, the degree of photosynthesis is decreasing as they can not assimilate as much CO_2 as before. In this way, the maximum pollen production cannot reach its springtime level because less energy and organic materials can be spent to pollen production. Several grass species move to the state of a constraint rest during the summer (with withering) that is manifested in the decrease of the late summer pollen counts. This process is continued in autumn as both withered and secondly mowed grasses and grazed grasslands are unable producing pollen any more.

The difference between both the multiple correlations and factor loadings of daily pollen counts on the current values of daily meteorological variables and on the cumulative values of daily meteorological variables as a function of the day of the year and of the accumulation length are presented in different shadows of grey (Fig. 3). Results received using the two methods revealed characteristic similarities. Namely, extreme differences of the effects of the current and past weather elements featured by different shades of grey indicate pronounced coincidences. This assumes that there are real associations between phyto-physiological processes on one hand and the current and past meteorological elements for given parts of the year and given accumulation lengths of days on the other.



Poaceae, multiple correlations



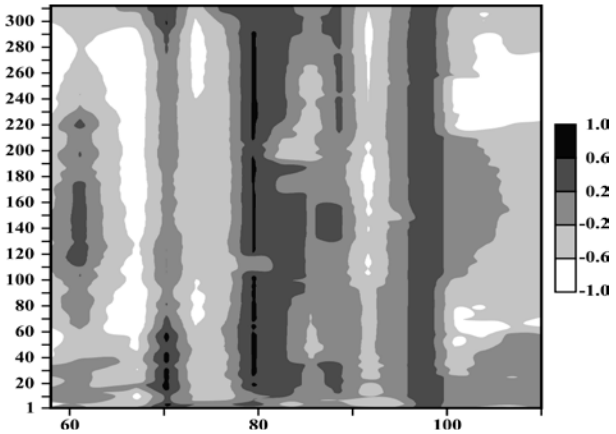
Poaceae, factor loadings

Figure 3b. Difference between both the multiple correlations and factor loadings of daily pollen counts on current values of daily meteorological variables and on cumulative values of daily meteorological variables as a function of the day of the year (horizontal axis) and of the cumulation length (vertical axis)

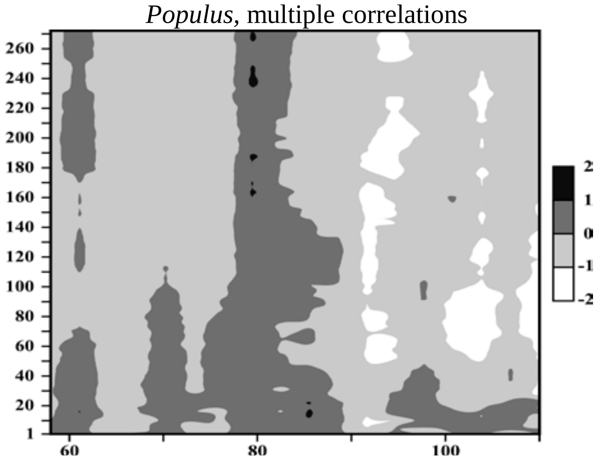
For *Ambrosia*, the importance of the current meteorological conditions is clearly detected by both methods on days 198-200 and 243, while substantial concurrent negative differences with the major effect of the past meteorological conditions are emphasized by both methods on days 220, 263, and 278, though multiple correlations show only a weak and flustered character of the difference on the latter two days in the year (Figure 3a). For the growth of *Ambrosia,* the appearance of the continental rainfall peak and its degree are determining. The duration, shifts and degree of this rainy period can substantially differ year by year. This phenomenon, its occurrence or absence influence remarkably early stages of the growth and florescence of the taxon. Additional local showers in the summer can strengthen the effect of the current meteorological elements. In warm and dry periods the effect of the past climate elements becomes stronger that is manifested in former precipitation stored in the soil (Stefanovits et al., 1999) (Fig. 3a).

