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Weather related ragweed pollen levels and prediction of ragweed pollen concentration for Szeged, Hungary

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Contetns

1. Introduction

1.1 Pollen allergy

Air pollution, as a major and permanently rising hazard for the environment, is associated with large increases in medical expenses, morbidity and is estimated to cause about 800,000 annual premature deaths worldwide (Cohen et al., 2005). The prevalence of allergic respiratory diseases has also increased during the last three decades, especially in industrialized countries (D’Amato, 2002; Asher, 2006; Lundback, 1998; ECRHS, 1996; ARIA, 2008). Furthermore, an examination of the historical record indicates that the prevalence of allergic rhinitis (AR) and allergic asthma have significantly increased over the past two centuries. Although the reasons for this increase are not fully elucidated, epidemiologic data suggest that certain pollutants produced from the burning of fossil fuels may have played an important role in the prevalence changes (Peterson and Saxon, 1996, Saxon and Diaz-Sanchez, 2005). This increase may be partly explained by changes in environmental factors. Urbanization, the ever increasing automobile traffic with its high levels of vehicle emissions (diesel exhaust is able to enhance IgE production, Peterson and Saxon, 1996; Krämer et al., 2000) and the changing lifestyle are linked to the rising frequency of respiratory allergic diseases (D'Amato et al., 2005). Weather conditions can also affect both the biological and chemical air pollutants. There are evidences on the effect of air pollution upon allergens, increasing exposure to the latter, their concentration and/or biological allergenic activity (Pénard-Morand et al., 2005; Bartra et al., 2007; Just et al., 2007).

Spatial distribution of ragweed pollen concentration in Europe is a function of geographical coordinates, which is modified by surface types, land use and topography (†Matyasovszky et al., 2017). Habitats and levels of ragweed pollen, are changing in Europe, as a result of more international trade and travel, cultural factors and climate change (Makra et al., 2002; Makra et al., 2005a; Vogl et al., 2008; Ariano et al., 2010; Cecchi et al., 2010; Kiss and Béres, 2006; Chapman et al., 2016). There is now considerable evidence to suggest that climate change will have, and has already had, impacts on aeroallergens. These include impacts on pollen amount, pollen allergenicity, pollen season, plant and pollen distribution, and other plant attributes (Beggs, 2004; Williams, 2005; D'Amato et al., 2007; Reid and Gamble, 2009; Kaminski and Glod, 2011). Hence, due to the continually increasing air pollution, respiratory diseases are of major concern worldwide.

Air pollution of Hungary is one of the highest in Europe. Around 16,000 annual premature deaths attributable to exposure to ambient PM_{10} concentrations are estimated in the country (Ågren, 2010; Barrett et al., 2008). Furthermore, airborne pollen levels are also high. The Carpathian Basin, involving Hungary is considered the most polluted region with airborne ragweed *(Ambrosia)* pollen in Europe. *Ambrosia* in Hungary discharges the most pollen of all taxa; the ratio of its pollen release compared to the total pollen release in the late summer period exceeds 40% (*Fig. 1*) (Juhász and Juhász, 1997). Highest counts on peak days in Szeged, Southern Hungary, are about one order of magnitude higher than those in other cities of Europe (Makra et al., 2005b; Makra and Baglyas, 2006). The sensitivity of patients to ragweed in Szeged is 83.7% (Kadocsa and Juhász, 2000). About 30% of the Hungarian population has some type of allergy, 65% of them have pollen-sensitivity, and at least 60% of this pollen-sensitivity is caused by *Ambrosia* (Járai-Komlódi, 1998). The number of patients with registered allergic illnesses has doubled and the number of cases of allergic asthma has become four times higher in Southern Hungary by the late 1990s over the last 40 years (Járai-Komlódi, 1998).

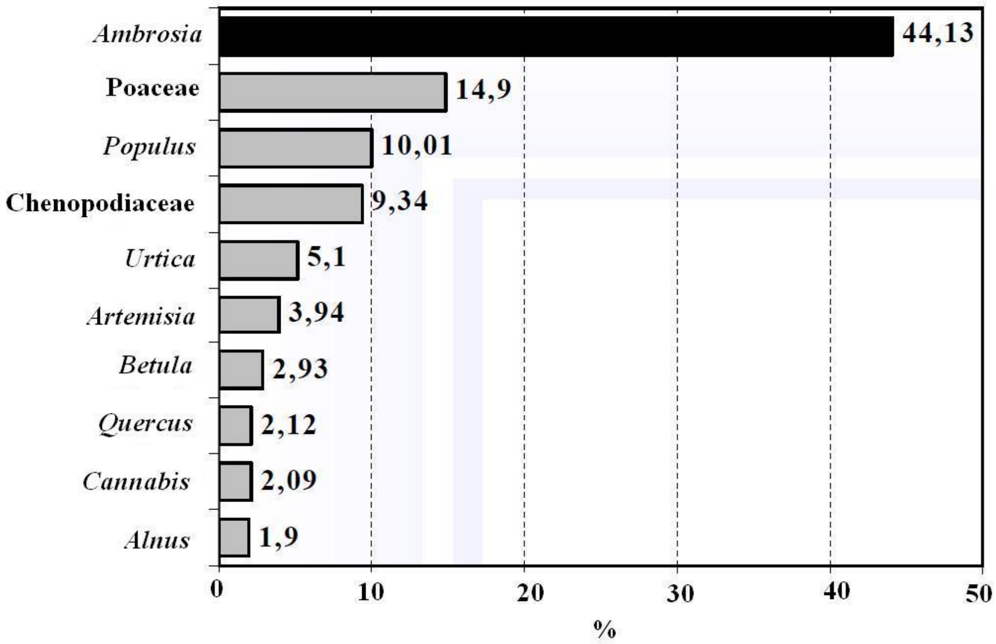


Fig. 1 Share of the individual taxa from the total annual pollen concentration, %, Szeged, 1990-1996, (Juhász and Juhász, 1997)

Allergic reaction occurs in two steps. The first step is the process of becoming sensitized. At the same time, the second step is the allergic reaction, itself. These two steps are visualized in some more detail in *Fig. 2* (Harsányi, 2009).

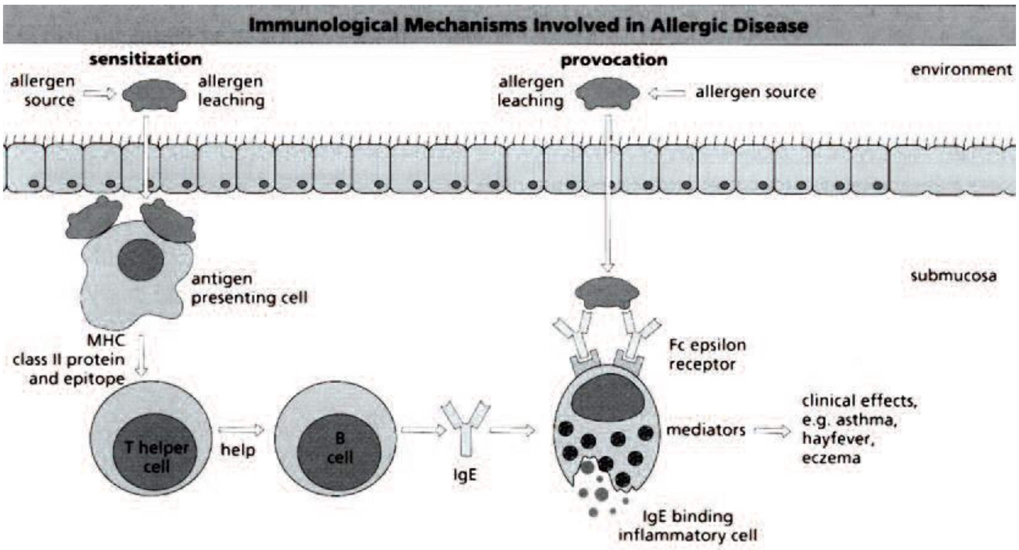


Fig. 2 Immunological mechanisms associated with allergic diseases.The first stimulus develops allergic sensitization, then repeated allergen provocation creates degranulation, and an inflammatory reaction will form (Harsányi, 2009).

1.2 Alarm levels for *Ambrosia* pollen used in Hungary

Level 0: there is no *Ambrosia* pollen in the air. Level 1: (1-9 pollen grains / m^3 of air): (very low pollen concentration, it produces no symptoms. Level 2: (10-29 pollen grains / m^3 of air): low pollen concentration, it may cause symptoms. Level 3: (30-49 pollen grains / m^3 of air): medium pollen concentration, it may generate symptoms even for less sensitive people. Level 4: (50-99 pollen grains / m^3 of air): medium high pollen concentration, it may induce medium strong reactions even for less sensitive people. Level 5: (100-199 pollen grains / m^3 of air): high pollen concentration, it may provoke strong or very strong symptoms for all sensitive people. Level 6: (200-499 pollen grains / m^3 of air): very high pollen concentration, health state of sensitive people may turn critical, asthmatic symptoms may also occur. Level 7: (500-999 pollen grains / m^3 of air): exceptionally high pollen concentration, it may provoke acute symptoms inducing serious decay in the quality of life. Level 8: (>1000 pollen grains / m^3 of air): extreme pollen concentration, excessively strong symptoms (Mányoki et al., 2011).

1.3 Economic losses

Seasonal drug cost of a ragweed pollen sensitive patient with hay fever in Hungary is around 100 EUR (Harsányi, 2009). For patients suffering from asthma, a 50% increase in treatment days involves an increase of 230% in the value of drugs spent for treatment (Harsányi, 2009).

According to conservative estimates, patients suffering from pollen allergy in Hungary spend a total of about 90 million EUR for allergic or asthmatic drugs (Mányoki et al., 2011). At the same time, drug costs represent only a portion of the direct costs incurring in health care. Furthermore, ambulatory and hospital treatment costs for patients suffering from pollen allergy amount to an additional 53-67 million EUR annually (Basky, 2009). Hence, the total amount is 143-157 million EUR annually (*Fig. 3*).

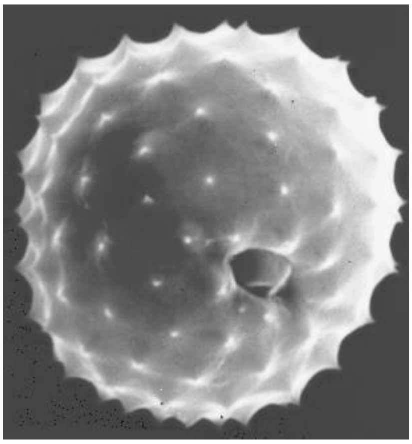


Fig.3 Electron microscope image of a ragweed pollen grain. The size of a ragweed pollen grain is 10-25 μm (Béres et al., 2005).

2. Objectives

Statistical analysis of ragweed pollen concentration and the study of its meteorological associations have of great practical importance. They may effectively help in preparing for the periods of severe pollen loads and for facilitating their health consequences. According to the above, the objectives of the dissertation are as follows.

a) To analyze the potential reasons of day-to-day variations of *Ambrosia* pollen counts for Szeged region of Southern Hungary in association with meteorological elements. For this purpose, a factor analysis with special transformation is performed on the daily meteorological and *Ambrosia* pollen data in order to find out the strength and sign of associations between meteorological (explanatory) variables and *Ambrosia* pollen (resultant) variable.

b) To study the relationship between pollen characteristics of *Ambrosia* and meteorological variables, furthermore between the rank of ordered *Ambrosia* pollen characteristics and the rank of ordered annual values of meteorological variables for Szeged in Southern Hungary.

c) To analyze how previous-day values of meteorological elements relate to actual-day values of extreme *Ambrosia* pollen load.

d) To separate the weight of the current and past climate conditions in determining the pollen concentrations of *Ambrosia* for the Szeged region in Southern Hungary applying two procedures, namely multiple correlation and factor analysis with special transformation.

e) Based on different statistical procedures i) to develop accurate forecasting models for operational use, ii) to evaluate Computational Intelligence (CI) methods that have not been previously applied for *Ambrosia* pollen, such as Multi-Layer Perceptron and regression trees and iii) to obtain a forecast of highest accuracy among CI methods based on input data of former prediction algorithms.

3. Material and methods

3.1 Materials

3.1.1 Study area

Szeged (46.25°N; 20.10°E) is the largest settlement in South-eastern Hungary (*Fig. 4*). The area is characterised by an extensive flat landscape of the Great Hungarian Plain with an elevation of 79 m above mean sea level. The built-up area covers a region of about 46 km^2. The city is the centre of the Szeged region with 203,000 inhabitants. In the Köppen system the climate of Szeged is the **Ca** type (warm temperate climate) with relatively mild and short winters and hot summers (Köppen, 1931).

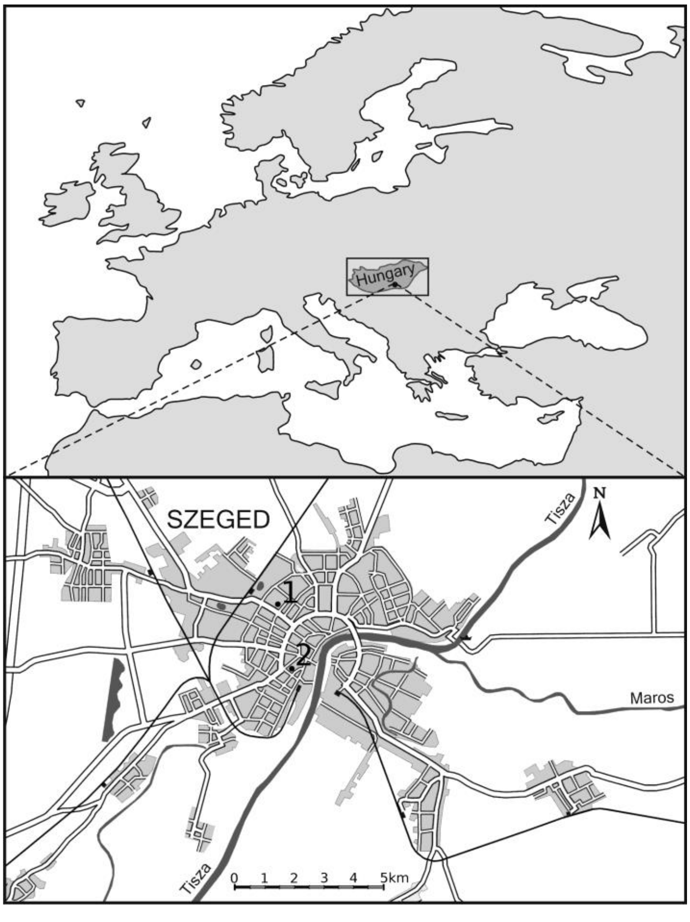


Fig. 4 Location of Szeged in Europe/Hungary (upper panel) and the urban web of Szeged with the positions of the data sources (lower panel). 1: meteorological station; 2: aerobiological station. The distance between the aerobiological and the meteorological station is 2 km. (Makra et al., 2012a)

3.1.2 Measuring stations

3.1.2.1 Meteorological station

The meteorological monitoring station (operated by the Environmental and Natural Protection and Water Conservancy Inspectorate of Lower-Tisza Region, Szeged under the auspices of the Ministry of Agriculture) is located in the downtown of Szeged about 10 m from the busiest main road (*Fig. 4*, lower panel).

3.1.2.2 Aerobiological station

The pollen content of the air was measured using a 7-day recording “Hirst-type” volumetric trap (Lanzoni VPPS 2000) (Hirst, 1952). The air sampler is located on top of the building of the Faculty of Arts, University of Szeged (20 m above the ground) in the downtown area (*Fig. 4*, lower panel) (Makra et al., 2008; Matyasovszky et al., 2011).

Pollen sampling was performed as follows. A specific tape was made adhesive by washing it with silicone oil. The sampler absorbed air at a rate of 10 $l \cdot min^{-1}$ (=14.4 $m^3 \cdot day^{-1}$, corresponding to the daily requirement of an adult) and was supplied with a timer to which a rotating drum was fitted. The drum moved the adhesive tape (2 $mm \cdot h^{-1}$) where pollen grains adhered. After a week of exposure, the tape was removed and cut to a length corresponding to 24-h pollen sampling, covered with a gel mounting agent containing a stain (fuxin). Then it was put onto a microscope slide. Afterwards, the samples were examined under a light microscope at a magnification of ×400, to determine pollen types and counts. Five horizontal sweeps were analysed on each slide. Horizontal sweeps were used because the variation in the concentration during the day can be observed along this axis (the direction of the tape shifts in the sampler). The accuracy of the measurement was proportional to the number of sweeps and the concentration of particles. Counting was done using a standard sampling procedure. Pollen concentrations were expressed as number of pollen grains / m^3 of air (Käpylä and Penttinen, 1981; Peternel et al., 2006).

3.1.3 Data

Data sets concerning the given analyses in the dissertation cover different periods. Its reasons are as follows: (1) shorter data sets available in former studies; (2) incomplete data sets of certain taxa; (3) when performing some tasks, shorter data sets proved to be sufficient.

3.1.3.1 Meteorological data (Szeged)

The database of the meteorological elements used involves daily values of 8 meteorological variables [mean temperature (T_{mean}); minimum temperature (T_{min}); maximum temperature (T_{max}); temperature range, as the difference of maximum and minimum temperatures, $\Delta T(=T_{max}–T_{min})$; irradiance (I) or total radiation (TR); relative humidity (RH); wind speed (V or WS) and rainfall (R)] for different periods (daily values for each day of the year or the term July 15 – October 15, regarding the periods 1997-2006; 1997-2010 or 1999-2007).

3.1.3.2 Pollen data (Szeged)

The pollen database involves the daily mean pollen concentration of *Ambrosia* (pollen grain / m^3 of air) for different periods (term July 15 – October 15, regarding the periods 1997-2006; 1997-2010 or 1999-2007).

The pollen season is defined by its start and end dates. For the start (end) of the season we used the first (last) date on which at least 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). Evidently, the pollen season varies from year to year. Here the longest observed pollen season during the ten-year period was considered for each year, even if the remaining years involve substantially different pollen seasons with either remarkably later start or notably earlier end of the pollen release (Makra et al., 2010; Matyasovszky et al., 2012; Makra et al., 2014a; 2014b).

3.1.4 Computer resources used

- Data preparation, a part of the calculations, and graphical representation of the results was carried out in EXCEL 2007;
- Factor analysis was performed by using SPSS 16.0 software;
- Clustering with the *k*-means algorithm was implemented by using MATLAB 7.7.0.471 software;
- Neural network analysis was performed by usin WEKA software.

3.2 Methods

3.2.1. t-test (Section 7)

Quantiles corresponding to probabilities 10%, 20% and 30%, furthermore 90%, 80% and 70% were determined first. Note that a *p*-quantile ($0<p<100\%$) q_p is the value below which the pollen load occurs with relative frequency *p*. The pollen loads were then assigned to two categories according to whether the actual pollen load is below or not the actual quantile. Values of daily meteorological variables corresponding to the next-day pollen load below its quantiles 10%, 20% and 30% and above the quantiles 90%, 80% and 70% were analysed. The Student *t*-test (Zimmerman, 1997) was used to decide whether pollen category related means of each meteorological variable differ significantly under each quantile for *Ambrosia* pollen.

3.2.2 Nearest neighbour (NN) technique (Section 7)

An NN technique was developed and applied in order to decide which one of the two categories of the next-day pollen load occurs under actual values of the 5 meteorological variables. A nearest neighbour of the actual daily meteorological variables is identified with the day where the explaining variables are the most similar to the actual explaining variables. Then the decision on the pollen load category for this case is the category being present on the selected day.