Concerning Poaceae, based on the two methods, strong simultaneous higher weight of the current meteorological conditions (positive differences with dark shade) occur on the following days: 109, 132, 160, 181, 208, 230, 240, 249, 253 and 279. On the other hand, important role of the past meteorological conditions (negative differences with light shade) are concurrent on days 153, 191-198, 210-212 and 247. Flowering and pollen production of Poaceae cover the whole growing season that is far much longer than those for the remaining taxa. Furthermore, Poaceae responds to robust weather events much more intensively and sensitively (Király, 2009). Rainfall due to both weather fronts and local showers contributes to the development of plants and, in this way, to the increase of their pollen production. During dry periods groundwater ensures water-supply for plants indicating the higher role of the past climate elements in these cases. The intensively stripped pattern, namely the frequent succession of the current (past) climate elements indicated by dark (light) shades shows that Poaceae is the most water sensitive of all the taxa analysed (Horváth et al., 1995) (Fig. 3b).

Considering *Populus,* the most important role of the current meteorological conditions with both methods can be detected concurrently on days 79-80, and day 70 but in this latter case only for the accumulation lengths of 1-100 days back from the present. At the same time, the highest concurrent weight of the past meteorological conditions occurs on days 66-68, 73-74 and 92, respectively. For *Populus,* at the beginning of the frost free period, predominance of the effect of the current climate elements is characteristic for both methods. This period is the start of the growing season in Hungary. Early springtime temperatures and precipitation conditions are determining for the development of the plants. Due to the precipitation, big amount of water can be stored in the soil that contributes to the increase of the effect of the past climate elements during dry periods, namely in the first and second decade of March, as well as at the beginning and the second half of April. The role of the current climate elements is strongly dominant in the third decade of March indicating an increased role of temperature and precipitation. At the same time, predominance of the effect of the current climate elements is much less characteristic in the first half of March that can be associated with late winter frosts or early beginning of springtime (Láng, 1998; Haraszty, 2004) (Fig. 3c).



Populus, multiple correlations



Populus, factor loadings

Figure 3c. Difference between both the multiple correlations and factor loadings of daily pollen counts on current values of daily meteorological variables and on cumulative values of daily meteorological variables as a function of the day of the year (horizontal axis) and of the cumulation length (vertical axis)

Herbaceous plants (for our case *Ambrosia* and Poaceae) are generally more sensitive to disturbances; however, they recover well faster compared to arboreal plants (for our case *Populus*) (Jones & Harrison, 2004). Therefore, one may conclude that studying past meteorological conditions on these species is unnecessary. However, the recovery of these herbs from natural disturbances (e.g. floods, drought and extreme values of the climatic parameters) and human disturbances (e.g. land use changes) is an essential factor. Seed-bank and nearby propagulum-sources help the regeneration processes. Since they are common plants, the lack of propagulum does not limit their fast recovery. The recovery itself can happen several times even within the year, but landscape-level local natural or human disturbances do not limit these species as they have an extended appearance and distribution in the landscape. However, for some species (e.g. for *Ambrosia*) human disturbances (e.g. land use changes) are favoured and even required for the appearance and spread. We stress selecting *Ambrosia*; since large areas are used as arable lands in the Szeged area and the lack of proper late summer soil-works can enhance their presence and spread several times, especially on sand soils. If an arable land is abandoned, *Ambrosia* is squeezed out fast by natural competitors of weeds and plants forming natural associations. In this way, a disturbance pattern and its degree are permanent for the analysed landscape. Herbs, especially *Ambrosia*, are adapted to these disturbances. Note that sensitivity of herbs to disturbances is different and modelling disturbances as influencing variables is very difficult. Annual trend of ragweed pollen levels in the function of the change in land use as human disturbance cannot be determined. On the other hand, change in land use for the Szeged area was negligible from the year 1990 to the year 2006 using CORINE Land Cover Database (Büttner et al., 2000). Accordingly, land use changes do not influence the pollen concentration of *Ambrosia* over the Szeged area in the period examined (Deák et al., 2013). Contrarily, extreme values of the climatic parameters as natural disturbances do affect daily pollen concentrations and since their daily values are available, their current and past effect to the target variable can be modelled.