The procedure was used for every day available. The similarity is measured with the Euclidean distance defined with the standardised explaining variables. Standardization is necessary to ensure the same magnitude of each explaining variable and hence to provide the same importance of them. It was performed for every explaining variable separately by dividing the difference between data and their mean by the standard deviation. Due to the annual trends in both the pollen loads and the meteorological variables a time window *h* was defined around each actual day *t* of the year and the nearest neighbours were searched within days from *t*-*h* to *t*+*h* of the years. Additionally, not only the unique nearest neighbour but the first *k* nearest neighbours were selected and the final decision on the category was defined as the majority decision of the *k* number individual decisions. Parameters *h* and *k* were determined from the first eight years (learning set) as to provide a best ratio of good decisions to all decisions, and the procedure was verified using data of the last year.

3.2.3 Regression (Section 8)

Linear regressions are used 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, *Ambrosia* exhibits a pollen season in Szeged from July 15 to October 15, and thus *D*=93 and *d*=273 days. Adjusted multiple correlations (e.g. Draper and 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 three taxa.

3.2.4 Factor analysis (Sections 5, 7, 8)

Factor analysis identifies linear relationships among examined variables and thus helps to reduce the dimensionality of a large data set of *p* correlated variables, expressing them in terms of *m* (*m* < *p*) new uncorrelated variables, the so-called components or factors. Calculation was based on PCA combined with varimax rotation keeping the factors uncorrelated (Sindosi et al., 2003). The number of components (factors) produced is equivalent to the number of original input variables and account for 100% of the total variance of all original variables. Since only a few components may account for the majority of the total variance, it may be unnecessary to retain all components. Several methods are available for determining the number of components to be retained (Jolliffe, 1990; 1993; McGregor and Bamzelis, 1995). One of the most known component selection techniques selects components with eigenvalues >1. This is based on the idea that all new variables should have greater explanatory power than the original variables, which have an eigenvalue of 1. Some papers have established that selecting components with eigenvalues <1 can result in an increase of the explanatory power and thus suggested retaining the number of components with the largest explained cumulative variance that account for at least 80% of the total variance of the original variables that has to be explained by the factors (Jolliffe, 1990). Note that these methods are considered subjective (McGregor and Bamzelis, 1995). We applied the latter procedure, as perhaps the most common method, for calculating the number of components to be retained (Sindosi et al., 2003; Liu, 2009). Factor analysis was applied to our initial standardized datasets in order to reduce the original set of variables to fewer uncorrelated variables. These new variables, called factors, can be viewed as latent variables explaining the joint behaviour of the meteorological elements and the pollen variables on the given days of the year.

3.2.5 Factor analysis with special transformation (Sections 5, 7, 8)

After performing the factor analysis, a special transformation of the retained factors was performed to find out to what degree the above-mentioned explanatory variables affect the resultant variable and to give a rank of their influence (Fischer and Roppert, 1965; Jahn and Vahle, 1968; Jolliffe, 1993). In more detail, when performing factor analysis on the standardized variables, factor loadings received are correlation coefficients between the factors and the standardized original variables and, after rotation, the coordinate values belonging to the turned axes (namely, factor values). Consequently, if the resultant variable is strongly correlated with a factor (the factor has high factor loading at the place of the resultant variable) and an influencing variable is highly correlated with the same factor, then the influencing variable is also highly correlated with the resultant variable. Accordingly, it is advisable to combine all the weights of the factors, together with the resultant variable, into a new factor. Namely, it is effective to rotate so that only one factor has great load with the resultant variable and the remaining factors are uncorrelated with the resultant variable; that is to say, are of *0* weights. This latter procedure is called special transformation (Fischer and Roppert, 1965; Jahn and Vahle, 1968).

After the transformations, when all weights of the retained factors at the place of both the explanatory variables and the target variable are incorporated into one factor, significance thresholds belonging to the factor loadings are determined as follows. Introducing the *0*-hipothesis, according to which factor loading of a given influencing variable is *0*, namely this influencing variable has no role in determining the target variable, the statistics

$$t = \sqrt{\frac{r^2(n-2)}{1-r^2}} \qquad (4.13.)$$

follows Student *t*-distribution with *n–2* degree of freedom, where *r* is the factor loading of the given influencing variable and *n* is the number of observations.

Since application of factor analysis with special transformation in Section 9 is not very easy to understand for the reader, the procedure is presented here in detail, as follows.

Factor analysis was applied to the initial datasets consisting of 9 correlated variables (8 explanatory variables including 4 meteorological variables (temperature, T; relative humidity, RH; global solar radiation, GSR; and precipitation, P) 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 *Ambrosia*) 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 first 5 variables of the above mentioned 9 variables include daily pollen concentrations and daily values of T, RH, GSR and P during the pollen season of *Ambrosia* for every year. The remaining 4 variables (cumulative T, RH, GSR and P) are defined as in section 3.2.3, 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 3.2.3. In more detail, generating the data matrices in order to perform the factor analysis for each taxon is as follows.

In order to assess the effect of the antecedent and current meteorological conditions on the current *Ambrosia* pollen concentration, the 1^{st}-day, 2^{nd}-day, … , 93^{th}-day values of both the pollen concentration and the four meteorological elements of the current pollen season were taken. (The duration of the *Ambrosia* pollen season in Szeged lasts from July 15 until October 15, namely 93 days. That is, the longest pollen season for *Ambrosia* during the 11-year period was considered for each year.) Furthermore, antecedent meteorological conditions in the pollen-free season preceding the actual pollen season were also considered. First take the matrix comprising the pollen and meteorological data of the 1^{st} day of the pollen season (July 15) for the 10-year period 1998-2007, as well as the meteorological data of the last day of the preceding pollen-free season. In this way we receive a matrix with 10 lines (10 identical days, i.e. July 15, for the ten years, 1998-2007) and 9 columns (a column for the daily pollen concentrations, 4 columns for the current meteorological data, i.e. daily values of T, RH, GSR and P, as well as 4 columns for the antecedent meteorological data, i.e. daily values of T, RH, GSR and P for the last day of the preceding pollen-free season). In the next steps only the 4 columns for the antecedent meteorological data will change, namely they will be cumulated daily values of T, RH, GSR and P for the last 2, 3, … , 272 days of the preceding pollen-free season, respectively. In this way we receive 272 matrices with 10 lines and 9 columns. In the following step we consider the data matrix comprising the pollen and meteorological data of the 2nd day of the pollen season in the first five columns and then we follow the same reasoning as above. Thereby we receive another 272 matrices with 10 lines and 9 columns. Repeating this procedure 93 times, at last we receive a data matrix comprising the pollen and meteorological data of the 93th day of the pollen season in the first five columns, while the last 4 columns consist of the antecedent meteorological data, i.e. cumulated daily values of T, RH, GSR and P for the last 272 days of the preceding pollen-free season. In this way we receive altogether 93x272=25,296 data matrices for *Ambrosia*.

3.2.6 Computational Intelligence (CI) (Section 9)

The following CI methods are evaluated in the dissertation. Multi-layer perceptron (MLP) (Haykin, 1999) models are artificial neural network models capable of modelling complex and highly nonlinear processes. Two types of neural networks are applied: a complex (MLP with more than one hidden layer) and a less complex (MLPRegressor with only one hidden layer) version. For predicting both the daily pollen concentrations and daily alarm levels of ragweed, several tree algorithms (M5P, REPTree, DecisionStump and J48) are used. These algorithms have not been used for the above tasks. The models have been developed in Matlab environment with WEKA implementation of the above algorithms, described in Hall et al. (2009).

3.2.6.1 Multi-layer Perceptron (MLP)

MLP (Haykin, 1999) is the most successful implementation of feedforward artificial neural networks and have been widely applied in the field of environmental science for classification, regression and function approximation problems. MLP can model complex and highly non-linear processes through the topology of the network. Multi-Layer Perceptron comprises an input and an output layer with one or more hidden layers of nonlinearly-activation functions. These capabilities have already been successfully utilized in previous studies in order to forecast pollen concentrations (e.g. Voukantsis et al., 2010), therefore MLP is an important procedure and this is the first occasion for using this method for predicting daily concentrations and daily alarm thresholds of ragweed pollen.

In the study, MLP model always has more than one hidden layer and MLP has several parameters that need to be set. They are training time, learning rate, hidden layers and neurons in the layers. Training time was 1500, while learning rate started from 0.3 and it was reduced in each step. This helps to stop the network from diverging from the target output as well as improve the general performance. The number of hidden layers is generated automatically by WEKA. MLP was applied with the same options for predicting both the daily pollen concentrations and daily alarm thresholds of ragweed.

MLPRegressor and MLP Classifier

Both classes are built-in WEKA modelling softwares (Hall et al., 2009). These algorithms are special parts of Multi-Layer Perceptrons. They always have only one hidden layer, where the number of neurons is user specific. Both use optimization by minimizing the squared error plus a quadratic penalty with the BFGS method. All parameters are standardized, including the target variable. The activation function is a logistic function. MLPRegressor and MLPClassifier are applied for predicting the daily pollen concentrations and daily alarm thresholds of ragweed, respectively.

3.2.6.2 Tree-based algorithms

M5P

This procedure is a reproduction of Quinlan's M5 algorithm (Quinlan, 1992) being a combination of decision trees and multivariate regression models. Contrary to other regression trees the leaves of the M5P tree structure consist of MLR models. So, it is possible to model local linearity within the data similarly to piecewise linear functions. This is the first study applying M5P to model daily ragweed pollen data.

DecisionStump

DecisionStump builds a decision tree with a single split point. It makes (1) regression based on mean-squared errors or (2) classification based on entropy depending on the data type to be forecasted.

REPTree

REPTree is a fast decision tree learner. It builds a decision tree using information gain or makes a regression tree from the variance. It applies pruning with backfitting for reducing error.

J48

J48 is an implementation of C4.5 algorithm in the WEKA data mining pool. C4.5 builds decision trees from a set of training data in the same way as ID3 using the concept of information entropy. J48 classifier achieves fast execution times and adequate scales of large datasets (Quinlan, 1993).

4. Ragweed and ragweed pollen related characteristics

4.1 Introduction

4.1.1 Origin and distribution of ragweed

Ambrosia originates in *North America* and has evolved in reaction to a dry climate and open environment. Among *Ambrosia* species only seaside *Ambrosia* (*Ambrosia maritima*) is native in Europe. Its earliest described colonization occurred in Dalmatia (Croatia) in 1842 (de Visiani, 1842), where it was an endemic plant on the sandy seashores of the Ragusa (recent name: Dubrovnik, Croatia) Budva (Montenegro) area, and on the islands. In Western Europe, the first temporary colonization of *Ambrosia* was reported from Brandenburg (Germany) in 1863 (Priszter, 1960). At that time, four American species had already become inhabited: *Ambrosia artemisiifolia* = *Ambrosia elatior* (ragweed with mugwort leaves = short ragweed), *Ambrosia trifida* (great or giant ragweed), *Ambrosia psilostachya* (perennial ragweed) and *Ambrosia tenuifolia* (silver ragweed). Short ragweed is the most widely spread in Western Europe and in Hungary (Járai-Komlódi and Juhász, 1993).

The distribution of *Ambrosia* in Europe started after the First World War (Comtois, 1998). Seeds of different *Ambrosia* species were transferred to Europe from America by purple clover seed shipments, and grain imports. Its distribution started probably from the European ports: e.g. from Rijeka towards Croatia and Transdanubia (the latter region is the western part of Hungary), from Trieste and Genoa towards Northern Italy, and from Marseille towards the Rhône valley.

Recently, there are three main regions infected by *Ambrosia* in Europe: the valley of the Rhône (France), Northern Italy and the Carpathian Basin (Juhász, 1998; Rybnícek and Jäger, 2001).

Data on ragweed pollen have carefully been documented in France (Thibaudon, 1992; Comtois and Sherknies, 1992; Déchamp and Déchamp, 1992). An epidemiological study for ragweed allergy was conducted on 646 employees of 6 factories located in the Rhône valley south of Lyon. In this study, 5.4% of subjects were symptomatic to ragweed pollen, whereas 5.9% were sensitized to this pollen (Harf et al, 1992). The spread of ragweed in the middle Rhône area over the 1980s has been considerable; this is especially true of the Drome, along the River Rhône. Although ragweed grows mainly in the plains, in this area it appears to be extending into the mountains (Couturier, 1992).

Spread of ragweed and ragweed pollinosis has become a rapidly emerging problem in Italy (Politi et al., 1992). In 21 cities across Italy, among 2,934 patients with respiratory diseases of suspected allergic origin, ragweed pollen was shown to provoke asthma much more frequently than any other pollen grains (Corsico et al., 2000). Children appear to be less sensitised to ragweed pollen than adults are; only 5.9% of 507 asthmatic children aged between 1 and 17 years from a central Italian area had been sensitized to ragweed species (Verini et al., 2001).

Ambrosia pollen came to Switzerland by the southerly winds from Northern Italy and the Rhône valley (Peeters, 1998). However, it was recently shown that there is native *Ambrosia* in Geneva, Switzerland (Clot et al., 2002). *Ambrosia* pollen is assumed to be transported from Hungary to Burgenland and Vienna during August and September, when south-eastern winds are predominant in the region. Jäger and Litschauer (1998) detected pollen of *Ambrosia* originating from Transdanubia in the air of Vienna. Native *Ambrosia* is also found in Austrian countryside (Jäger and Berger, 2000). The source region of *Ambrosia* in Slovakia is the Csallóköz (i.e. the plain of Danube) and Eastern Slovakia. The first description of its presence (Komárno, Southwest Slovakia) dated back to 1949. Seeds are partly native; partly transported by the southerly winds from Hungary (Makovcová et al., 1998). They might have been also introduced with cereals from the former Soviet Union (Makovcová et al., 1998). *Ambrosia artemisiifolia* arrived at Slovenia at the end of the Second World War. The map of its distribution was first published in 1978 and its appearance was considered to be temporary. However, *Ambrosia* managed to spread widely and very fast in the lowlands of the country (Seliger, 1998). In Russia, the most contaminated areas are Krasnodar, Stavropol and Sochi in the southern European part of the country (Juhász, 1998; Rybnícek and Jäger, 2001).

4.1.2 Ragweed in Hungary

In Hungary, *Ambrosia* was detected at the beginning of the 20th century at Orsova (Jávorka, 1910), near the southern border of the country, along the banks of the river Danube. One of the popular names of *Ambrosia* in Hungary is „Serbian grass", which also refers to its place of origin. *Ambrosia artemisiifolia* were found in the southern part of Transdanubia in the 1920s, and in 30 years it occupied the whole region. At the same time, even in 1968 no one single ragweed pollen was found in the air of Szeged (Simoncsics et al., 1968). Today it is the most common weed in Hungary. Its distribution phases in Hungary are primarily known on the works of Priszter (1957; 1960), Béres (1981), as well as Béres and Hunyadi (1991) (*Fig. 5*).

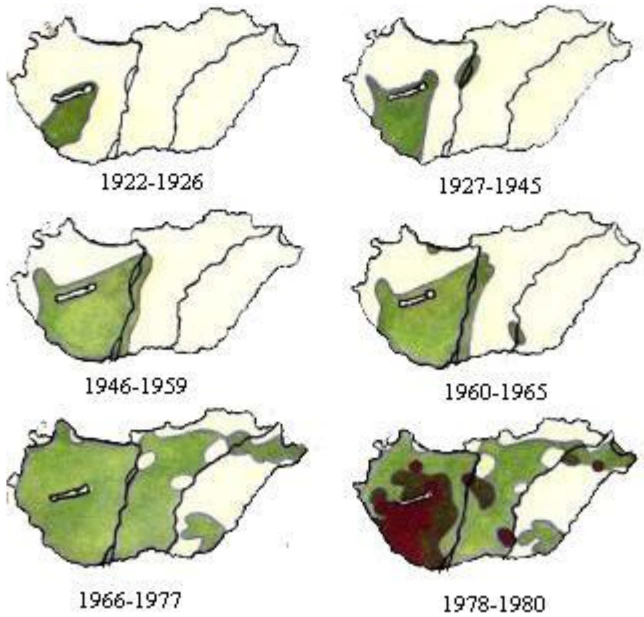


Fig. 5 The phases of the spread of ragweed in Hungary (Priszter, 1957; 1960; Béres and Hunyadi, 1991)

4.1.3 Climatological, ecological, agricultural, health related and social background of ragweed

4.1.3.1 Climatic associations

Ambrosia species are adapted to the arid climates of the desert. Ragweed favours temperate climate and prefers dry, sunny and grassy plains, sandy soils, river banks, roadsides, and ruderal sites (disturbed soils) such as vacant lots and abandoned fields (Ziska et al., 2007; Kazinczi et al., 2008a; 2008b).

Ragweed can take hold up and prosper if the temperature sum exceeds the threshold of 1400°C, necessary for its floral and seed development (Cunze et al., 2013). Below this threshold, under maritime climate (north-eastern Spain, Netherlands), ragweed populations seem only survive. At the same time, if the temperature sum is too high, for example in the Mediterranean, summers are hot and dry that involves a substantial decline of pollen release. However, the species is widely distributed in countries that are largely unsuitable for ragweed but import lots of seed, such as Netherlands or Belgium. In these countries, the distribution overstates the very low impact of the casual introductions (Bullock et al., 2010).

The northern and high-elevation range margin of ragweed is regulated by thermal and photoperiod constraints. Beyond their habitat areas, ragweed occurs casually and is unable to set seeds (Dahl et al., 1999; Saar et al., 2000). In the northern range of its habitat area, even though the populations can produce seed, low temperatures or the cold climate promotes extinction. In general, over these areas ragweed grows to adulthood but fails to reproduce properly because it is too cold. At the same time, in the southern edge of its habitat, drought is considered a major factor limiting the invasion. This is the main aspect explaining a lack of ragweed pollen records from Spain and Portugal, where seed import rates should cause many introductions to occur (Bullock et al., 2010).

Long-range transport of ragweed pollen (traveling more than 100 km distance between the source area and the arrival point) can deliver pollen over less polluted areas, e.g. from the Pannonian Plain in Central Europe over the Basin of Vienna, northern Slovakia, Poland, Balkans or northern Greece and in the same way, from Ukraine over Poland (Makra and Pálfi, 2007; Makra et al., 2007a; Šikoparija et al., 2009; Makra et al., 2010; Kasprzyk et al., 2011; Šikoparija et al., 2013; Makra et al., 2015; Makra et al., 2016).

4.1.3.2 Ecological background

In Hungary, the flowering of *Ambrosia* starts in the second half of July and ends in October. The peak season occurs in August. The timing and manner of pollination depend greatly on meteorological factors: temperature, humidity and global solar flux. Increasing temperature and decreasing humidity enhance pollination. The daily pollen production of *Ambrosia* is the function of the geographical location, taxon and weather. Accordingly, daily pollen release of a given taxon may show substantial differences year after year. Daily pollen release of ragweed in Szeged is unimodal with pollen release between around 8 a.m. and 16 p.m. with a maximum around noon (Juhász and Juhász, 1997).

4.1.3.3 Impact on Agriculture

The extensive spread of *A. artemisiifolia* can be associated to the political transitions in 1990s that led to the formation of young democracies in Eastern Europe. During these processes, the structure and the size of the cultivated areas, as well as land use changed. Namely, co-operatives were cut into smaller parcels due to privatization. Thus large, formerly well-kept agricultural fields were abandoned and quickly colonised by *A. artemisiifolia* (Kiss and Béres, 2006).

Ambrosia is a noxious agricultural weed. It grows frequently on roadsides, railway embankments, waste places and in cultivated lands. It can overgrow alfalfa and purple clover entirely, cause severe damages in potato fields and occurs often in sunflower and corn fields, as well. *Ambrosia* appears in large quantities in stubbles, effectively utilize large amounts of fertilizer, have high productivity, and regenerate well in dry and infertile soils. Their ability to block sunlight causes reduced crop productivity (Xie et al., 2001). Furthermore, it does not have any natural competitors. *Ambrosia* has less sensitivity to herbicides than other weeds (Voevodin, 1982; Ballard et al., 1995; Patzoldt et al., 2001; Makra et al., 2014c; Makra et al., 2015).