Accordingly, the analysis was performed for the above two herbaceous taxa as well, since it served a clear possibility for comparing the difference in the weight of both the current and past meteorological conditions on the pollen production of both herbaceous and arboreal taxa. Note that diurnal pollen concentrations of trees are much more irregular without having a clear and recurrent annual pattern than those for herbaceous taxa (Kapyla, 1984; Galán et al., 1998). Furthermore, once anthesis has started in trees, it is relatively independent of weather variables (Kapyla, 1984). In accordance with the above statement, higher climate sensitivity of the herbaceous taxa can be definitely established compared to the arboreal *Populus*. Namely, the frequent succession of the dark (white) strips indicating the predominance of the effect of the current (past) climate elements shows an obviously higher climate sensitivity (especially water sensitivity) for *Ambrosia* and Poaceae than for *Populus* (Fig. 3).

Note that both multiple correlation analysis and factor analysis with special transformation can only be applied if it is assumed that the relationships between the variables are linear. The associations analysed in the study can be non-linear, hence our results are possibly distorted. However, our methodologies are capable of separating the joint effect of the current and past weather elements respectively and, in this way; the results received can be considered as a first step towards discovering these non-linear relationships.

We should remark, that only 11-year data sets were available that involve a limitation for the analysis. The difference between both the multiple correlations and factor loadings of daily pollen counts on the current values of daily meteorological variables and on the cumulative values of daily meteorological variables as a function of the day of the year and of the accumulation length were based on only 11 data on identical days of the year corresponding to the 11-year data set. Therefore, there is no sense to evaluate the statistical significance of the differences among the correlations indicated by the different shadows of grey. Hence, the short data set constrains not to involve further influencing variables.

Phyto-physiological associations of the climate parameters used are as follows. Global solar flux has a major direct effect on the photosynthetic processes, as well as an indirect effect on the plants development through the temperature parameters. The start and run of the photosynthetic and generative processes occur in a limited range of temperature. In this way, extreme global solar flux involves too high or too low temperatures and, due to this, the available water may limit the vegetative and generative processes (see winter and summer periods) (Makra et al., 2011; Deák et al., 2013). Concerning the four climatic parameters, the current and past components of temperature and precipitation indicate a major effect on the current pollen concentration. Long-time effect of the precipitation is manifested in the storage of groundwater or in the stored water in the plants. Relative humidity is a largely variable parameter that has a rather small long-time effect on the current pollen production. An optimum relative humidity is necessary for the plants for performing generative and vegetative (e.g. photosynthesis) processes smoothly. Water captured in stomas is essential for these processes. However optimum relative humidity assumes optimum temperature and precipitation conditions. Relative humidity has a major role only in dry climate conditions (see Mediterranean, deserts, steppes, savannas), where the limitation or lack of groundwater is substituted partly by relative humidity. However, these conditions are not typical in the temperate belt (Láng, 1998; Haraszty, 2004; Makra et al., 2011; Deák et al., 2013). Wind speed is omitted from consideration, due to its irrelevant role as a component of the past meteorological conditions.

The association of the pollen production with the climate elements differs for the different species that is clearly represented in the study (Figs. 2-3). Its reason is that the different taxa show very different dispersal behaviour with the influencing variables used in the study (Jones & Harrison, 2004).

The question arises, whether the results received are valid for other locations as well, namely general inferences can be drawn or they are location dependent. The inferences can not be independent of the environmental conditions of a certain region as the species composition and metabolism features are adapted to a certain climate zone. Of course, for areas having similar species (at least genus), the composition can have similar answer to the meteorological variables involved; however, results can be interpreted just for the temperate climate zone.