4.1.3.4 Health related effects

Climate change in association with an extended urbanization, with high levels of vehicle emissions in urban areas, living in artificial environment with little movement may contribute to increasing frequency of respiratory allergy and asthma (D'Amato, 2011). Pollen is an important trigger of respiratory diseases. Greater concentrations of carbon dioxide and, consequently, higher temperatures may increase pollen quantity and induce longer pollen seasons (Ziska and Caulfield, 2000; Clot, 2008). Pollen allergenicity can also increase as a result of these changes in climate. Furthermore, there is evidence that high levels of traffic-derived air pollutants may interact with pollen and bring about more intense respiratory allergy symptoms (Hjelmroos et al., 1999; Andersen et al., 2007; Díaz et al., 2007; Alves et al., 2010). Accordingly, global warming may induce a wide pollen-related public health problem, for which the societies should be prepared in time.

Symptoms due to common ragweed include a runny nose, sneezing, puffy or irritated eyes, and a stuffy or itchy nose and throat, as well as hay-fever allergies (Matyasovszky et al., 2011). Furthermore, *A. artemisiifolia* has a wide ecological tolerance and can colonize a large range of disturbed habitats (Kazinczi et al., 2008a; Pinke et al., 2011; Makra et al., 2011a). Its invasion is also facilitated by its resistance to certain herbicides (Kazinczi et al., 2008b), the lack of natural enemies (MacKay and Kotanen, 2008) and the high genetic variability of invasive populations (Genton et al., 2005; Chun et al., 2010). These harmful effects, with its potential for rapid spread has made ragweed one of the most dangerous invasive non-native species in Europe. The European Commission has identified the species as a significant problem for many Member States of the EU and a very serious threat for others (Makra et al., 2015).

4.1.3.5 Social costs

Common ragweed and its pollen cause serious losses in the economy and several fields of the everyday life.

Common ragweed and its pollen cause serious losses in the economy and several fields of the everyday life. The current costs of *A. artemisiifolia* in terms of human health and agriculture were estimated by Bullock et al. (2010) for 40 European countries. All the costs are given in Euros at 2011 prices. The human health impacts were estimated to affect around 4 million people with total estimated medical costs of €2,136 million per year. Furthermore, total estimated workforce productivity losses and agricultural costs due to *A. artemisiifolia* as high estimates were €529 million and €3,559 million, respectively. The estimated total costs are valued at €6.224 billion per year. Over 80% of these impacts are lost crop yields. Estimated agricultural, human health, workforce and total costs are the highest in Ukraine, Romania and Hungary with €995, €770 and €605 million, respectively (Bullock et al., 2010). At the same time, in the USA, allergic disorders represent an important group of chronic diseases with estimated costs at approximately $21 billion per year. Among twenty-five of the most harmful invasive species of China, economic losses due to ragweed, found in most of the provinces, amount to 397.9 million USD, taking ragweed the 2nd most harmful species in the country (Ding et al., 2014; Li et al., 2014).

Realizing the danger, those countries polluted with ragweed, have introduced anti-*Ambrosia* campaigns under the control of the National Ministries of either Health Affairs or Agriculture (Makra et al., 2015).

4.1.4 Pollen season and annual course of the pollen concentration of ragweed compared to other taxa

Makra et al. (2006; 2007) analyzed pollen release of altogether 24 taxa for the pollen trap of Szeged. The joint pollen season of these taxa lasts from the beginning of February until the end of October (*Fig. 6*).

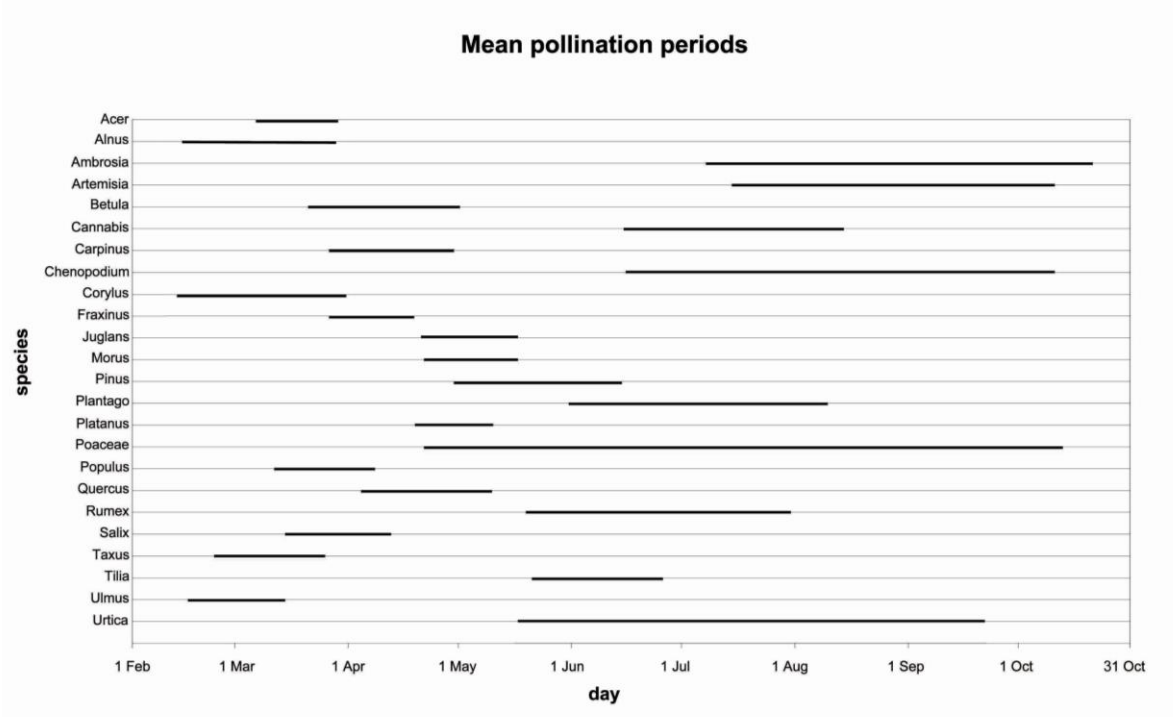


Fig. 6 Mean pollination periods of the taxa considered, February 1 – October 31, 1997-2001 (Makra et al., 2006a; Makra, 2006b; Makra et al., 2007b; 2007c)

Daily pollen counts of the individual taxa are generally below 100 pollen grains / m^3 of air (*Fig. 7*). However, mean daily pollen counts of maple *(Acer)* (mean pollen season: from the beginning of March until the end of March) exceeds this value some days. Nevertheless, pollen release of ragweed *(Ambrosia)* (mean pollen season: from the middle of July until middle of October) is the most effective of all taxa considered (*Figs. 7-8*). On the days with the heaviest pollen load (ragweed pollen concentration > 400 pollen grains / m^3 of air), pollen release of ragweed is on order of magnitude higher than that of the other taxa. (*Figs. 7-8*).

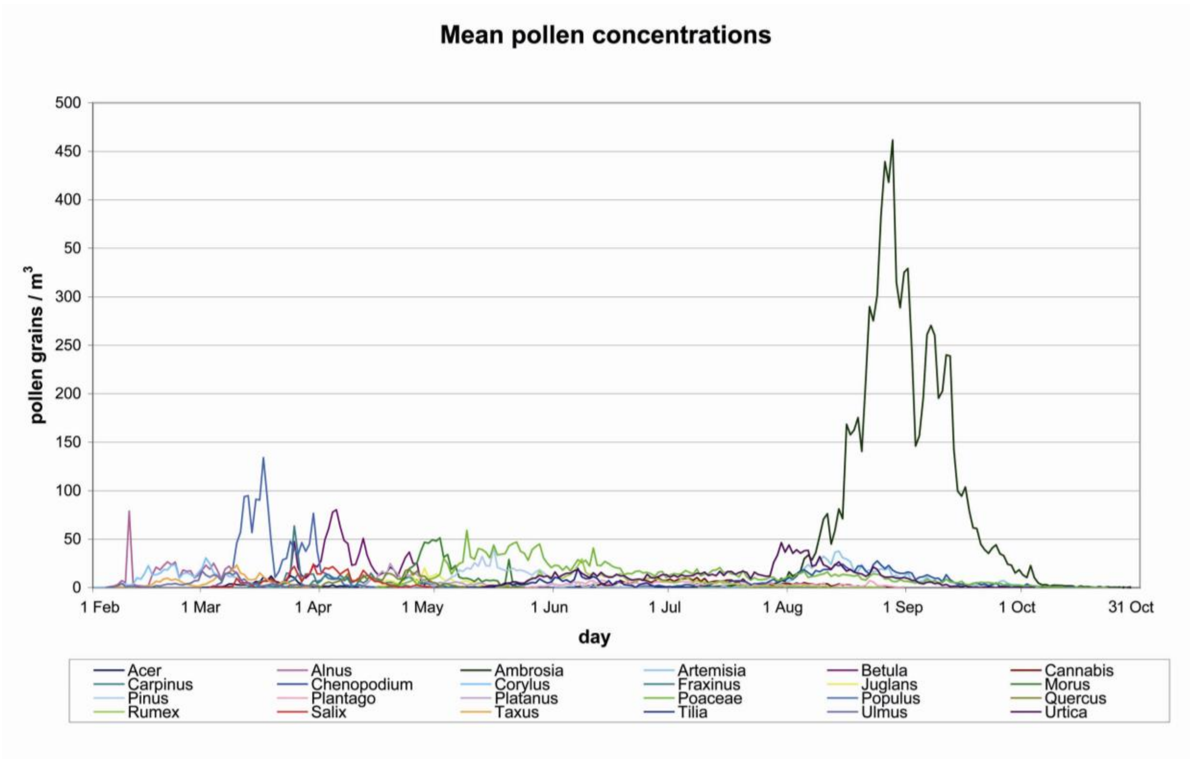


Fig. 7 Mean daily pollen counts of the taxa considered, Szeged, February 1 – October 31, 1997-2001 (Makra et al., 2006a; Makra, 2006b;)

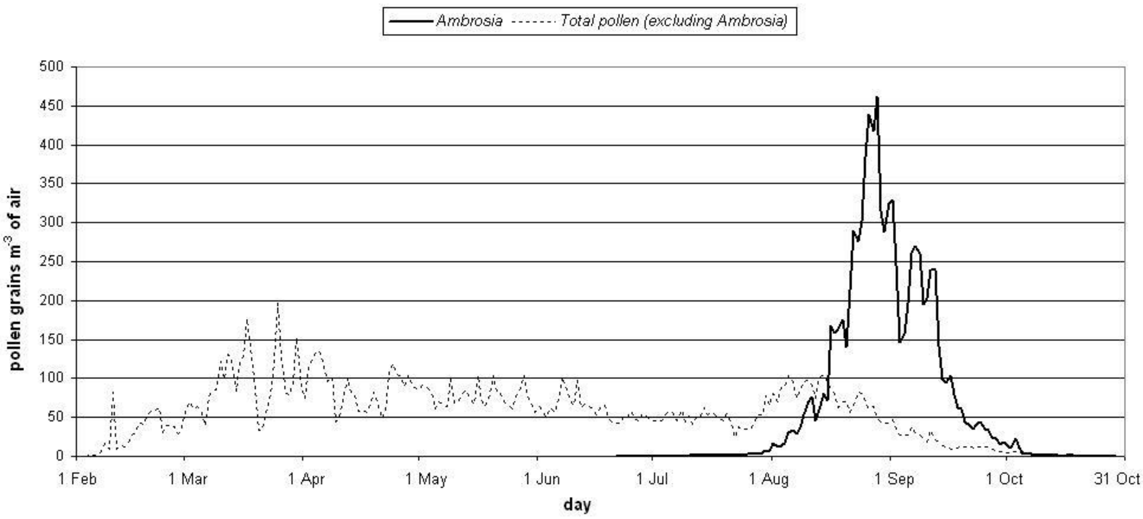


Fig. 8 Mean daily pollen counts of the taxa considered, Szeged, February 1 – October 31, 1997-2001 (Makra et al., 2007b; 2007c)

5. Potential reasons of day-to-day variations of ragweed (Ambrosia) pollen counts in association with meteorological elements

5.1 Introduction

We analyze the potential reasons of day-to-day variations of *Ambrosia* pollen counts for Szeged region of Southern Hungary in association with meteorological elements. For this purpose, a factor analysis with special transformation is performed on the daily meteorological and *Ambrosia* pollen data in order to find out the strength and sign of associations between meteorological (explanatory) variables and *Ambrosia* pollen (resultant) variable.

5.2 Results

For each day of the analysis daily differences in meteorological variables (value on the given day – value on the day before) were assigned to the daily ratios of *Ambrosia* pollen counts (A) (value on the given day per value on the day before). Three data sets were subjected to an analysis: (1) the total data set, (2) those daily differences in meteorological variables for which A ≤ 1 and (3) those for which A > 1, respectively. For all three data sets, the days examined were classified into four categories, respectively. These categories are as follows: (a) rainy day, preceded by a rainy day; (b) rainy day, preceded by a non-rainy day; (c) non-rainy day, preceded by a rainy day; (d) non-rainy day, preceded by a non-rainy day.

5.2.1 Factor analysis with special transformation

After performing a factor analysis on all three data sets (altogether 3x4=12 factor analyses) (*Tables 1-3*), 4, 5, 4 and 4 factors were retained for (a), (b), (c) and (d) categories in the total data set (*Table 1*); 4, 5, 3 and 4 factors were considered for (a), (b), (c) and (d) categories in the data set for which A ≤ 1 (*Table 2*); while, for the remaining case (in the data set for which A > 1.00) altogether 4 factors were retained for each category, respectively (*Table 3*). In order to calculate the rank of importance of the explanatory (meteorological) variables for determining the resultant variable (daily ratios of *Ambrosia* pollen counts), loadings of the retained factors were projected onto Factor 1 for all 12 factor analyses with a special transformation (*Tables 1-3*) (Jahn and Vahle, 1968).

Those relationships between the meteorological and pollen variables are only analysed for all data sets that were significant at 10%, 5% or 1% probability levels. Considering the total data set (Table 1), for category (a) rainfall (R), maximm temperature (T_{max}), mean temperature (T_{mean}) and temperature range (ΔT) in decreasing order of their importance are the most important variables denoting a proportional association with daily ratios of *Ambrosia* pollen counts. At the same time, wind speed (V) indicates a weak inverse connection with the resultant variable. For category (b) rainfall (R) and wind speed (V) are the only relevant meteorological parameters, both influencing inversely the resultant variable. For category (c) no significant explanatory variables occur, while for category (d) only the role of relative humidity (RH) is substantial representing an inverse association with daily pollen ratios (Table 1).

Regarding the data set for which daily ratios of *Ambrosia* pollen counts are smaller or equal to unit ($A \leq 1$) (Table 2), for category (a) rainfall (R) and wind speed (V) proportionally, while temperature range (ΔT) and mean temperature (T_{mean}) inversely influence the resultant variable, respectively. For category (b) wind speed (V) is the only substantial parameter indicating a positive association with daily pollen ratios. For category (c) wind speed (V) and minimum temperature (T_{mean}) are in an inverse, while temperature range (ΔT) and maximum temperature (T_{max}) are in a proportional association with daily ratios of *Ambrosia* pollen counts. For category (d) mean temperature (T_{mean}), maximum temperature (T_{max}), relative humidity (RH) and temperature range (ΔT) inversely, while irradiance (I) and wind speed (V) proportionally influence the resultant variable.

Concerning the data set for which daily ratios of *Ambrosia* pollen counts are higher than unit ($A \leq 1$) (Table 3), for category (a) a proportional association of rainfall (R), while for category (b) an inverse association of wind speed (V) and rainfall (R) with daily pollen ratios are the most important, respectively. For category (c) temperature range (ΔT) is negatively, while minimum temperature (T_{mean}) is positively associated with the resultant variable, respectively. For category (d) irradiance (I) and relative humidity (RH) are the most important, both inversely influencing daily pollen ratios.

Table 1 Special transformation. Effect of the daily differences in meteorological variables [1] on the daily ratios of *Ambrosia* pollen counts (A) [2], as resultant variables and the rank of importance of the explanatory variables on their factor loadings transformed to Factor 1 for determining the resultant variable, total data set
(thresholds of significance: *italic:* $x_{0.10}$; **bold**: $x_{0.05}$; **bold**: $x_{0.01}$)
(Csépe et al., 2012a; Matyasovszky et al., 2012; Makra et al., 2014d)

[1]Daily differences in meteorological variables	[2]Daily ratios of *Ambrosia* pollen counts (A)							
	a		b		c		d	
	thresholds of significance							
	0.139		*0.140*		*0.139*		*0.073*	
	0.165		**0.166**		**0.166**		**0.087**	
	0.217		**0.218**		**0.218**		**0.115**	
	weight	rank	weight	rank	weight	rank	weight	rank
Ambrosia	0.869	–	0.895	–	0.999	–	0.988	–
T_{mean}	**0.250**	3	0.118	3	0.083	2	-0.023	6
T_{min}	-0.029	8	0.063	6	0.117	1	0.059	3
T_{max}	**0.263**	2	0.074	4	0.049	4	-0.007	7
ΔT	**0.199**	4	-0.009	8	-0.082	3	-0.058	4
I	0.108	6	-0.069	5	0.029	6	-0.071	2
RH	0.092	7	0.056	7	0.046	5	**-0.166**	1
V	*-0.165*	5	**-0.291**	2	0.002	7	-0.034	5
R	**0.548**	1	**-0.359**	1	–	–	–	–

[1]: value on the given day – value on the day before; [2]: value on the given day per value on the day before; a: rainy day, preceded by a rainy day; b: rainy day, preceded by a non-rainy day; c: non-rainy day, preceded by a rainy day; d: non-rainy day, preceded by a non-rainy day; T_{mean} = daily mean temperature; T_{min} = daily minimum temperature, T_{max} = daily maximum temperature, ΔT = daily temperature range; I = irradiance, RH = relative humidity; V = wind speed; R = rainfall;

5.3 Discussion

The analysis of day-to-day variations of *Ambrosia* pollen counts is an important area of pollen researches, due to its immediate association with public health. Our study can be considered specific, since these kinds of papers have not been found in the international literature, accordingly *Ambrosia* pollen, the most allergenic pollen type has neither been studied from this point of view. A novel procedure is applied in our study; namely, factor analysis with special transformation.

Factor analysis with special transformation was applied in order to examine the role of the meteorological variables in day-to-day variations of *Ambrosia* pollen concentrations and to determine their rank of importance in influencing daily ratios of *Ambrosia* pollen counts.

Table 2 Special transformation. Effect of the daily differences in meteorological variables[1] on the daily ratios of *Ambrosia* pollen counts (A)[2], A ≤ 1.00 as resultant variables and the rank of importance of the explanatory variables on their factor loadings transformed to Factor 1 for determining the resultant variable, (thresholds of significance: *italic:* $x_{0.10}$; **bold**: $x_{0.05}$; **bold**: $x_{0.01}$) (Csépe et al., 2012a; Matyasovszky et al., 2012; Makra et al., 2014d)

[1]Daily differences in meteorological variables	[2]Daily ratios of *Ambrosia* pollen counts (A), A ≤ 1.00							
	a		b		c		d	
	thresholds of significance							
	0.185		*0.197*		*0.191*		*0.106*	
	0.220		**0.233**		**0.225**		**0.126**	
	0.286		**0.304**		**0.294**		**0.167**	
	weight	rank	weight	rank	weight	rank	weight	rank
Ambrosia	-0.790	–	-0.813	–	0.656	–	-0.929	–
T_{mean}	*0.193*	4	0.087	5	0.181	5	**0.260**	1
T_{min}	-0.166	6	0.165	2	**-0.316**	4	-0.023	7
T_{max}	0.170	5	0.027	8	**0.397**	3	**0.234**	2
ΔT	**0.249**	2	-0.129	4	**0.553**	2	**0.151**	4
I	0.000	8	-0.156	3	0.160	6	**-0.144**	5
RH	-0.072	7	-0.064	6	-0.084	7	**0.176**	3
V	**-0.243**	3	**-0.657**	1	**-0.631**	1	*-0.119*	6
R	**-0.725**	1	-0.058	7	–	–	–	–

[1]: value on the given day – value on the day before;

[2]: value on the given day per value on the day before;

a: rainy day, preceded by a rainy day; b: rainy day, preceded by a non-rainy day;
c: non-rainy day, preceded by a rainy day; d: non-rainy day, preceded by a non-rainy day;

T_{mean} = daily mean temperature; T_{min} = daily minimum temperature,
T_{max} = daily maximum temperature, ΔT = daily temperature range; I = irradiance,
RH = relative humidity; V = wind speed;
R = rainfall;

Rainfall (R) belongs to the first two most important meteorological parameters for all three data sets, except for category (b) for which A ≤ 1.00 (Table 2). However its association with daily ratios of *Ambrosia* pollen counts is different for categories (a) and (b). Namely, for category (a) rainfall is proportionally associated with daily pollen ratios in all three data sets (Table 1-3). The reason of this relationship can be as follows. Due to a rainfall on the preceding day, water balance of the taxon may improve substantially, facilitating a higher pollen release on the given day (positive effect). However a rainfall on the given day, depending on its intensity, may substantially reduce airborne pollen counts (negative effect). As a result, since summer rainfalls are generally short showers early in the afternoon, higher however short rainfall may involve higher pollen counts adding a higher weight to the given-day-related pollen count increase associated with the preceding-day rainfall compared to the given-day-related decrease in pollen counts induced by a rainfall on the given day (Table 1-3). At the same time, for category (b) in the total data set (Table 1) and in that for which A > 1.00 (Table 3) rainfall is in an inverse association with daily pollen ratios. This association can be explained (1) by the well-known wash-out effect: after rainfall the pollen content of the air reduces sharply (Déchamp and Penel, 2002; Kasprzyk, 2008; Hernández-Ceballos et al., 2011); (2) another reason of a negative association between rainfall and the pollen variable is the fact that rainfall is accompanied with a fall in temperature, which slows the metabolism of the taxon down (Deák, 2010) (Table 1; Table 3). Based on the international literature, the role of rainfall is not clear in influencing daily pollen counts. Fornaciari et al. (1992) and Galán et al. (2000) found the impact of rainfall complicated just because of the negative effect of rain intensity on pollen counts. Fornaciari et al. (1992) computed the best correlation by comparing pollen concentrations (Urticaceae) and meteorological parameters on non-rainy days. For several cases *Ambrosia* pollen grains were negatively correlated with rainfall (Barnes et al., 2001; Déchamp and Penel, 2002; Peternel et al., 2005; Peternel et al., 2006; Kasprzyk, 2008); at the same time, Bartková-Ščevková (2003) did not find statistically significant association.

Table 3 Special transformation. Effect of the daily differences in meteorological variables[1] on the daily ratios of *Ambrosia* pollen counts (A)[2], A > 1.00 as resultant variables and the rank of importance of the explanatory variables on their factor loadings transformed to Factor 1 for determining the resultant variable,

(thresholds of significance: *italic:* $x_{0.10}$; **bold**: $x_{0.05}$; **bold:** $x_{0.01}$)

(Csépe et al., 2012a; Matyasovszky et al., 2012; Makra et al., 2014d)

[1]Daily differences in meteorological variables	[2]Daily ratios of *Ambrosia* pollen counts (A), A > 1.00							
	a		b		c		d	
	thresholds of significance							
	0.233		*0.218*		*0.224*		*0.105*	
	0.276		**0.258**		**0.265**		**0.125**	
	0.358		**0.335**		**0.344**		**0.164**	
	weight	rank	weight	rank	weight	rank	weight	rank
Ambrosia	-0.985	–	0.794	–	-0.931	–	0.991	–
T_{mean}	0.014	7	0.176	3	0.102	5	0.096	3
T_{min}	0.031	6	0.107	5	**-0.391**	2	0.071	4
T_{max}	0.067	5	0.138	4	0.153	4	0.066	5
ΔT	0.010	8	-0.010	7	**0.454**	1	-0.042	6
I	0.083	4	-0.081	6	0.007	7	**-0.127**	1
RH	-0.165	3	0.002	8	0.061	6	*-0.117*	2
V	0.185	2	**-0.623**	1	0.215	3	-0.023	7
R	**-0.294**	1	*-0.254*	2	–	–	–	–

[1]: value on the given day – value on the day before;

[2]: value on the given day per value on the day before;

a: rainy day, preceded by a rainy day; b: rainy day, preceded by a non-rainy day;
c: non-rainy day, preceded by a rainy day; d: non-rainy day, preceded by a non-rainy day;

T_{mean} = daily mean temperature; T_{min} = daily minimum temperature,
T_{max} = daily maximum temperature, ΔT = daily temperature range; I = irradiance,
RH = relative humidity; V = wind speed;
R = rainfall;

Importance of mean temperature (T_{mean}) is varying and its role is ambivalent for the different data sets and categories (*Tables 1-3*). For category (a) in the total data set (*Table 1*) it is in a positive, while for categories (a) and (d) in the data set for which A ≤ 1.00 (*Table 2*) it is in a negative association with daily pollen ratios, respectively. These relationships can be explained as follows. In the case of adequate humidity conditions an increase in mean temperature (T_{mean}), if it is not too far from its optimum value, can accelerate vegetative and hence generative functions. Accordingly, it involves an increase in pollen concentrations, indicating a proportional association [*Table 1*, category (a)] (confirmed by Bartková-Ščevková, 2003; Gioulekas et al., 2004; Kasprzyk, 2008). At the same time, during lack of available water, an excessive increase in mean temperature (T_{mean}) can mean a barrier for the pollination of *Ambrosia*, as the plant concentrates on preserving of water and maintaining of its vegetative life functions in contrast to the generative functions (Deák, 2010). Hence, in this case mean temperature (T_{mean}) indicates an inverse association with daily ratios of *Ambrosia* pollen counts [*Table 2*, categories (a) and (d)].

Minimum temperature (T_{min}) is a relevant parameter for category (c) both in the data set for which $A \leq 1.00$ (*Table 2*) and for which ($A > 1.00$) (*Table 3*), indicating an inverse and a proportional association, respectively. The inverse relationship can be explained by the following reason. If preceding day is rainy, the cooling effect of rainfall can make a low temperature early in the morning; however, daily pollen ratio increases, since the given-day-related pollen count increase associated with the preceding-day rainfall has a higher weight compared to the given-day-related decrease in pollen counts induced by a low minimum temperature on the given day (*Table 2*). The potential reason of the proportional association between these variables is that very low minimum temperatures can be a barrier of the pollen production as low temperatures make the life functions of *Ambrosia* slower (*Table 3*).

Maximum temperature (T_{max}) is an important variable representing a proportional association with daily pollen ratios for category (a) in the total data set (*Table 1*); at the same it is in a proportional and an inverse relationship with the resultant variable for categories (c) and (d) in the data sets for which $A \leq 1.00$ (*Table 2*) and for which ($A > 1.00$) (*Table 3*), respectively. The proportional relationship may be explained as follows. Dehiscence of anthers and release of pollen result from dehydration of walls of anther sacs (Kozlowski and Pallardy, 2002), that is facilitated by higher maximum temperatures. Accordingly, higher values of this explanatory variable contribute to higher pollen release. At the same time this association my not be valid for a non-rainy day, preceded by a non-rainy day [category (d) in the data set for which $A \leq 1.00$; *Table 2*]. In summer time, extreme high maximum temperatures may indicate a limit for pollen production. In this period the loss of water can mean a barrier for the plant, so for preserving water it may decrease pollen production.

Temperature range (ΔT) is in a significant positive relationship with daily ratios of *Ambrosia* pollen counts for category (a) in the total data set (*Table 1*) and for category (c) in the data set for which A ≤ 1.00 (*Table 2*). At the same time, these variables indicate an inverse association for categories (a) and (d) in the data set for which A ≤ 1.00 (*Table 2*) and for category (c) in the data set for which A > 1.00 (*Table 3*). An increase in temperature range (ΔT) may occur through a decrease in minimum temperature (T_{min}) or an increase in maximum temperature (T_{max}) or both. The reason of an inverse relationship is that very low temperatures make a slower metabolism in the plant inducing a smaller pollen production, while in the case of extreme high temperatures the plant is forced to preserve water in its body for survival and, hence, decreases its pollen production. Accordingly, an increase in temperature range (ΔT) is inversely associated with daily ratios of *Ambrosia* pollen counts. However, if an increase in temperature range (ΔT) remains within a limit, it may show a proportional relationship with daily pollen ratios.

Irradiance (I) represents a proportional and an inverse association with daily ratios of *Ambrosia* pollen counts for category (c) in the data sets for which A ≤ 1.00 (*Table 2*) and for which A > 1.00 (*Table 3*), respectively. The proportional association is due to the fact that this variable contributes to maintaining elementary vegetative phyto-physiological processes that are important for producing pollen grains. However, the inverse association can be connected to an extreme high irradiance (I) related excessive increase in mean temperature (T_{mean}), when the plant concentrates on preserving of water and maintaining of its vegetative life functions and is pressed to restrict its generative functions (Deák, 2010).

Relative humidity (RH) is inversely associated with daily pollen ratios for category (c) in all three data sets, respectively (*Tables 1-3*). In general, pollen shedding is associated with shrinkage and rupture of anther walls by low relative humidity (Kozlowski and Pallardy, 2002). Hence, relative humidity is inversely associated with pollen release (Bartková-Ščevková, 2003; Gioulekas et al., 2004). Furthermore, humid air promotes sticking of pollen grains, which also contributes to an inverse association (affirmed by Kasprzyk, 2008).

Wind speed (V) is associated with daily ratios of *Ambrosia* pollen counts inversely for category (a) in the total data set (*Table 1*), for category (b) in the total data set (*Table 1*) and in the data set for which A > 1.00 (*Table 3*) and for category (c) in the data sets for which A ≤ 1.00 (*Table 2*), respectively. At the same time, this association is proportional for categories (a), (b) and (d) in the data set for which A ≤ 1.00, respectively (*Table 2*). When analysing the role of wind speed a (1) physical (Deák, 2010), a (2) physiological (Deák, 2010) and a (3) transport factor (Makra and Pálfi, 2007; Makra et al., 2007a; 2010) should be considered. (1) Wind speed can hinder sticking of pollen grains (positive effect); at the same time, (2) higher wind speed increases evapotranspiration leading to loss of water in the plant and the soil. This can be a limiting factor for pollination indirectly, since the plant is forced to preserve water that is more important for its life functions than producing pollen grains (negative effect). Furthermore, (3) long range pollen transport may also have a substantial effect to local pollen counts (Makra et al., 2010). As a proportional association, low mean temperature related slow life functions of the taxon, in accordance with factor (2), reduce pollen production. Parallel to this, long range transport together with its physical effect in factor (1) may have a higher weight in increasing pollen counts than the physiological factor through its decreasing effect. A positive association between wind speed and daily pollen ratios is confirmed by Gioulekas et al. (2004), Kasprzyk (2008) and Hernández-Ceballos et al. 2011). Reversely, an inverse relationship can be explained as follows. If mean temperature (T_{max}) is around its optimum for *Ambrosia*, it facilitates to produce a substantial amount of pollen. Then, wind transports away locally produced pollen and instead a smaller amount of pollen is transported from far away to the local environment. A further possibility for an inverse association can be traced back to an extremely high mean temperature (T_{max}), which can result in a significant decrease in available water, leading to a limited pollen production. In this case, transported pollen from far away may have a higher weight in total pollen amount then locally produced pollen.

5.4 Conclusions

When using factor analysis with special transformation, for all four categories examined in the three data sets, wind speed (V), rainfall (R) and temperature range (ΔT) were the most important parameters with 7, 5 and 5 significant associations with daily ratios of *Ambrosia* pollen counts, respectively. At the same time, minimum temperature (T_{min}) and irradiance (I) were the least important meteorological variables influencing the resultant variable. After dividing the total data set into two groups, a tendency of stronger associations between the meteorological variables and the pollen variable was found in the data set for which $A \leq 1.00$ (*Table 2*), compared to that for which $A > 1.00$. This is due to the difference in the behaviour of the plant to stand environmental stress. Namely, the data set for which $A \leq 1.00$ can be associated to lower summer temperatures with near-optimum phyto-physiological processes, while the category of $A > 1.00$ is involved with high and extreme high temperatures modifying life functions and, hence, interrelationships of the meteorological and pollen variables (*Tables 1-3*) (Csépe et al., 2012a; Matyasovszky et al., 2012b; Makra et al., 2014c).

6. The influence of extreme high and low temperatures and precipitation totals on pollen seasons of Ambrosia in Szeged, Southern Hungary

6.1 Introduction

We analyzed the relationship between pollen characteristics of *Ambrosia* and meteorological variables, furthermore between the rank of ordered pollen characteristics of *Ambrosia* and the rank of ordered annual values of meteorological variables for Szeged in Southern Hungary.

6.2 Results

Correlations between the pollen characteristics and the cumulated daily values of meteorological variables (temperature and precipitation) are summarised *in Table 4*. For *Ambrosia*, only temperature related associations are important. In a first approach, correlations were determined for every year, and then they were computed for the three warmest and coldest as well as for the three wettest and driest years (extreme years), respectively (*Table 4*). This is done because correlating the 14 data pairs the role of warmest/coldest and wettest/driest years can be lost as correlation measures the overall relationship between the entire set of data pairs. Taking the three warmest and coldest (wettest and driest) years from the data sets, the correlation based on just the 6 most extreme years is tailored to extremes. When considering every year, the correlation between the annual peak pollen concentration (APC) and temperature is inversely proportional. For the extreme years, both the total annual pollen amount (TPA) and the annual peak pollen concentration (APC) are in substantial negative connection with temperature (*Table 4; Figs. 9-10*).

Table 4 Correlations between daily *Ambrosia* pollen characteristics and cumulated daily values of meteorological variables. TPA: Total Pollen Amount during the pollen season; APC: Annual Peak Concentration; PS: Start of the Pollen Season; PS: End of the Pollen Season, DPS: Duration of the Pollen Season.

(**bold**: non-zero correlations, in parentheses with no higher than 10% probability levels)

(Csépe et al., 2012b; Makra et al., 2012b)

Ambrosia pollen characteristics	Temperature		Precipitation	
	Every year	*6 years	Every year	*6 years
TPA	-0.39	**-0.81** (5%)	0.15	0.14
APC	**-0.49** (8%)	**-0.90** (1%)	0.43	0.67
SPS	0.16	0.05	0.39	0.56
EPS	-0.25	-0.22	0.00	0.06
DPS	-0.28	-0.32	-0.23	-0.42

*6 years: the three warmest / coldest and the three wettest / driest years, respectively.

Correlations between the rank of pollen characteristics and the rank of years based on cumulated temperature and precipitation were calculated for *Ambrosia* since the rank correlation is less sensitive than the correlation to outliers that are in the tails of the sample. This is important when analysing extreme years as they correspond to the tail areas of the sample. Specifically, only 5 significant correlations can be observed in *Table 4*, but 8 rank correlations are significant in *Table 5*. This might be due to the smaller sensitivity of the rank correlation to outliers, or the relationship is possibly not linear.

For *Ambrosia*, only temperature related correlations are relevant. When considering every year, the rank of annual peak concentrations (APC) is inversely proportional to the rank of the annual temperature data. However, for the extreme years, the ranks of both the total pollen amount (TPA) and the APC are negatively associated with the rank of the annual temperature data. In more detail, in the warmest year (2003), the TPA was the 2nd smallest and the APC was the 3rd smallest. In the coldest year (2001), the TPA was the 2nd highest and the APC was the 3rd highest (*Table 5; Figs. 9-10*).

Table 5 Correlations between the rank of daily *Ambrosia* pollen characteristics and the rank of years based on cumulated daily values of temperature and precipitation. TPA: Total Pollen Amount during the pollen season; PC: Annual Peak Concentration; PS: Start of the Pollen Season; EPS: End of the Pollen Season, DPS: Duration of the Pollen Season. (**bold:** non-zero correlations, in parentheses with no higher than 10% probability levels) (Csépe et al., 2012b; Makra et al., 2012b)

Ambrosia pollen characteristics	Temperature		Precipitation	
	Every year	*6 years	Every year	*6 years
TPA	-0.39	**-0.88** (1.8%)	0.24	0.28
APC	**-0.51** (6%)	**-0.97** (0.2%)	0.38	0.61
SPS	0.20	0.09	0.17	0.26
EPS	-0.27	-0.07	-0.07	-0.02
DPS	-0.35	-0.20	-0.15	-0.20

*6 years: the three warmest / coldest and the three wettest / driest years, respectively.

Interestingly, the pollen season of *Ambrosia* falls to the driest period of summer in Hungary. Extreme warm condition can limit the pollination of *Ambrosia* especially in the lack of water, namely even this desert-origin plant group tries to preserve the water in its body. The lack of precipitation, even the occurrence of arid months before the usual late July-August pollen season may lead to a decrease in its pollen production in its main pollination period. High temperatures are accompanied with low precipitation, which occurred in the warmest year (2003), as well. So in warm years *Ambrosia* concentrates on its survival, rather than on propagation. Cooler years involve high precipitation in early summer or even in late spring (May-July). As an example, in 2010, the far above average May-July precipitation in Szeged region helped the increase of the *Ambrosia* population even in natural open sand vegetation types forming belt around depressions (*Figs. 9-10*).

6.3 Discussion

A moderate warming is favourable for *Ambrosia* (Ziska et al., 2011). The increase of mean temperature for the warm-tolerant *Ambrosia*, especially in summer time (August), can restrict its ability to pollinate, since the plant concentrates on preserving water and maintaining its vegetative life functions rather than its generative functions. This is in accordance with the negative association between its pollen count characteristics (TPA and APC) and temperature (*Tables 4-5*). 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 may be awaited especially on sand soils (Deák, 2010) in spite of the expected warming and drying summers in the Carpathian basin (Bartholy et al., 2008).

Concerning statistical approaches to forecast the pollen season of *Ambrosia*, Laaidi et al. (2003) applied two models, namely (1) summing the temperatures and (2) a multiple regression on 10-day or monthly meteorological parameters (minimum-, maximum- and mean air temperature, rainfall, relative humidity, sunshine duration and soil temperature), for predicting the start and the duration of the pollen season of *Ambrosia* for Lyon, France. The start of the pollen season (SPS) was predicted with both methods and the results were more accurate when applying the regression method (the errors between the predicted and the observed SPS ranged from 0 to 3 days). The duration of the pollen season was predicted by a regression model producing errors ranging from 0 to 7 days. Our method is partly similar to that of Laaidi et al. (2003) as we considered cumulated daily values of meteorological variables (temperature and precipitation) when correlating them with the pollen characteristics (TPA and APC).