We should stress that papers comparing the weight of current and past weather parameters in influencing the current local pollen production are not available in the literature. Though there are some studies presenting the impact of past weather conditions on certain phenological phases of different taxa only few papers deal with this area. Additionally, no papers have been found demonstrating the influence of past meteorological elements on phenological phases of the four taxa analysed.

It is to be mentioned that not all possible influencing variables were considered and perhaps not the most influential variables were used in the study. However, acknowledging the limiting factors mentioned above, this is the first approach to separate the weight of the current and past weather elements in determining the current local pollen production of two herbaceous taxa and the arboreal *Populus*.

Separation of the weight of the current and past climate conditions for different taxa presented in the study involves practical importance not only for pollen sensitized people but also for agricultural production. Namely, the knowledge of taxon specific effects of the past weather depending in time may help to predict future pollen levels well ahead in time; furthermore, it may contribute to reduce weather dependence of agricultural 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. This research was supported by the European Union and the State of Hungary, co-financed by the European Social Fund in the framework of TÁMOP 4.2.4. A/2-11-1-2012-0001 'National Excellence Program'.

REFERENCES

Akaike, H., 1974. *A new look at the statistical model identification.* IEEE Transactions on Automatic Control, 19, 6, 716-723.

Bartková-Ščevková, J., 2003. *The influence of temperature, relative humidity and rainfall on the occurrence of pollen allergens (Betula, Poaceae, Ambrosia artemisiifolia) in the atmosphere of Bratislava (Slovakia).* International Journal of Biometeorology, 48, 1, 1-5.

Bocking, C., Renz, H. & Pfefferle, P.I., 2012. *Prevalence and socio-economic relevance of allergies in Germany.* Bundesgesundheitsblatt-Gesundheitsforschung-Gesundheitsschutz 55, 3, 303-307.

Büttner, G., Feranec, J., Jaffrain, G., 2000. *Corine land cover update 2000.* Technical guidelines. Technical report, 89, European Environment Agency, Copenhagen, Denmark, 56 p.

Chuine, I., 2000. *A Unified Model for Budburst of Trees.* Journal of Theoretical Biology, 207, 337-347.

D'Amato, G., Baena-Cagnani, C.E., Cecchi, L., Annesi-Maesano, I., Nunes, C., Ansotegui, I., D'Amato, M., Liccardi, G., Sofia, M. & Canonica, W.G., 2013. *Climate change, air pollution and extreme events leading to increasing prevalence of allergic respiratory diseases.* Multidsciplinary Respiratory Medicine, Vol. 8, Article No. 12,

Deák, J.Á.. 2011. A növényzet tájléptékű változásai a Kiskunság délkeleti részén. Környezeti változások és az Alföld. (Landscape-level changes of the vegetation of south-east Kiskunság. Environmental changes and the Great Plain.). In: (ed) Rakonczai J, A Nagyalföld Alapítvány kötetei (Volumes of Great Plains Foundation), 7, pp. 327-338. Békéscsaba (in Hungarian)

Deák, J.Á., Makra, L., Matyasovszky, I., Csépe, Z. & Muladi, B., 2013. *Climate sensitivity of allergenic taxa in Central Europe associated with new climate change – related forces.* Science of the Total Environment, 442, 36-47.

Draper, N. & Smith, H., 1981. *Applied Regression Analysis,* 2nd ed. John Wiley & Sons, New York

Emberlin, J., Norris-Hill, J., 1991. *Annual, daily and diurnal variation of Urticaceae pollen in North-Central London.* Aerobiologia 7, 1, 49-56.

Emberlin, J., Mullins, J., Corden, J., Millington, W., Brooke, M., Savage, M. & Jones, S., 1997. *The trend to earlier Birch pollen seasons in the U.K.: a biotic response to changes in weather conditions?* Grana 36, 1, 29-33.

Emberlin, J., Smith, M., Close, R. & Adams-Groom, B., 2007. *Changes in the pollen seasons of the early flowering trees Alnus spp. and Corylus spp. in Worcester, United Kingdom, 1996- 2005.* International Journal of Biometeorology, 51, 3, 181-191.