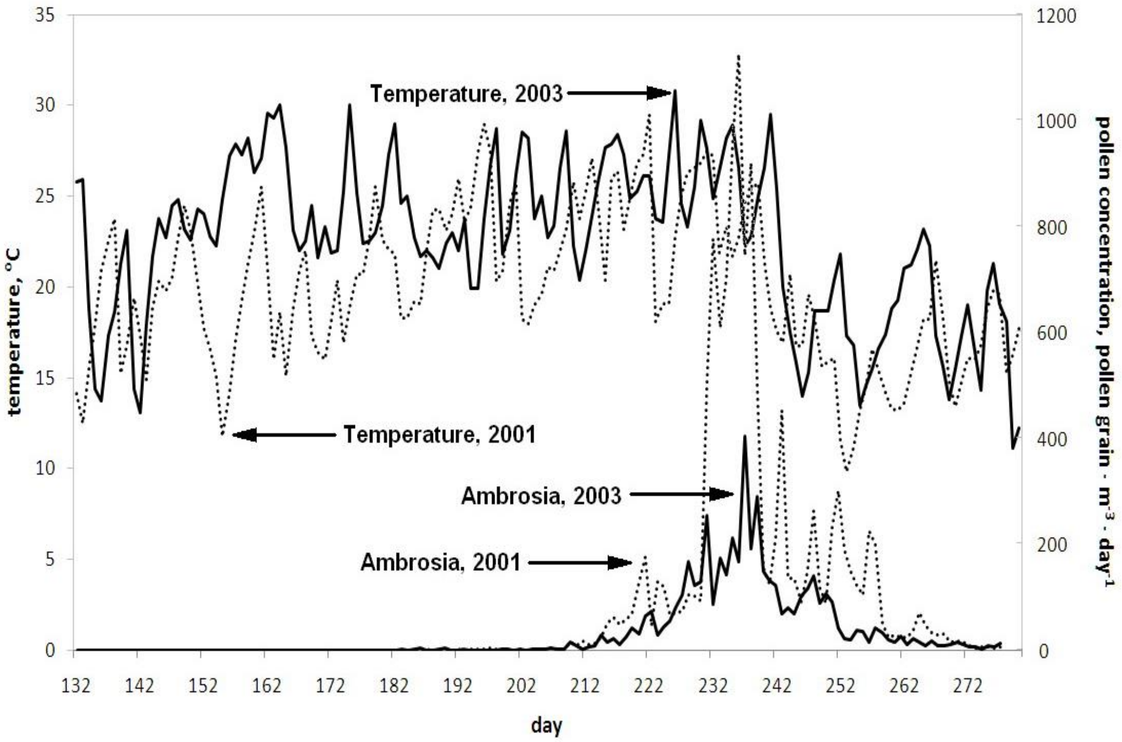


Fig. 9 Daily pollen concentrations of *Ambrosia* in years with extreme temperature (days of the year examined: 132-280; warmest year 2003, coldest year: 2001) (Csépe et al., 2012b; Makra et al., 2012b)

Deen (1998) showed that the rate of development of common ragweed increased with temperature. Furthermore, strong associations of *Ambrosia* pollen counts with temperature and rainfall have been determined by several authors. Pollen counts were found to increase with temperature and decrease with rainfall for *Ambrosia* (Bartková-Ščevková, 2003; Makra et al., 2004; Peternel et al., 2006; Piotrowska and Weryszko-Chmielewska, 2006; Kasprzyk, 2008; Ščevková et al., 2010). In a more detailed study, Makra et al. (2011) found that an association measure is negative between the annual cycles of the daily slopes of *Ambrosia* and Poaceae pollen concentration trends on one hand and the annual cycles of the daily slopes of mean temperature trends on the other. This measure is positive between the above mentioned slopes of Poaceae pollen counts and rainfall. Laaidi et al. (2003) found that an increase in temperature implied an earlier start of the *Ambrosia* pollen season. Regarding the pollen season of *Ambrosia* a tendency for a later start can be observed (Makra et al., 2011b).

The heat weave 2003 analyzed e.g. by Gehrig (2006) modified the start, end, as well as the duration of the pollen season only by 1-2 days for *Ambrosia*, but influenced the pollen concentrations substantially in Szeged. Compared to the mean values of the remaining years, sizeable reduction of annual total pollen counts of *Ambrosia* (-41.6%) can be observed in 2003. However, annual peak pollen counts (annual maximum daily pollen counts) changed not clearly in 2003 compared to the mean values of the remaining years. Namely, for *Ambrosia* (-9.8%) a slight decrease was observed.

Based on our data set, *Ambrosia* is sensitive either to temperature or to precipitation. On the whole, due to a warming and drying climate expected in the Carpathian Basin (Bartholy et al., 2008) pollen count characteristics (TPA and APC) indicate a decrease for *Ambrosia*. Habitat of *Ambrosia* will increase, due to a change in land use. This is expected to have a less significant effect on the pollen release than heat stress in hot summers, which restricts the ability of *Ambrosia* to pollinate. To be more specific, it would be important to distinguish the changes in atmospheric concentrations of pollen resulting from the effect of climate and the long-term changes, which may result from land use changes. An attempt can be made to separate these two components: the effect of climate can be characterised by meteorological variables, while land use changes can be described by changes in the ratios of agricultural areas, industrial areas, urban areas, forestries, meadows, vineyards, orchards and fallows. Applying an appropriate statistical procedure (such as factor analysis with special transformation) the load of both climate related and land use related components of atmospheric pollen concentrations can be estimated. However, information on changes in land use is only available for years 1990, 2000 and 2006 in CORINE Land Cover Database http://www.eea.europa.eu/publications/COR0-landcover) and, hence, such a statistical procedure cannot be performed.

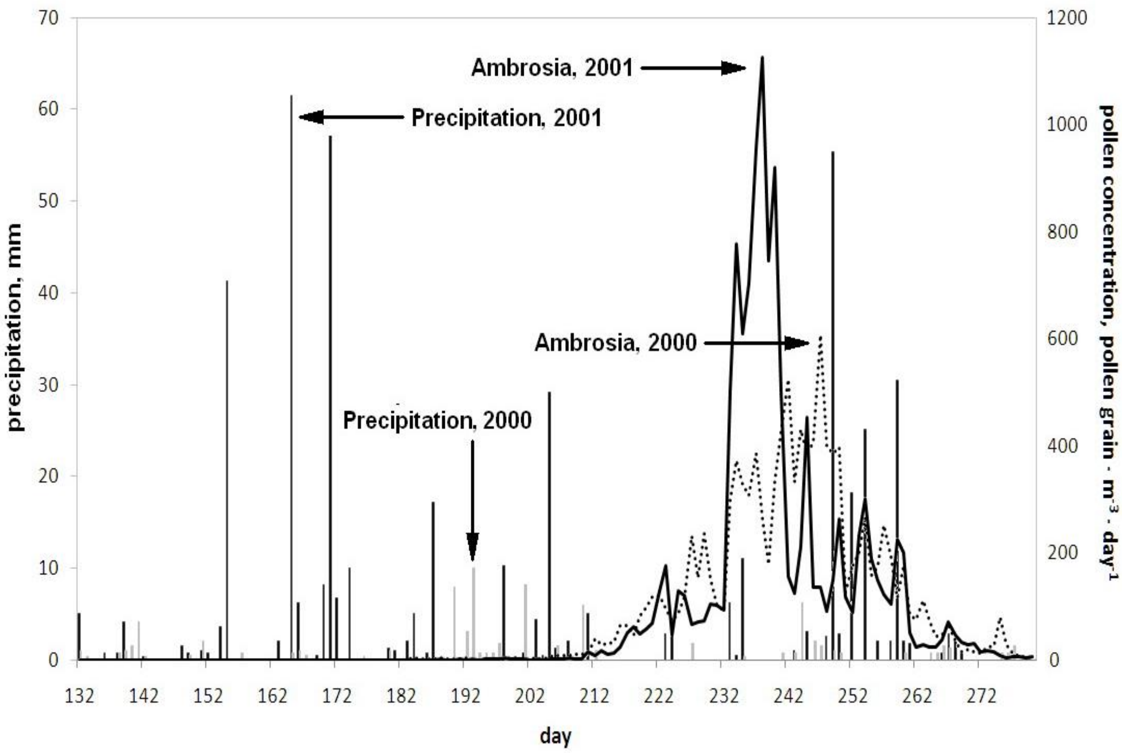


Fig. 10 Daily pollen concentrations of *Ambrosia* in years with extreme precipitation (days of the year examined: 132-280; wettest year: 2001, driest year: 2000) (Csépe et al., 2012b; Makra et al., 2012b)

6.4 Conclusions

Correlation analysis between the original variables and between their ranks was performed in the study. Both Pearson correlations and Spearman rank correlations were calculated since the rank correlation is less sensitive than the correlation to outliers that are in the tails of the sample. This is important when analysing extreme years as they correspond to the tail areas of the sample. Our results suggest that *Ambrosia* is sensitive either to temperature or precipitation. This taxon is reversely related to temperature (negative correlations). On the whole, due to a warming and drying climate, pollen count characteristics (TPA and APC) indicate a decrease for *Ambrosia*.

Based on the daily pollen counts of *Ambrosia* depending on both extreme temperatures (*Fig. 9*) and extreme precipitations *(Fig. 10*), we came to the conclusion that the coldest and the wettest years (*Figs. 9-10*) highly facilitate its pollen production.

Concerning spatial distribution, abundance and pollen release of *Ambrosia*, only effect on pollen release is based on the current study, while inferences about the effects on abundance and distribution are based on other sources. Increasing temperature may benefit the first two, while it interferes pollen production in the lack of rainfall. If landscape use alters, the potential abundance and distribution of *Ambrosia* can substantially modify. Nevertheless, this taxon can give a special response to the yearly changing weather conditions (see its pollen counts due to the warmest/driest and wettest/driest years; *Figs. 9-10*). Although overall trends of its pollen counts can be explained partly by landscape use changes, seasonal changes reflect weather conditions, which can enhance or suppress (hide, blunt) the overall trends. The genetic background of *Ambrosia* gives a special response to the changing weather conditions that can determine its potential distribution influenced by landscape use.

Since the analysis covers a rather short time span of 14 years for investigating the climate-pollen relationship, results should be considered as indications rather than definite conclusions (Csépe et al., 2012b; Makra et al., 2012b).

7. Estimating extreme daily pollen loads for Szeged, Hungary using previous-day meteorological variables

7.1 Introduction

In order to determine the association between meteorological variables on one hand and *Ambrosia* pollen load as well as the total pollen load excluding *Ambrosia* pollen on the other, previous-day values of five meteorological variables (mean temperature, mean global solar flux, mean relative humidity, mean sea-level pressure and mean wind speed) and actual-day values of the two pollen variables were considered.

7.2 Results and Discussion

7.2.1 Factor analysis with special transformation and *t*-test

After performing the two factor analyses, 4 factors were retained both for the pollen season of *Ambrosia* and the pollen season of remaining pollen excluding that of *Ambrosia*. In order to calculate the rank of importance of the explaining variables (meteorological parameters) for determining the resultant variable (pollen variables), loadings of the retained factors were projected onto Factor 1 with a special transformation (Jahn and Vahle, 1968) (*Tables 6-7*).

Table 6 Special transformation. Effect of the explanatory variables on *Ambrosia* pollen load and the rank of importance of the explanatory variables on their factor loadings transformed to Factor 1 for determining the resultant variable (rank 1 = highest weight, i.e. the most important meteorological variable; rank 5 = lowest weight, i.e. the least important variable) (thresholds of significance: *italic:* $x_{0.05} = 0.068$; **bold:** $x_{0.01} = 0.090$) (Csépe et al., 2012c; Matyasovszky and Makra, 2012)

Variables	weight	rank
Ambrosia (pollen$\cdot$m$^{-3}\cdot$day^{-1})	1.000	–
Temperature (°C)	**0.153**	1
Global solar flux (W$\cdot$m^{-2})	**0.136**	3
Relative humidity (%)	**-0.110**	4
Air pressure (hPa)	**-0.143**	2
Wind speed (m$\cdot$s^{-1})	0.045	5

It is found that except for wind speed, the remaining four meteorological variables display significant associations with *Ambrosia* pollen load. Temperature and global solar flux indicate positive proportional, while air pressure and relative humidity inversely proportional associations with *Ambrosia* pollen loads. Explaining variables in decreasing order of their substantial influence on *Ambrosia* pollen load are temperature, air pressure, global solar flux, and relative humidity (*Table 6*).

Table 7 Special transformation. Effect of the explanatory variables on total pollen load excluding *Ambrosia* pollen and the rank of importance of the explanatory variables on their factor loadings transformed to Factor 1 for determining the resultant variable (rank 1 = highest weight, i.e. the most important meteorological variable; rank 5 = lowest weight, i.e. the least important variable)
(thresholds of significance: *italic:* $x_{0.05} = 0.041$; **bold**: $x_{0.01} = 0.054$)
(Csépe et al., 2012c; Matyasovszky and Makra, 2012)

Variables	weight	rank
Total pollen excluding *Ambrosia* (pollen·m^{-3}·day^{-1})	1.000	–
Temperature (°C)	**0.188**	3
Global solar flux (W·m^{-2})	**0.237**	2
Relative humidity (%)	**-0.276**	1
Air pressure (hPa)	**-0.068**	5
Wind speed (m·s^{-1})	**0.121**	4

The remaining pollen load excluding that of *Ambrosia* indicates notable association with all five meteorological variables (*Table 7*). The signs of the connections between the meteorological parameters and the remaining pollen are the same as they are between the meteorological parameters and *Ambrosia* pollen (*Tables 6-7*). The meteorological variables thus affect the two pollen variables similarly despite their different pollen seasons. Explaining variables in decreasing order of their influence are relative humidity, global solar flux, temperature, wind speed and air pressure. Importance of the individual meteorological parameters based on their factor loadings differ in determining the two pollen variables due to their different characteristics including different length of pollen seasons and different climate requirements (*Tables 6-7*).

Table 8 Results of *t*-test. Significance levels for differences between means of meteorological variables corresponding to below and above the *p* quantiles q_p of pollen loads. Symbols x, xx, xxx and xxxx refer to the 10%, 5%, 1% and 0.1% probability levels, respectively.
T - temperature, G - global solar flux,
RH - relative humidity, P - air pressure,
W - wind speed.
(Csépe et al., 2012c; Matyasovszky and Makra, 2012)

			Ambrosia			
p	90%	80%	70%	10%	20%	30%
	q_{90}=1016	q_{80}=552	q_{70}=348	q_{10}=4	q_{20}=12	q_{30}=28
T	xx	xxx	xxxx	xxx	x	xx
G	xxx	xxxx	xxxx	x		
RH		xxx	xxxx		x	xx
P	xxxx	xx	xxx	xxxx	xxxx	xxxx
W				xx		
			Total pollen excluding *Ambrosia*			
p	90%	80%	70%	14.65%	20%	30%
	q_{90}=333	q_{80}=245	q_{70}=188	$q_{14.65}$=1	q_{20}=17	q_{30}=50
T		xxxx	xxxx	xxxx	xxxx	xxxx
G	xx	xxxx	xxxx	xxxx	xxxx	xxxx
RH	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
P	x	xxx	xxx	xxx	xxx	xxx
W	xxx	xxxx	xxxx	xxxx	xxxx	xxxx

The *t*-test shows rather significant differences between means of meteorological variables corresponding to below and above the quantiles of pollen loads excluding *Ambrosia* (*Table 8*) potentially due to the annual trends in both the meteorological elements and the pollen load. Here 14.65% is used instead of 10% as the relative frequency of zero loads is 14.65%. However, similar differences are less significant for the load of *Ambrosia* pollen mainly for wind speed and partially for low quantiles (*Table 8*). This might partly due to the fact that annual trends are not so characteristic during the relatively short pollen season of *Ambrosia*. One may suspect, therefore, that these highly significant differences are found due to just the annual cycles inherent in both the meteorological variables and pollen concentrations.

Factor analysis gave a first insight into the relationship between pollen load variables and meteorological variables and the *t*-test showed, the possibility of distinguishing between extreme and non-extreme pollen events using meteorological elements as explaining variables.

7.2.2 NN technique

In order to clarify whether the 5 meteorological elements as explaining variables are informative to discriminate between extreme and non-extreme pollen events an NN technique was applied. The optimal time window h is 3 days and 5 days for *Ambrosia* pollen load and total pollen load excluding *Ambrosia* pollen, respectively. The choice of such a small window for *Ambrosia* pollen is reasonable because the pollen load varies in a very wide range (from 0 to 5540 in the 8 years) during a relatively short pollen season. In contrast, the load of the remaining pollen varies in a narrower range (from 0 to 3020 in the 8 years) during a three times longer period. The optimal number k of nearest neighbours is 7 for *Ambrosia* pollen and 5 for the remaining of pollen, respectively. The larger value of k for *Ambrosia* seems to balance the narrower time window. Values of h and k were determined as to minimise the number of false decisions only for events exceeding or not exceeding the quantiles corresponding to $p_M = \max\{p, 1-p\}$ or $p_m = \min\{p, 1-p\}$, respectively, as there is a tendency to underestimate these events and overestimate the complementary events.

Table 9 Percentages of cases when *Ambrosia* pollen load is above and below its quantiles corresponding to probability p. (A quantile assigned to probability p is the value below which the pollen load occurs with relative frequency p.) Values in columns include percentages of estimated cases against observed cases (rows). Percentages in parentheses show relative frequencies of all decisions corresponding to Above/Below events under p-quantiles. Estimation is obtained with the Nearest Neighbour technique.
(Csépe et al., 2012c; Matyasovszky and Makra, 2012)

Set	p							
	80%		70%		20%		30%	
Learning	Above (21.1%)	Below (78.9%)	Above (31.1%)	Below (68.9%)	Above (82.2%)	Below (17.8%)	Above (72.6%)	Below (27.4%)
Above	77.2%	22.8%	87.1%	12.9%	94.4%	5.6%	94.8%	5.2%
Below	7.2%	92.8%	7.4%	92.6%	27.8%	72.2%	16.8%	83.2%
Verification	Above (20.2%)	Below (79.8%)	Above (30.1%)	Below (69.9%)	Above (84%)	Below (16%)	Above (73.4%)	Below (26.6%)
Above	73.7%	26.3%	85.7%	4.3%	94.9%	5.1%	95.5%	4.5%
Below	6.7%	93.3%	7.6%	92.4%	31.2%	68.8%	18.5%	81.5%

Tables 9 and 10 compare the observed below or above quantile events to events obtained from NN decisions. Quantiles p=10% and 90% are not included here because the number of events exceeding the quantile of 90% and not exceeding that of 10% is strongly underestimated even with the optimal time window and the number of nearest neighbours. The percentage of correct decisions is slightly over 30% for this case, while the similar percentage for complementary events (not exceeding the quantile of 90% and exceeding that of 10%) is around 97–99%. The procedure, however, works quite well for quantiles of 20% and 80%, and even better for those of 30% and 70%. The question is whether pollen loads corresponding to the quantiles of 20–30% and 70–80% can be labelled extremes. The answer is yes when taking into account the clinical threshold of pollen load. Specifically, Kadocsa et al. (1991) detected *Ambrosia* pollen sensitization over 10 pollen grains m^{-3} air in Szeged. The quantile of 30% (pollen load of 28 for *Ambrosia*, *Table 8*) corresponds to 7 pollen grains / m^3 air that approximately fit the limit of 10 pollen grains / m^3 air concentration being a clinical threshold for sensitive people (Kadocsa et al., 1991). In contrast, the quantile of 80% accompanied with pollen load 552 for *Ambrosia* (*Table 8*) is well above the clinical threshold of pollen load and hence this value indicates serious adverse effects for those being sensitive for respiratory ailments.

Table 10 Percentages of cases when total pollen load except for *Ambrosia* pollen is above and below its quantiles corresponding to probability *p*. (A quantile assigned to probability *p* is the value below which the pollen load occurs with relative frequency *p*.) Values in columns include percentages of estimated cases against observed cases (rows). Percentages in parentheses show relative frequencies of all decisions corresponding to Above/Below events under *p*-quantiles. Estimation is obtained with the Nearest Neighbour technique.
(Csépe et al., 2012c; Matyasovszky and Makra, 2012)

Set	*p*							
	80%		70%		20%		30%	
Learning	Above (20.4%)	Below (79.6%)	Above (29.3%)	Below (70.7%)	Above (79.4%)	Below (30.6%)	Above (71.1%)	Below (28.9%)
Above	54.4%	45.6%	68.2%	31.8%	95.3%	4.7%	96%	4%
Below	12%	88%	12.7%	87.3%	15.3%	84.7%	13%	87%
Verification	Above (20.4%)	Below (79.6%)	Above (29.6%)	Below (70.4%)	Above (80%)	Below (20%)	Above (70.8%)	Below (29.2%)
Above	54.2%	45.8%	68.1%	31.9%	95.8%	4.2%	95.8%	4.2%
Below	11.4%	88.6%	13.1%	86.9%	16.7%	83.3%	12.5%	87.5%

The relative frequency of the number of decisions for exceeding the quantiles of 80%, 70%, 20% and 30% is 21.1%, 31.1%, 82.2% and 72.6% respectively in the learning set, and 20.2%, 30.1%, 84% and 73.4% respectively in the test set for *Ambrosia* (*Table 9*). Similar relative frequencies for the remaining pollen are 20.4%, 29.3%, 79.4% and 71.1% for the learning set and 20.4%, 29.6%, 80.0% and 70.8% for the test set, respectively (*Table 10*). These numbers explain that the NN procedure avoids substantial under- or overestimation of event frequencies defined by the above quantiles especially for the pollen load without *Ambrosia*. The relative frequency of good decisions for exceeding / not exceeding the different quantiles show that the five meteorological elements as explaining variables are informative to discriminate between extreme and non-extreme pollen events. Note that the larger the percentages in above-above or below-below rows-columns in *Tables 9 and 10* the better the estimation is delivered by the NN technique.