Galán, C., Fuillerat, M.J., Comtois, P., & Domínguez-Vilches, E., 1998. *Bioclimatic factors affecting daily Cupressaceae flowering in Southwest Spain.* International Journal of Biometeorology, 41, 3, 95-100.

Galán, C., Alcázar, P., Cariňanos, P., Garcia, H. & Domínguez-Vilches, E., 2000. *Meteorological factors affecting daily Urticaceae pollen counts in southwest Spain.* International Journal of Biometeorology, 43, 4, 191-195.

Galán, C., Cariňanos, P., García-Mozo, H., Alcázar, P. & Domínguez-Vilches, E., 2001. *Model for forecasting Olea europaea L. airborne pollen in South-West Andalusia, Spain.* International Journal of Biometeorology, 45, 2, 59-63.

Hänninen, H., Kellomäki, S., Laitinen, K., Pajari, B. & Repo, T., 1993. *Effect of increased winter temperature on the onset of height growth of Scots pine: a filed test of a phenological model.* Silva Fennica, 27, 4, 251-257.

Harsányi, E., 2009. *Parlagfű és allergia. (Ragweed and allergy.)* Növényvédelem 45, 8, 454-458. (in Hungarian)

Hirst, J.M., 1952. *An automatic volumetric spore trap.* Annals of Applied Biology, 39, 2, 257-265.

Haraszty, Á. (ed), 2004. *Növényszervezettan és növényélettan. (Plant Anatomy and Plant Physiology.)* Nemzeti Tankönyvkiadó, Budapest (in Hungarian) 798 p.

Horváth, F., Dobolyi, Z.K., Morschhauser, T., Lőkös, L., Karas, L. & Szerdahelyi, T., 1995. Taxon-lista és attribútum-állomány. (Flora database 1.2. Taxon list and attribute stock.) Flóra Munkacsoport MTA Ökológiai és Botanikai Kutatóintézete és MTM Növénytár, Vácrátót - Budapest, 252 pp. (in Hungarian) 252 p.

Jahn, W. & Vahle, H., 1968. *Die Faktoranalyse und ihre Anwendung.* Verlag die Wirtschaft, Berlin (in German) 231 p.

Jolliffe, I.T., 1993. *Principal component analysis: A beginner's guide – II. Pitfalls, myths and extensions.* Weather 48:246-253.

Jones, A.M. & Harrison, R.M., 2004. *The Effects of Meteorological Factors on Atmospheric Bioaerosol Concentrations – A Review.* Science of the Total Environment, 326, 151-180.

Kadocsa, E. & Juhász, M., 2002. *Study of airborne pollen composition and allergen spectrum of hay fever patients in South Hungary (1990-1999).* Aerobiologia, 18, 3-4, 203-209.

Kapyla, M., 1984. *Diurnal variation of tree pollen in the air in Finland.* Grana, 23, 3, 167-176.

Kasprzyk, I., 2008. *Non-native Ambrosia pollen in the atmosphere of Rzeszow (SE Poland): Evaluation of* *the effect of weather conditions on daily concentrations and starting dates of the pollen season.* International Journal of Biometeorology, 52, 5, 341-351.

Kazinczi, G., Béres, I., Pathy, Zs. & Novák, R., 2008. *Common ragweed (Ambrosia artemisiifolia): A review with special regards to the results in Hungary. II. Importance and harmful effect, allergy, habitat, allelopathy and beneficial characteristics.* Herbologia, 9, 1, 94-118.

Király, G. (ed), 2009. *Új magyar füvészkönyv I-II. Magyarország hajtásos növényei. Határozókulcsok - Ábrák. (New Hungarian grass book I-II. Shooted plants of Hungary. Adverbs keys - Figures.)* Aggteleki Nemzeti Park Igazgatóság, Jósvafő (in Hungarian), 1291 p.

Köppen, W., 1931. *Grundriss Der Klimakunde.* Walter De Gruyter & Co, Berlin (in German) 388 p.