Explaining variables in decreasing order of their influence on *Ambrosia* pollen load are temperature, global solar flux, relative humidity, air pressure and wind speed, while on the load of the remaining pollen are temperature, relative humidity, global solar flux, air pressure and wind speed. These orders were determined with the help of the numbers of good decisions for events of exceeding or not exceeding the quantiles corresponding to p_M or p_m. Namely, the NN technique was performed with omitting a specific explaining variable from all of the five variables. This narrower set of variables delivered fewer good decisions than the entire set of variables. The larger the effect of this underlying variable on good decisions the larger its influence is on the extreme pollen load. Performing this procedure with each variable provided an order of their importance. Note that the rank of importance of the meteorological elements determining the two pollen variables partly differ from the above orders when using factor analysis with special transformation. Its reason is that factor analysis explores linear relationships among variables coming from two sources. Namely, the relationship between two variables is partly due to the similarity (or dissimilarity) of their annual cycles but partly due to the correlation between variations around these annual cycles. Hence, factor analysis shows an overall picture, while the NN technique reflects the relationship between daily variations of explaining variables and pollen loads excluding the annual cycles when using time windows. Additionally, application of the NN procedure allows a non-linear relationship between explaining variables and pollen loads.

7.2.3 Comparison of similar studies and techniques

Finding relationships between pollen level characteristics and meteorological elements has a vast amount of literature, but extreme daily pollen concentration has received so far a relatively low attention. For instance, besides studies mentioned in the Introduction section, Antepara et al. (1995) found that daily peak pollen values higher than 50 grains$\cdot$m^{-3} coincide with average daily temperatures of 18.7±3°C. The total severity of the pollination seems to depend on the rainfall prior to the start of the pollen season. According to their model, during pollination, the days with the above temperature and an absence of rainfall between 4 and 12 hours will exceed the above pollen threshold. Stach et al. (2007) found that winds coming from the east and northeast were dominant on the peak Artemisia pollen days in Poznaň, Poland. Other authors in Europe (Wahl and Puls, 1989; Spieksma et al., 2000) have also indicated high influence of wind on daily peak values of Artemisia species pollen. Nevertheless, de Morton et al. (2011) developed a model for the short and long-term prediction of atmospheric grass pollen concentrations. They found that extreme pollen events are associated with anomalous downward velocities over Melbourne. This has been demonstrated for two completely different atmospheric conditions leading to extreme pollen count increase in Melbourne.

These results, however, come from case studies or by-products of studies addressing questions not directed at extreme pollen levels. For instance, as a multiple linear regression model is defined on the entire range of observed data one might hope that such a model is able to reproduce observed extremes, too. Unfortunately, estimates from a regression model are most accurate (have smallest variances) at moderate values and are weakening (have increasing variances) towards high and low values. In other words, such techniques are not tailored to handling extremes, and thus a different methodology is needed to estimate extreme pollen load events. Such a method can be the NN technique applied in this paper (Csépe et al., 2012c; Matyasovszky and Makra, 2012).

8. Plants remember past weather: a study for atmospheric pollen concentrations of Ambrosia

8.1 Introduction

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. In this section we separate the weight of the current and past climate conditions in determining the pollen concentrations of *Ambrosia* for the Szeged region in Southern Hungary applying two procedures, namely multiple correlation and factor analysis with special transformation.

8.2 Results and Discussion

Multiple correlations of daily pollen counts of *Ambrosia* on the daily values of the meteorological variables are determined (*Fig. 11*). 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 found that multiple correlations are quite modest and do not necessarily exhibit annual cycles during the pollen seasons of *Ambrosia* (*Fig. 11*). 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 higher than 10%) based on *t*-test, so that correlations should be considered constant (solid line).

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 *Fig. 12*. 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 were carried out. Namely, in total 25,296 procedures were performed for every day of the pollen season with (1) every accumulation length for *Ambrosia* in the past, and another 25,296 procedures were carried out for every day of the pollen season with (2) every individual day for *Ambrosia* in the past. Hence, altogether 50,592 factor analyses with special transformations were performed. However, due to the smaller variability of the associations, only those for (1) are analyzed in the dissertation (*Fig. 3a*).

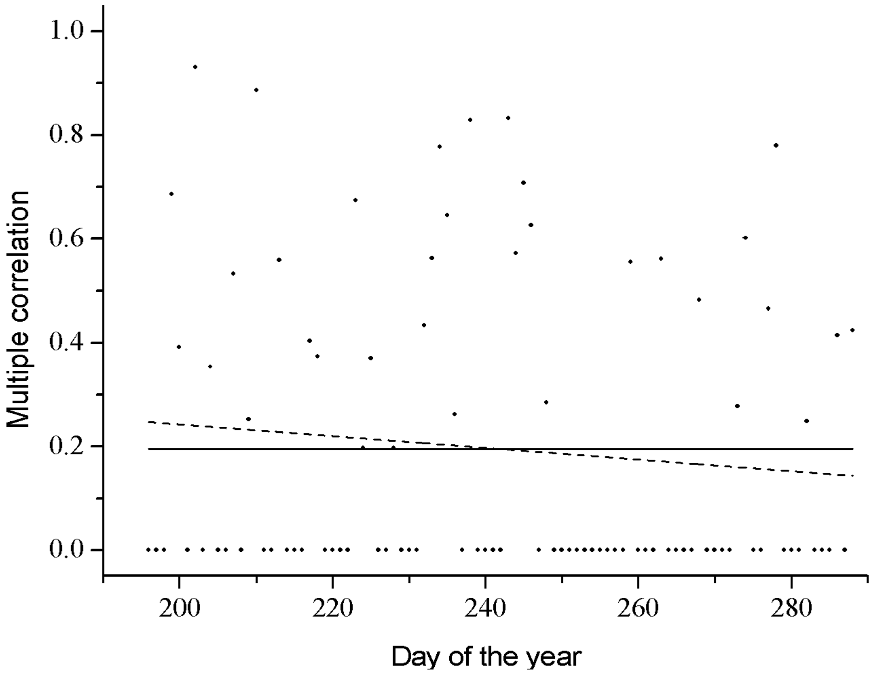
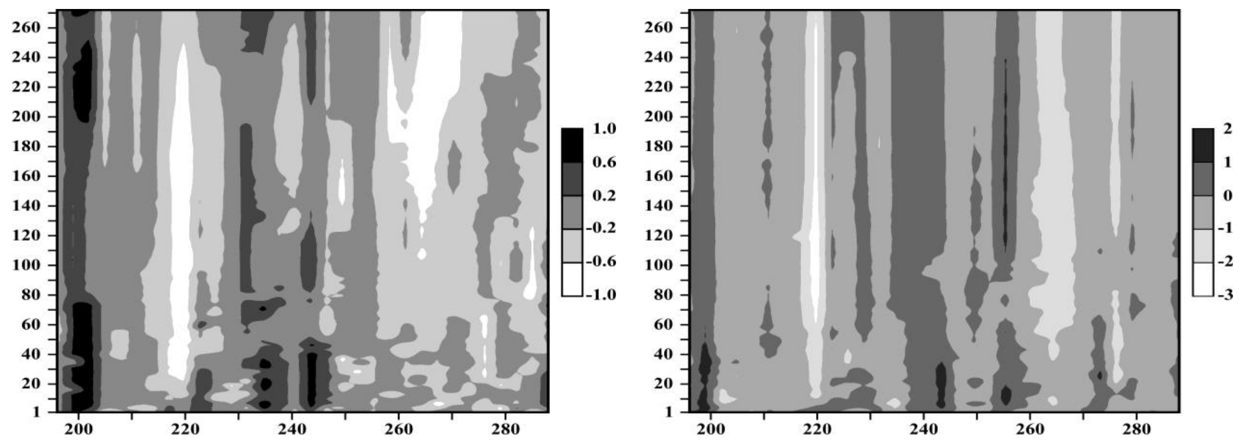


Fig. 11 Multiple correlations of daily *Ambrosia* pollen counts on simultaneous values of daily meteorological variables as a function of the day of the year (Matyasovszky et al., 2014a;)

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.

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*.



Ambrosia, multiple correlations *Ambrosia,* factor loadings

Fig. 12 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), *Ambrosia* (Matyasovszky et al., 2014a)

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. 12*). 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.

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 *(Fig. 12,* left panel). 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, 1999) (*Fig. 12*).

Mean temperature, relative humidity, global solar radiation and precipitation amount as the most important meteorological factors influencing pollen production of *Ambrosia* are confirmed by other authors (Bartková-Ščevková, 2003; Kasprzyk and Walanus, 2010; Ščevková et al., 2010; Sabariego et al., 2011; Aboulaich et al., 2013). In Hungary, due to a warming and drying climate, pollen count characteristics (total annual pollen amount and annual peak pollen concentration) indicate a decrease for *Ambrosia* (Makra et al., 2012b). Concerning extreme weather events, the coldest and the wettest years highly facilitate *Ambrosia* pollen production (Makra et al., 2012b). Furthermore, Matyasovszky et al. (2012) established a tendency to stronger associations between the meteorological variables and the ragweed pollen variable in the pre-peak pollen season, compared to the post-peak pollen season (late summer to early autumn) that is confirmed by Giner et al. (1999) and Laadi (2001). This is in accordance with the statement of Makra et al. (2014) who found that definitely stronger associations between the meteorological variables and the Poaceae pollen variable are found in the data sets for lower summer temperatures with near-optimum phyto-physiological processes compared to those for high and extreme high temperatures modifying life functions and, accordingly, interrelationships of the meteorological and pollen variables. This is due to the difference in the behaviour of the plants to stand environmental stress. The above findings are clearly confirmed by the decreasing multiple correlations of daily pollen counts on simultaneous values of daily meteorological variables towards the end of the pollen season for *Ambrosia*.

Herbaceous plants (for our case *Ambrosia*) are generally more sensitive to disturbances; however, they recover well faster compared to arboreal plants (Jones and 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 (http://www.eea.europa.eu/publications/COR0-landcover). 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.

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 dissertation 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., 2011b; Deák et al., 2013). Concerning the 4 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., 2011b; 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 for *Ambrosia* is shown in *Figs. 11–12*.

For us it was a really big challenge to find a way to show these associations for the readers. However, we think that at last we solved the task successfully. *Fig. 12* (1) show specific and unique "imprints" of *Ambrosia*; namely, it is characteristic to *Ambrosia* and, in turn, this taxon has its own "imprint"; (2) the here-mentioned "imprints" of *Ambrosia* received using the two methodologies are surprisingly similar.

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.

The analysis of the relationship of the past values of the meteorological elements with the actual pollen season is an issue of great importance in aerobiology. 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. Laaidi (2001) established in general that heat and enough rainfall to satisfy the water requirements during the month before pollination allow a plant to complete its development, and in particular its pollen production, and so pollinate earlier. 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. In Melbourne, Ong et al. (1997) used only the rainfall sum of July for developing a regression equation that predicted the beginning of grass pollination (which takes place between 20 October and 24 November) with a satisfactory precision of 76%. Käpylä (1984) and Galán et al. (1998) detected that diurnal pollen concentrations of trees were much more irregular without having a clear and recurrent annual pattern than those for herbaceous taxa. Furthermore, once anthesis has started in trees, it is relatively independent of weather variables (Käpylä, 1984). Emberlin and Norris-Hill (1991) established 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. Giner et al. (1999) associated 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. In order to group years according to the allergenic potential of airborne Poaceae pollen, Sánchez Mesa et al. (2005) separated winter variables from early spring variables when considering pre-season meteorological variables, due to the nature of the Mediterranean climate. However, this was a similar but not the same step applied in this study, namely separating the weight of the current and antecedent meteorological variables.

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. Namely, time dependent daily pollen concentrations are influenced by numerous other underlying processes, as well. 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 were omitted from further consideration. 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 *Ambrosia*.

Separation of the weight of the current and past climate conditions for *Ambrosia* 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 (Makra et al., 2014e; Matyasovszky et al, 2014a; 2014b).

9. Predicting daily ragweed pollen concentrations using Computational Intelligence techniques over two heavily polluted areas in Europe

9.1 Introduction

In this section we aimed at i) developing accurate forecasting models for operational use, ii) evaluating computational Intelligence (CI) methods that have not been previously applied for *Ambrosia* pollen, such as Multi-Layer Perceptron and regression trees and iii) obtaining a forecast of highest accuracy among CI methods based on input data of former prediction algorithms. Note that (1) data-driven modeling methods including neural networks have never been used in forecasting daily *Ambrosia* pollen concentration, (2) daily alarm thresholds are firstly predicted in the aerobiological literature; furthermore (3) algorithm J48 has never been used in palynological forecasts.

Calculations are pefortmed for two European cities, namely Lyon (Rhône Valley, France) and Szeged (Pannonian Plain, Hungary) as they represent heavily polluted areas with ragweed pollen in Europe (*Fig. 13*).

Both for Szeged and Lyon, the data were separated into two parts: the training set (1997–2004) to develop forecasting models, and the test set (2005–2006) to validate these models.

9.2 Results and Discussion

9.2.1 Performance evaluation

9.2.1.1 The weight of the influencing variables in determining a future day pollen level

The importance of the serial number of the day in the year, furthermore daily values of eight meteorological variables and *Ambrosia* pollen level were analysed in determining a future day pollen level for 1–7 days ahead using factor analysis with special transformation (*Tables 11–12*). When comparing the results very little similarity was received for the two cities. The importance of the serial number of the day of the year shows a tendency of higher weights towards increasing target days for both Szeged and Lyon; however, this effect is more remarkable for Szeged. From the meteorological influencing variables, only TR and *Ambrosia* pollen level showed similarly significant positive weights with values of the same magnitude in determining a future day pollen level (*Tables 11–12*). The weights of actual day *Ambrosia* pollen level emerge extraordinarily from all variables indicating its high significance for both cities. This confirms former findings according to which the most decisive influencing variable of all is actual day *Ambrosia* pollen level for assigning pollen levels 1–7 days ahead (Makra et al., 2011a; Makra and Matyasovszky, 2011).

Table 11 Special transformation, Szeged. Relevance of the influencing variables in defining the resultant variable (pollen levels) 1–7 days ahead and the rank of importance of the influencing variables for determining the resultant variable.
(thresholds of significance: *italic:* $x_{0.05}$ = 0.064; **bold:** $x_{0.01}$= 0.084) (Csépe et al., 2014a; 2014b).

[1]Day	Influencing variables																			
	[2]Day		[3]T_{mean}		[4]T_{max}		[5]T_{min}		[6]ΔT		[7]RH		[8]TR		[9]P		[10]WS		*Ambrosia*	
	weight	rank	weight	rank	weight	rank	weight	rank	weight	rank	weight	rank	weight	rank	weight	rank	weight	rank	weight	rank
+1	0.00	7	**0.13**	7	**0.14**	7	0.06	7	**0.10**	4	-0.01	6	**0.11**	7	*-0.07*	4	*0.07*	1	**0.96**	1
+2	-0.02	6	**0.16**	6	**0.17**	6	*0.07*	6	**0.11**	3	-0.02	3	**0.13**	6	-0.06	6	0.06	2	**0.93**	2
+3	-0.04	5	**0.18**	5	**0.19**	5	**0.09**	4	**0.12**	2	-0.02	2	**0.15**	5	*-0.08*	3	0.05	3	**0.90**	3
+4	-0.06	4	**0.20**	4	**0.21**	4	**0.09**	5	**0.15**	1	-0.03	1	**0.17**	1	*-0.07*	5	0.02	4	**0.87**	4
+5	*-0.08*	3	**0.21**	3	**0.21**	3	**0.14**	3	**0.09**	5	-0.01	5	**0.15**	4	-0.05	7	-0.01	5	**0.84**	5
+6	**-0.13**	2	**0.26**	2	**0.25**	2	**0.19**	2	*0.07*	6	0.00	7	**0.16**	3	**-0.10**	1	0.01	6	**0.81**	6
+7	**-0.17**	1	**0.29**	1	**0.27**	1	**0.25**	1	0.03	7	0.01	4	**0.16**	2	**-0.09**	2	0.00	7	**0.78**	7

[1]: target day of the forecast; [2]: serial number of the day in the year; [3]: daily mean temperature (°C); [4]: daily maximum temperature (°C); [5]: daily minimum temperature (°C); [6]: daily temperature range (°C); [7]: daily relative humidity (%); [8]: daily total radiation ($W \cdot m^{-2}$); [9]: daily mean air pressure (hPa); [10]: daily wind speed ($m \cdot s^{-1}$);

Table 12 Special transformation, Lyon. Relevance of the influencing variables in defining the resultant variable (pollen levels) 1–7 days ahead and the rank of importance of the influencing variables for determining the resultant variable.
(thresholds of significance: *italic:* $x_{0.05}$ = 0.064; bold: $x_{0.01}$= 0.084) (Csépe et al., 2014a; 2014b).

[1]Day	Influencing variables																			
	[2]Day		[3]T_{mean}		[4]T_{max}		[5]T_{min}		[6]ΔT		[7]RH		[8]TR		[9]P		[10]WS		*Ambrosia*	
	weight	rank	weight	rank	weight	rank	weight	rank	weight	rank	weight	rank	weight	rank	weight	rank	weight	rank	weight	rank
+1	0.05	2	**0.12**	1	**0.11**	1	**0.09**	5	*0.08*	1	**-0.14**	5	**0.17**	5	0.03	7	-0.02	7	**0.87**	1
+2	0.04	4	0.06	5	0.05	2	*0.07*	7	0.03	6	**-0.17**	3	**0.24**	2	**0.16**	2	**-0.11**	4	**0.71**	2
+3	0.01	6	0.05	7	0.04	4	*0.08*	6	0.01	7	**-0.18**	1	**0.26**	1	**0.16**	1	**-0.13**	2	**0.69**	4
+4	-0.01	7	0.06	6	0.03	7	**0.13**	4	-0.03	5	**-0.17**	2	**0.18**	4	**0.10**	3	**-0.09**	6	**0.70**	3
+5	-0.03	5	*0.07*	4	0.03	6	**0.14**	3	-0.03	4	**-0.15**	4	**0.19**	3	**0.10**	4	**-0.11**	3	**0.66**	5
+6	-0.05	3	*0.08*	3	0.04	5	**0.17**	2	-0.03	2	**-0.12**	6	**0.17**	6	**0.11**	5	**-0.10**	5	**0.62**	7
+7	*-0.07*	1	**0.09**	2	0.04	3	**0.17**	1	-0.03	3	**-0.11**	7	**0.10**	7	0.05	6	**-0.14**	1	**0.62**	6

[1]: target day of the forecast; [2]: serial number of the day in the year; [3]: daily mean temperature (°C); [4]: daily maximum temperature (°C); [5]: daily minimum temperature (°C); [6]: daily temperature range (°C); [7]: daily relative humidity (%); [8]: daily total radiation ($W \cdot m^{-2}$); [9]: daily mean air pressure (hPa); [10]: daily wind speed ($m \cdot s^{-1}$);

For Szeged, T_{mean}, T_{max} and ΔT indicate significant and substantially higher positive weights compared to Lyon. While the importance of RH and WS can be negligible for Szeged, these parameters show highly relevant negative associations in formation pollen levels 1–7 days ahead for Lyon. P shows significant negative and positive weights for Szeged and Lyon, respectively. The here-mentioned definite difference in the weights and signs of the influencing variables for the two cities can be explained by their different climate and relief. The temperate oceanic climate of Lyon with cool-to-warm summers and a uniform annual precipitation distribution confirms the role of humidity parameters (RH) here, while the location of the city in the Rhone valley on the foothills of High Alps emphasizes the weight of the wind (WS). The warm, temperate climate of Szeged with hot summers highlights the importance of the temperature parameters (T_{mean}, T_{max}, T_{min} and ΔT) and shows insignificant weights for the humidity (RH), while the central location of the city in the Pannonian Plain makes negligible the role of the wind (WS) (*Tables 11–12*).

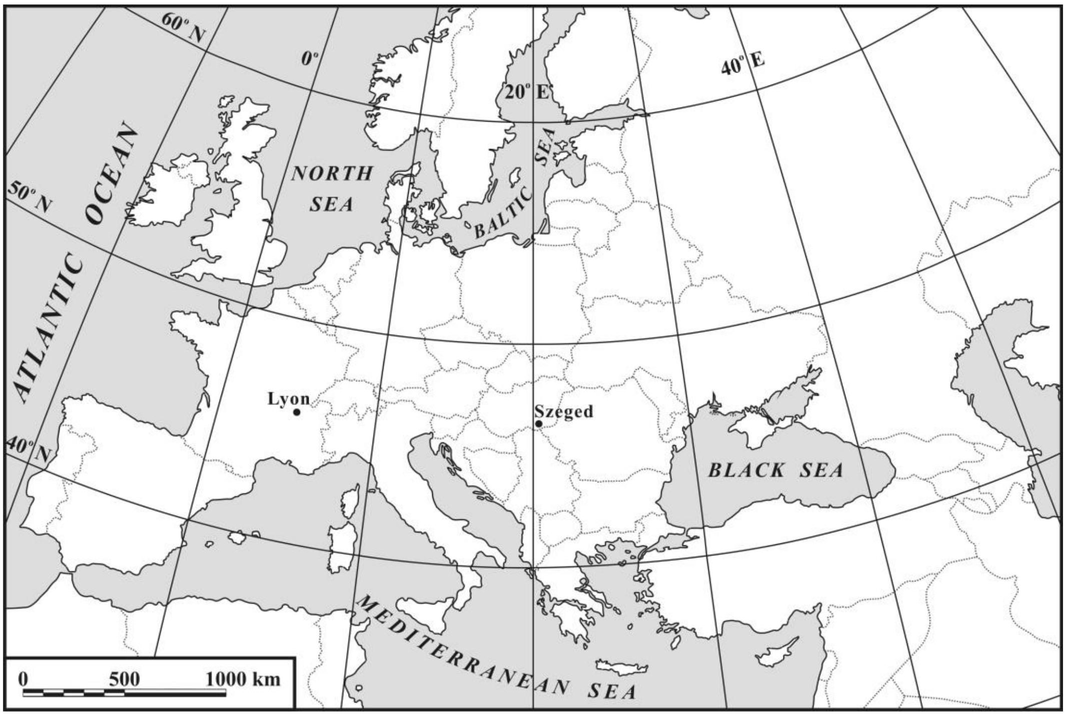


Fig. 13 The geographical positions of Lyon and Szeged (Csépe et al., 2014a; 2014b)

10.2.1.2 Performance of the forecasting models

The following statistical indices were used to compare the performance of the models: (1) correlation coefficient as a measure of the strength; (2) Root Mean Square Error (RMSE) as a measure of the error in the forecast; and (3) Mean Absolute Error (MAE) as another measure of the error in the forecast.

For Szeged, MLP provides the best results for the forecasting horizon (1–7 days) that is confirmed by former studies (Sánchez-Mesa et al., 2002; Voukantsis et al., 2010). 1-day forecast indicates the best performance. This can be explained by the close association between the pollen concentrations of consecutive days and the predominant role of local pollen release in the measured pollen concentration in Szeged (Makra et al., 2010). The efficiency of MLPRegressor declines intensely when forecasting more than 2 days ahead due to its simpler construction (*Table 13; Fig. 14*). Considering decision trees, performance of REPTree decreases for >1-day forecasts, while DecisionStump provides an overall weak result for the forecasting horizon. MLPRegressor serves the best performance for 1 and 2-day ahead forecasts; however, when the forecasting horizon exceeds 2 days, the accuracy of the predictions sharply decrease. High values of RMSE and MAE can be attributed to the very high variability of the daily ragweed pollen concentrations. There are no periods in the pollen season that can be approximated linearly with high confidence. This is why M5P is not a reliable method for >2 days forecasts. Based on the scatter plots, when the forecasting horizon expands, (1) the accuracy of the forecast weakens and (2) the best method (MLP) increasingly underestimates the pollen concentration (*Fig. 14*). Note that for the remaining methods, under- and overestimation may occur at both the beginning and end of the pollen season. However, MLP underestimates consistently regardless the day of the pollen season and the length of the forecasting horizon. On the whole, all the methods analysed in the study (except for the simplest DecisionStump) perform well for 1 and 2-day ahead forecasts for Szeged. Note, however, that MLP provides correlation coefficient 0.96 even for 4-day forecast and the efficiency of the prediction does not decrease below r=0.90 even for 7-day forecast. For the remaining methods the accuracy of the forecasts for >2 days ahead indicate sharp decay (*Table 13; Fig. 14*).

Predicting alarm levels is another area of pollen forecasts. Their fast and efficient prediction serves a simple and easily traceable tool for sensitive people in preparing to days of high pollen load. In order to better predicting *Ambrosia* pollen alarm levels introduced for Hungary (Mányoki et al., 2011), the original 0-1 and 7–8 categories were aggregated. In the scatter plots of forecasting alarm levels for both Szeged and Lyon, the horizontal axis indicates the observed alarm level, while the vertical axis shows the forecasted alarm level. Starting from the actual day several alarm levels can be expected on the target day depending on the initial day, and the forecasts for the target day can result in different alarm levels. Note that with the increase of the forecasting horizon the uncertainty of the alarm level increases. The numbers beside the forecasted alarm levels indicate their total occurrences for the data set examined (*Figs. 14–15*).

MLP shows the best results for the alarm levels of Szeged. The decision tree based REPTree model provides better or similarly good performance than MLP since alarm levels form classes for which RAPTree is very sensitive. Besides these methods the simply constructed MLPClassifier, that has a faster run-time compared to MLP, is yet capable for predicting alarm levels with good performance. When forecasting 1-day alarm level, three methods (MLP, REPTree and MLPClassifier) indicate the same efficacy (*Table 14*). 1, 2 and 3-day ahead predictions of alarm levels perform well, while forecasts for >3 days ahead indicate substantial decrease for all the methods applied. Note that MLP provides good result even for a 5-day forecast, as well; whereas, the performance of DecisionStump is the worst due to the construction of the method: it carries out only one single split (*Table 14; Fig. 14*).

For Lyon, MLP provides the best performance of all the procedures. One-layer MLPRegressor is the least efficient and, similarly to the case of Szeged, DecisionStump is not capable for predicting alarm levels. As wind speed shows significant negative associations with the measured pollen concentrations for 1–7 days ahead (*Table 12*), this parameter strongly destroys the performance of the methods (*Tables 15–16; Fig. 15*).

The procedures perform well for Szeged, but they are not really efficient for Lyon. For the latter case, neither pollen concentrations nor alarm levels indicate definite annual course, due to the substantially smaller pollen concentrations, furthermore different climate and relief in Lyon compared to those of Szeged (*Tables 15–16*). Predictability of alarm levels for Lyon is quite weak that can be explained with the following reasons: (1) alarm levels introduced for Hungary cannot be applied well for Lyon due to the different distribution of pollen concentrations for the two cities, (2) structure of the association between the influencing and resultant variables are different for Szeged and Lyon (*Tables 11– 12; Tables 15–16; Fig. 15*).

Table 13 Statistical evaluation of the *Ambrosia* pollen concentration forecasting models for Szeged in terms of the correlation coefficient (r), the Root Mean Square Error (RMSE) and the Mean Absolute Error (MAE). T indicates the forecasting horizon (in days). (MLP: Multi-Layer Perceptron model, M5P: Regression tree model, REPTree: regression tree model, DecisionStump: decision tree model and MLPRegressor: Multi-Layer Perceptron model). (Csépe et al., 2014a; 2014b).

T	MLP			M5P			REPTree			DecisionStump			MLPRegressor		
(day)	r	RMSE	MAE	r	RMSE	MAE	r	RMSE	MAE	r	RMSE	MAE	r	RMSE	MAE
+1	0.99	45.08	17.11	0.98	52.34	18.60	0.95	63.69	24.25	0.75	128.86	78.95	0.97	60.89	20.28
+2	0.99	66.66	27.54	0.83	115.81	38.30	0.85	110.29	38.11	0.64	150.69	64.11	0.97	76.02	34.72
+3	0.98	80.08	33.79	0.82	117.62	46.30	0.80	123.15	45.26	0.63	152.21	64.09	0.61	153.23	56.85
+4	0.96	94.02	40.69	0.78	126.04	54.91	0.71	138.79	58.79	0.63	153.05	64.97	0.54	162.09	61.61
+5	0.94	111.30	50.43	0.59	153.11	73.12	0.69	143.99	59.74	0.62	154.44	65.28	0.42	175.27	73.71
+6	0.92	121.51	58.88	0.53	161.07	81.92	0.49	166.75	77.98	0.60	157.77	66.24	0.65	149.11	71.15
+7	0.90	127.13	63.34	0.43	172.45	83.79	0.43	174.15	75.35	0.60	157.97	66.34	0.54	161.88	80.57

Table 14 Statistical evaluation of the *Ambrosia* pollen alarm level forecasting models for Szeged in terms of the correlation coefficient (r), the Root Mean Square Error (RMSE) and the Mean Absolute Error (MAE). T indicates the forecasting horizon (in days). (MLP: Multi-Layer Perceptron model, J48: decision tree model, REPTree: decision tree model, DecisionStump: decision tree model and MLPClassifier: Multi-Layer Perceptron model). (Csépe et al., 2014a; 2014b).

T	MLP			J48			REPTree			DecisionStump			MLPClassifier		
(day)	r	RMSE	MAE	r	RMSE	MAE	r	RMSE	MAE	r	RMSE	MAE	r	RMSE	MAE
+1	0.98	0.37	0.14	0.94	0.70	0.44	0.98	0.40	0.16	0.74	1.32	0.92	0.98	0.37	0.14
+2	0.95	0.67	0.40	0.91	0.88	0.52	0.96	0.60	0.32	0.74	1.32	0.92	0.96	0.62	0.37
+3	0.96	0.67	0.38	0.87	1.01	0.63	0.90	0.93	0.58	0.74	1.32	0.93	0.90	0.94	0.53
+4	0.80	1.19	0.73	0.85	1.08	0.73	0.91	0.85	0.54	0.74	1.32	0.93	0.81	1.22	0.70
+5	0.94	0.77	0.46	0.79	1.26	0.87	0.92	0.78	0.46	0.73	1.32	0.94	0.82	1.14	0.78
+6	0.82	1.18	0.78	0.73	1.39	0.95	0.83	1.10	074	0.73	1.32	0.94	0.86	1.05	0.67
+7	0.76	1.36	0.88	0.72	1.41	0.93	0.77	1.32	0.92	0.73	1.32	0.95	0.74	1.39	1.02

Table 15 Statistical evaluation of the *Ambrosia* pollen concentration forecasting models for Lyon in terms of the correlation coefficient (r), the Root Mean Square Error (RMSE) and the Mean Absolute Error (MAE). T indicates the forecasting horizon (in days). (MLP: Multi-Layer Perceptron model, M5P: Regression tree model, REPTree: regression tree model, DecisionStump: decision tree model and MLPRegressor: Multi-Layer Perceptron model). (Csépe et al., 2014a; 2014b).

T	MLP			M5P			REPTree			DecisionStump			MLPRegressor		
(day)	r	RMSE	MAE	r	RMSE	MAE	r	RMSE	MAE	r	RMSE	MAE	r	RMSE	MAE
+1	0.96	33.53	12.73	0.97	28.26	11.62	0.70	48.99	15.89	0.81	45.88	18.39	0.36	62.09	22.44
+2	0.91	48.31	21.67	0.68	52.14	21.05	0.42	60.85	23.63	0.43	60.13	23.33	0.59	56.29	20.08
+3	0.81	53.59	24.74	0.64	55.12	22.76	0.57	56.42	20.21	0.43	60.88	25.20	0.33	62.86	25.72
+4	0.74	63.17	29.13	0.29	63.06	24.80	0.41	60.85	24.47	0.43	60.63	24.19	0.01	70.02	29.37
+5	0.64	58.82	26.67	0.19	65.15	26.80	0.42	59.91	22.83	0.35	62.18	25.65	-0.01	73.23	32.35
+6	0.78	55.92	24.81	0.43	59.93	23.81	0.33	62.05	24.75	0.35	62.15	25.54	0.01	72.99	32.16
+7	0.92	51.67	22.47	0.80	52.29	21.84	0.34	61.75	23.94	0.34	62.06	25.33	0.12	69.23	30.04

Table 16 Statistical evaluation of the *Ambrosia* pollen alarm level forecasting models for Lyon in terms of the correlation coefficient (r), the Root Mean Square Error (RMSE) and the Mean Absolute Error (MAE). T indicates the forecasting horizon (in days). (MLP: Multi-Layer Perceptron model, J48: decision tree model, REPTree: decision tree model, DecisionStump: decision tree model and MLPClassifier: Multi-Layer Perceptron model). (Csépe et al., 2014a; 2014b).

T	MLP			J48			REPTree			DecisionStump			MLPClassifier		
(day)	r	RMSE	MAE	r	RMSE	MAE	r	RMSE	MAE	r	RMSE	MAE	r	RMSE	MAE
+1	0.91	1.12	0.53	0.80	1.05	0.46	0.84	0.75	0.29	-	1.48	0.69	0.73	0.97	0.40
+2	0.65	1.31	0.62	0.35	1.67	0.85	0.52	1.22	0.48	-	1.48	0.70	0.51	1.20	0.58
+3	0.26	1.60	0.80	0.17	1.66	0.90	–	1.48	0.70	-	1.48	0.70	0.44	1.29	0.60
+4	0.39	1.41	0.67	0.63	1.07	0.49	0.47	1.33	0.63	-	1.48	0.70	0.45	1.35	0.60
+5	0.26	1.45	0.70	0.37	1.32	0.72	0.65	1.11	0.51	-	1.48	0.70	0.59	1.23	0.54
+6	0.46	1.40	0.68	0.38	1.28	0.61	0.52	1.23	0.52	-	1.48	0.70	0.31	1.30	0.68
+7	-	1.48	0.71	0.38	1.49	0.75	0.48	1.32	0.62	-	1.48	0.70	0.14	1.43	0.74

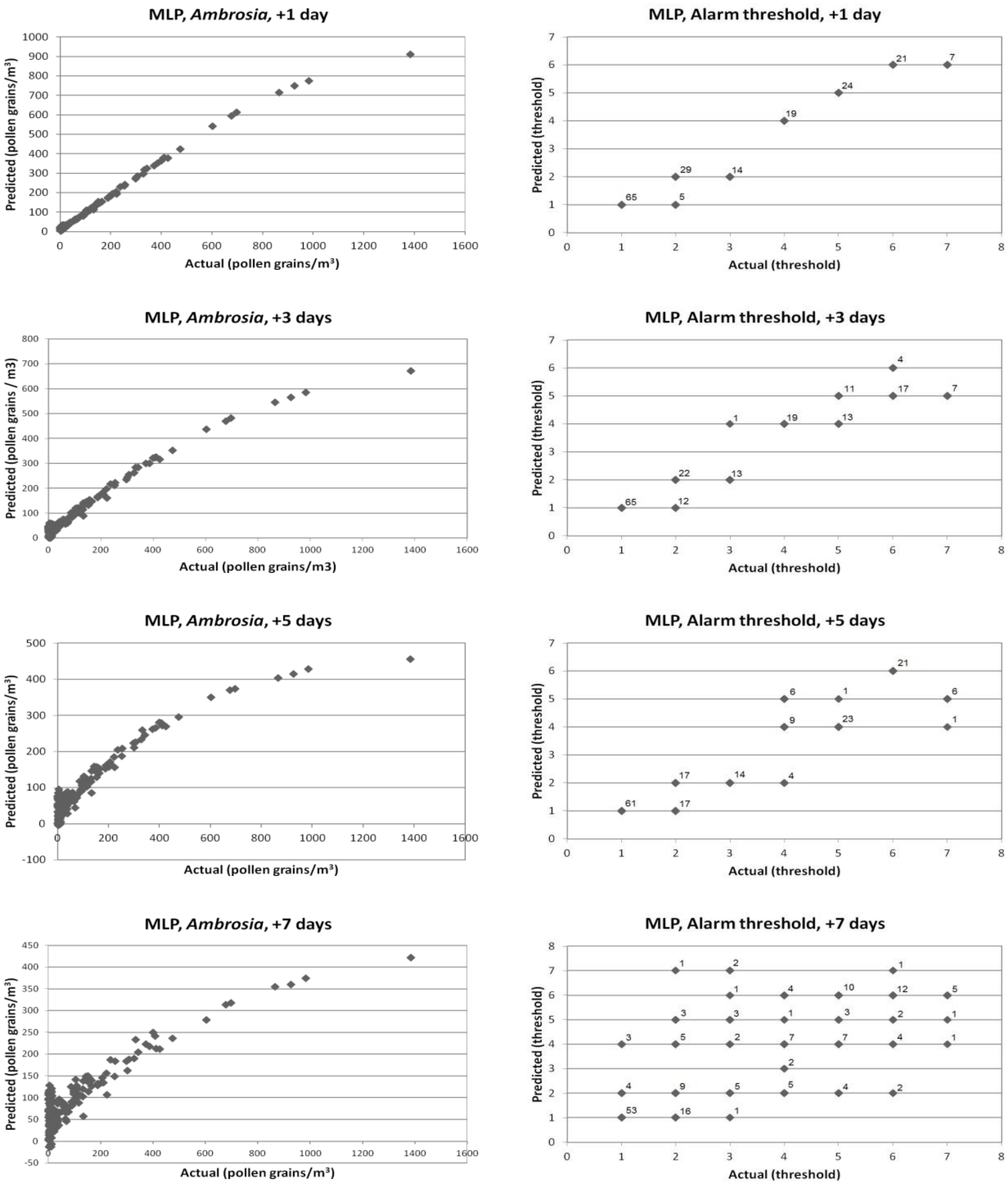


Fig. 14 Scatter plots, Szeged. Selected scatter plots of actual and predicted *Ambrosia* pollen concentrations (MLP), as well as alarm thresholds (MLP). The forecasting horizon is given in days (Csépe et al., 2014a; 2014b).