Láng, F. (ed), 1998. *Növényélettan. A növényi anyagcsere. (Plant physiology. Metabolism of plants.)* ELTE Eötvös Kiadó, Budapest (in Hungarian) 998 p.

Langen, U., Schmitz, R. & Steppuhn, H., 2013. *Prevalence of allergic diseases in Germany. Results of the German Health Interview and Examination Survey for Adults (DEGS1).* Bundesgesundheitsblatt-Gesundheitsforschung-Gesundheitsschutz, 56, 698-706.

Linderholm, H.W., 2006. *Growing season changes in the last century.* Agricultural and Forest Meteorology, 37, 1-2, 1-14.

Makra, L., Sánta, T., Matyasovszky, I., Damialis, A., Karatzas, K., Bergmann, K.C. & Vokou, D., 2010. *Airborne pollen in three European cities: Detection of atmospheric circulation pathways by applying three-dimensional clustering of backward trajectories.* Journal of Geophysical Research: Atmospheres, 115, D24220. doi: 10.1029/2010JD014743

Makra, L. & Matyasovszky, I., 2011. *Assessment of the Daily Ragweed Pollen Concentration with Previous-Day Meteorological Variables Using Regression and Quantile Regression Analysis for Szeged, Hungary.* Aerobiologia, 27, 3, 247-259.

Makra, L., Matyasovszky, I. & Deák, J.Á., 2011. *Trends in the characteristics of allergenic pollen circulation in Central Europe based on the example of Szeged, Hungary.* Atmospheric Environment, 45, 33, 6010-6018.

Munuera Giner, M,. Carrión García, J.S. & García Sellés, J., 1999. *Aerobiology of Artemisia airborne pollen in Murcia (SE Spain) and its relationship with weather variables: annual and intradiurnal variations for three different species. Wind vectors as a tool in determining pollen origin.* International Journal of Biometeorology, 43, 2, 51-63.

Páldy, A., Bobvos, J., Magyar, D., Nékám, K., Bitay, Zs., Csajbók, V. & Kelemen, A., 2010. *Parlagfűallergia. A parlagfű pollinózis – a poliszenzitizáltság kezdete? (Ragweed allergy. Ragweed pollinosis – the start of the pollen sensitivity?)* Egészségtudomány 54, 4, 47-55. (in Hungarian)

Prtenjak, M.T., Srnec, L., Peternel, R., Madzarevic, V., Hrga, I. & Stjepanovic, B., 2012. *Atmospheric conditions during high ragweed pollen concentrations in Zagreb, Croatia.* International Journal of Biometeorology, 56, 6, 1145-1158.

Štefanič, E., Kovačevič, V. & Lazanin Ž., 2005. *Airborne ragweed pollen concentration in north-eastern Croatia and its relationship with meteorological parameters.* Annals of Agricultural and Environmental Medicine, 12, 1, 75-79.

Spieksma, F.T.M., Emberlin, J.C., Hjelmroos, M., Jäger, S. & Leuschner, R.M., 1995. *Atmospheric birch (betula) pollen in europe - trends and fluctuations in annual quantities and the starting dates of the seasons.* Grana, 34, 1, 51-57.

Stefanovits, P., 1999. *A talajok osztályzása. Főtípusok, típusok és altípusok. (Classiciation of soils. Main types, types and sub-types.) In: Stefanovits P, Filep Gy, Füleky Gy (ed) (1999) Talajtan. (Soil science.)* Mezőgazda Kiadó, Budapest. pp. 239-314. (in Hungarian)

Veriankaitè, L, Šaulienè, I. & Bukantis, A., 2011. *Evaluation of meteorological parameters influence upon pollen spread in the atmosphere.* Journal of Environmental Engineering and Landscape Management, 19, 1, 5-11.

Received at: 20. 01. 2014
Revised at: 08. 06. 2014
Accepted for publication at: 28. 01. 2015
Published online at: 03. 02. 2015