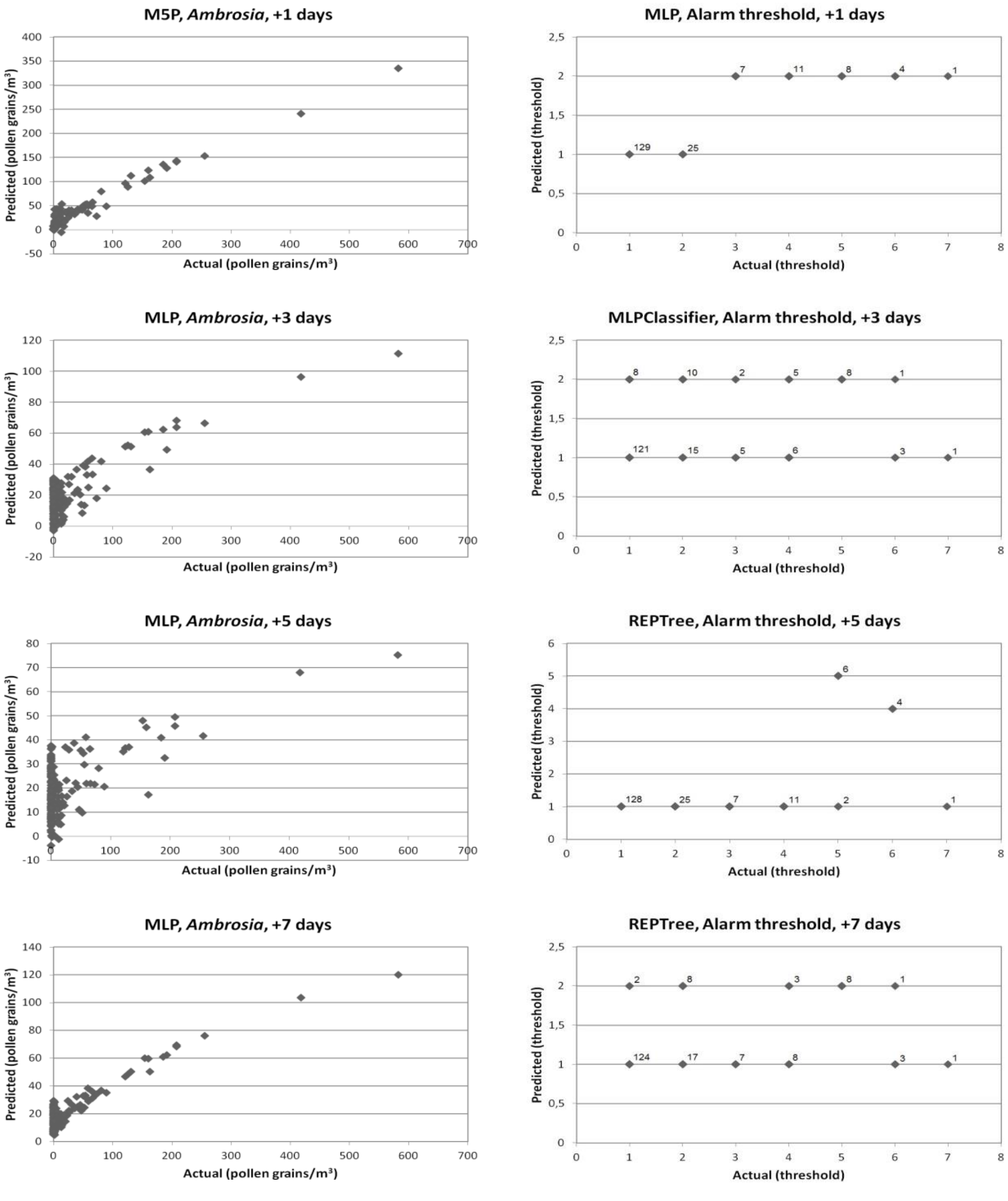
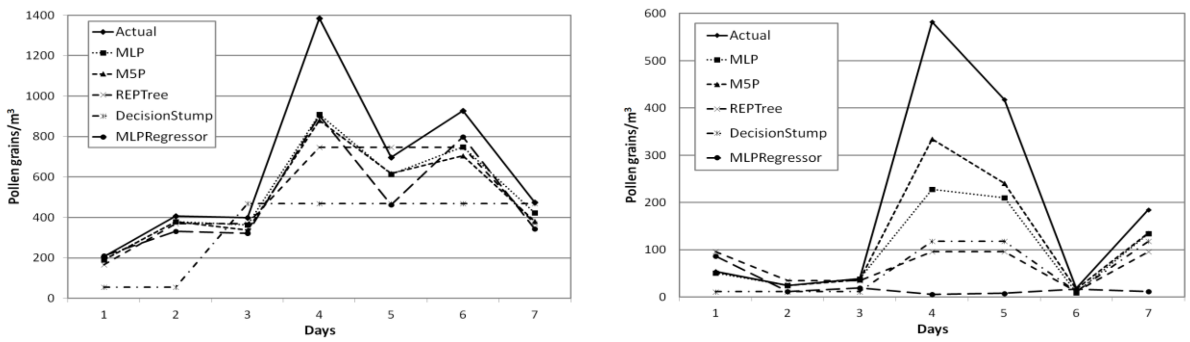


Fig. 15 Scatter plots, Lyon. Selected scatter plots of actual and predicted *Ambrosia* pollen concentrations (M5P, MLP), as well as alarm thresholds (MLP, MLPClassifier, REPTree). The forecasting horizon is given in days (Csépe et al., 2014a; 2014b).

Uncertainties in the accuracy of the forecasts can be explained by the lack of sufficient number of influencing variables including the fact that environmental associations of ragweed pollen level has not been fully discovered. For example, high air pollutant concentrations are likely to have either short or long term impact on pollen levels (Minero et al., 1998; Jäger et al., 1991), especially in a polluted urban environment like Szeged and Lyon. The results show that the learning strategies of the algorithms can perform well, but the really good model is MLP for predicting both pollen concentrations and alarm levels for each city. The results received for Szeged and Lyon show that we can perform accurate forecasts of the daily pollen concentrations and alarm levels for several days ahead. The efficiency of the models belongs to the best ones compared to those reported in the literature. When forecasting, the following values of coefficient of determination (R^2) (i.e. squared correlations) of one day ahead forecasts were received: 0.60 for Poaceae using neural networks (Sánchez-Mesa et al., 2002); 0.93 again for Poaceae using neural networks (Rodríguez-Rajo et al., 2010); 0.45 for grass pollen (whole season) using correlation analysis (Stach et al., 2008) and 0.79 for Poaceae using Multiple Linear Regression (Voukantsis et al., 2010). Our study provides a coefficient of determination of 0.98 (*Ambrosia,* Szeged, one day and two days ahead) using Multi-Layer Perceptron that ranks this model the best one in the literature.

10.2.2 Model fitting on the days of the highest pollen levels

Pollen concentrations on the days exhibiting the highest pollen levels during a 7-day period were predicted and analysed for both cities (*Fig. 16*).



Szeged

Lyon

Fig. 16 One-day forecasts for a seven-day period encompassing the day of the highest pollen load of *Ambrosia* (Actual: measured pollen concentrations, MLP: Multi-Layer Perceptron model, M5P: regression tree model, REPTree: decision tree model, DecisionStump: decision tree model, MLPRegressor: Multi-Layer Perceptron model) (Csépe et al., 2014a; 2014b).

For example, regarding the absolute maximum pollen counts within the 10-year period examined, for Szeged and Lyon the best 1-day forecast is provided by MLP (actual value: 1385 pollen grains / m^3; forecasted value: 910 pollen grains / m^3) and M5P (actual value: 582 pollen grains / m^3; forecasted value: 335 pollen grains / m^3), respectively. However, all methods underestimate the pollen concentrations in these episodic situations.

The message of the above experiment is that MLP, M5P and MLPRegressor follow well the annual course of the pollen concentration. This is important information as the usefulness of a good forecast is much higher for the days of the highest pollen concentrations than for those of small pollen levels at the beginning and end of the pollen season. Accordingly, these methods can help in developing personalized information services that could improve the overall quality of life of sensitized people.

9.3. Conclusions

We applied Computational Intelligence procedures in order to predict daily values of *Ambrosia* pollen concentrations and alarm levels for Szeged (Hungary) and Lyon (France). Contrary to the difficulties in availability of daily pollen levels (they are at disposable only once a week), forecasts of daily ragweed pollen concentrations and alarm levels were successful for 1–7 days ahead for both cities. The importance of the influencing variables (the serial number of the day in the year, meteorological and pollen variables) in forming the resultant variable (pollen levels or alarm levels for 1–7 days ahead) was analysed. The weights of *Ambrosia* pollen level emerge extraordinarily from all variables indicating its high significance in determining pollen levels (alarm levels) for 1–7 days ahead for both cities. The weights of the rest of influencing variables are different for the two cities. For instance, the most important variables are temperature-related ones for Szeged, while relative humidity and wind speed have the most important role in forming pollen concentrations in Lyon.

For Szeged, Multi-Layer Perceptron models provide results similar with tree-based models for predicting pollen concentration 1 and 2-days ahead, while for more than two days ahead they deliver better results than tree-based models. For Lyon, only Multi-Layer Perceptron gives acceptable result for predicting pollen levels 1 and 2-days ahead. Concerning the alarm levels, the efficiency of the procedures differs substantially.

When fitting the models to the days of the highest pollen levels the more complex CI methods proved better for both cities. MLP and M5P methods provided the best results for Szeged and Lyon, respectively. We have shown that the selection of the optimal method depends on climate as a function of geographical location and relief.

Procedures of Computational Intelligence showed better performance in predicting daily values of *Ambrosia* pollen concentrations compared to traditional statistical tools, such as nonparametric regression methods (Makra et al., 2011a), autoregressive models (Matyasovszky and Makra, 2011) and quantile regression analysis (Makra and Matyasovszky, 2011).

Results received can be utilized for the national pollen information services. Total medical costs of ragweed pollen can be substantially reduced if sensitized people can be prepared in time for serious ragweed pollen episodes. Decision-makers are responsible for introducing regulations and actions in order to facilitate the problem caused by ragweed pollen. Furthermore, responsibility of aero-biologists is developing personalized information services in order to improve the overall quality of life of sensitized people. Note however, that due to the restrictions of the sampling procedure used (daily pollen counts are available only after a 7-day period) the applicability of the methods presented is limited in terms of operational use. Accordingly, for the time-being the methodology introduced here can only be used as supportive means to the original forecasting methods (models). This problem can only be solved if low-cost, automatic pollen samplers based on a totally new principle will be introduced by “in situ” recognizing pollen types and measuring pollen counts.

The methods applied are sensitive to the number of the influencing parameters. A further aim is to use much more influencing parameters (including further meteorological parameters, in addition chemical air pollutants, land use, relief, etc.) in order to develop a general model for different locations (Csépe et al., 2014a; 2014b).

10. Summary

Statistical analysis of the associations of phenological and quantitative characteristics of different taxa with meteorological elements is a relatively new area of science, since observations with pollen trap have only started in Europe since the 1960's and the first papers on the field have been published around 30 decades later (Declavijo et al., 1988; Emberlin and Norrishill, 1991; Peeters et al., 1994). In Hungary, this area of science is completely new; no one has dealt with pollen climatology so far.

The topic of weather related ragweed pollen levels has of great literature due to its high practical importance. Results of this kind of research may effectively help sensitive individuals in preparing for the periods of severe pollen loads and for facilitating their health consequences.

Results of the dissertation are received by using different statistical procedures. Among them, factor analysis with special transformation has not yet been applied for studying this kind of relationships. Even, this procedure has never been used before in the special literature, for studying meteorological processes. This method has only been applied in the economics so far. Furthermore, for predicting future daily ragweed pollen concentrations, methods of Computational Intelligence are used in the dissertation. For predicting both the daily pollen concentrations and daily alarm levels of ragweed, several tree algorithms (M5P, REPTree, DecisionStump and J48) are used here. These algorithms have not yet been applied for the above tasks in the special literature. These models have been developed in Matlab environment with WEKA implementation of the above algorithms, described in Hall et al. (2009).

Major findings of the dissertation are as follows.

1) When analyzing the potential reasons of day-to-day variations of *Ambrosia* pollen counts for Szeged region of Southern Hungary in association with meteorological elements, for each day of the analysis daily differences in meteorological variables (value on the given day – value on the day before) were assigned to the daily ratios of *Ambrosia* pollen counts (A) (value on the given day per value on the day before). Three data sets were subjected to an analysis: (1) the total data set, (2) those daily differences in meteorological variables for which $A \leq 1$ and (3) those for which $A > 1$, respectively. For all three data sets, the days examined were classified into four categories,

respectively. These categories are as follows: (a) rainy day, preceded by a rainy day; (b) rainy day, preceded by a non-rainy day; (c) non-rainy day, preceded by a rainy day; (d) non-rainy day, preceded by a non-rainy day.

A unique procedure, namely factor analysis with special transformation was performed on the daily meteorological and *Ambrosia* pollen data in order to find out the strength and sign of associations between meteorological (explanatory) variables and *Ambrosia* pollen (resultant) variable.

When using factor analysis with special transformation, for all four categories examined in the three data sets, wind speed (V), rainfall (R) and temperature range (ΔT) were the most important parameters with 7, 5 and 5 significant associations with daily ratios of *Ambrosia* pollen counts, respectively. At the same time, minimum temperature (T_{min}) and irradiance (I) were the least important meteorological variables influencing the resultant variable. After dividing the total data set into two groups, a tendency of stronger associations between the meteorological variables and the pollen variable was found in the data set for which $A \leq 1.00$, compared to that for which $A > 1$. This is due to the difference in the behaviour of the plant to stand environmental stress. Namely, the data set for which $A \leq 1.00$ can be associated to lower summer temperatures with near-optimum phyto-physiological processes, while the category of $A > 1.00$ is involved with high and extreme high temperatures modifying life functions and, hence, interrelationships of the meteorological and pollen variables (Csépe et al., 2012a; Matyasovszky et al., 2012; Makra et al., 2014c).

2) When analyzing the relationship between *Ambrosia* pollen characteristics and meteorological variables, furthermore between the rank of ordered *Ambrosia* pollen characteristics and the rank of ordered annual values of meteorological variables for Szeged in Southern Hungary, the following results were received.

Ambrosia pollen is sensitive either to temperature or precipitation. Furthermore, it is reversely related to temperature (negative correlations). On the whole, due to a warming and drying climate, pollen count characteristics (total annual pollen amount and annual peak pollen concentration) indicate a decrease for *Ambrosia*.

Based on the daily pollen counts of *Ambrosia* depending on both extreme temperatures and extreme precipitations, we established that the coldest and the wettest years highly facilitate pollen production.

Increasing temperature may benefit spatial distribution and abundance, while it interferes pollen release in the lack of rainfall. Although overall trends of *Ambrosia* pollen counts can be explained partly by landscape-use changes, seasonal changes reflect weather conditions, which can enhance or suppress (hide, blunt) the overall trends. The genetic background of *Ambrosia* gives a special response to the changing weather conditions that can determine their potential distribution influenced by landscape use (Csépe et al., 2012b; Makra et al., 2012b).

3) In order to determine how previous-day values of meteorological elements relate to actual-day values of extreme *Ambrosia* pollen load, we performed factor analysis with special transformation and found that four meteorological variables (mean temperature, mean global solar flux, mean relative humidity and mean sea-level pressure) except for mean wind speed display significant associations with *Ambrosia* pollen load. Temperature and global solar flux indicate positive proportional, while air pressure and relative humidity inversely proportional associations with *Ambrosia* pollen loads. Explaining variables in decreasing order of their substantial influence on *Ambrosia* pollen load are temperature, air pressure, global solar flux, and relative humidity.

Factor analysis gave a first insight into the relationship between pollen load variables and meteorological variables and the *t*-test showed the possibility of distinguishing between extreme and non-extreme pollen events using meteorological elements as explaining variables. Using selected low and high quantiles corresponding to probability distributions of *Ambrosia* pollen, the quantile and beyond-quantile averages of pollen loads were compared and evaluated. As a result, the number of events exceeding the quantile of 90% and not exceeding that of 10% is strongly underestimated. However, the procedure works well for quantiles of 20% and 80%, and even better for those of 30% and 70%.

A nearest neighbour (NN) technique was applied to discriminate between extreme and non-extreme pollen events using meteorological elements as explaining variables. It was found that explaining variables in decreasing order of their influence on *Ambrosia* pollen load are temperature, global solar flux, relative humidity, air pressure and wind speed. Furthermore, the relative frequency of good decisions for exceeding / not exceeding the different quantiles shows that the five meteorological elements as explaining variables are informative to discriminate between extreme and non-extreme pollen events. Note that the larger the percentages in above-above or below-below rows-columns in *Tables 9 and 10* the better the estimation is delivered by the NN technique (Csépe et al., 2012c).

4) 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. In this section we separated the weight of the current and past climate conditions in determining the pollen concentrations of *Ambrosia* for Szeged region in Southern Hungary applying two procedures, namely multiple correlation and factor analysis with special transformation.

Using the two methods, results revealed characteristic similarities. For *Ambrosia,* 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. High climate sensitivity (especially water sensitivity) of *Ambrosia* as herbaceous taxon can be definitely established.

We found that 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.

Fig. 12 (1) shows specific and unique "imprints" of *Ambrosia*; namely, they are characteristic to this taxon and, in turn, *Ambrosia* has its own "imprint" and (2) the here-mentioned "imprint" of *Ambrosia* received using the two methodologies are surprisingly similar.

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 (Matyasovszky et al., 2014a; 2014b).

5) We performed predictions in order to assess ragweed pollen concentrations several days ahead. For this aim we used factor analysis with special transformation, a novel technique for detecting the importance of the influencing variables in defining the pollen levels for 1–7 days ahead. In addition, further procedures applied, such as (1) data-driven modeling methods including neural networks have never been used in forecasting daily *Ambrosia* pollen concentration, (2) daily alarm thresholds are firstly predicted in the aerobiological literature; furthermore (3) algorithm J48 has never been used in palynological forecasts.

We applied Computational Intelligence procedures in order to predict daily values of *Ambrosia* pollen concentrations and alarm levels for Szeged (Hungary) and Lyon (France). Contrary to the difficulties in availability of daily pollen levels (they are available only once a week), forecasts of daily ragweed pollen concentrations and alarm levels were successful for 1–7 days ahead for both cities. The importance of the influencing variables (the serial number of the day in the year, meteorological and pollen variables) in forming the resultant variable (pollen levels or alarm levels for 1–7 days ahead) was analysed. The weights of *Ambrosia* pollen level emerge extraordinarily from all variables indicating its high significance in determining pollen levels (alarm levels) for 1–7 days ahead for both cities. The weights of the rest of influencing variables are different for the two cities. For instance, the most important variables are temperature-related ones for Szeged, while relative humidity and wind speed have the most important role in forming pollen concentrations in Lyon.

For Szeged, Multi-Layer Perceptron models provide results similar with tree-based models for predicting pollen concentration 1 and 2-days ahead, while for more than two days ahead they deliver better results than tree-based models. For Lyon, only Multi-Layer Perceptron gives acceptable result for predicting pollen levels 1 and 2-days ahead. Concerning the alarm levels, the efficiency of the procedures differs substantially.

When fitting the models to the days of the highest pollen levels the more complex CI methods proved better for both cities. MLP and M5P methods provided the best results for Szeged and Lyon, respectively. We have shown that the selection of the optimal method depends on climate as a function of geographical location and relief.

Results received can be utilized for the national pollen information services. Total medical costs of ragweed pollen can be substantially reduced if sensitized people can be prepared in time for serious ragweed pollen episodes. Decision-makers are responsible for introducing regulations and actions in order to facilitate the problem caused by ragweed pollen. Furthermore, responsibility of aero-biologists is developing personalized information services in order to improve the overall quality of life of sensitized people. Note however, that due to the restrictions of the sampling procedure used (daily pollen counts are available only after a 7-day period) the applicability of the methods presented is limited in terms of operational use. Accordingly, for the time-being the methodology introduced here can only be used as supportive means to the original forecasting methods (models). This problem can only be solved if low-cost, automatic pollen samplers based on a totally new principle will be introduced by "in situ" recognizing pollen types and measuring pollen counts.

The methods applied here are sensitive to the number of the influencing parameters. A further aim is to use much more influencing parameters (including further meteorological parameters, in addition chemical air pollutants, land use, relief, etc.) in order to develop a general model for different locations (Csépe et al., 2014a; 2014b).

11. Összegzés

A meteorológiai elemek és a különböző taxonok kvantitatív és fenológiai jellemzői közötti kapcsolatok statisztikai elemzése egy viszonylag új tudományterület. Ugyanis a pollencsapdás megfigyelések csupán az 1960-as években indultak meg Európában, és az első kapcsolódó tanulmányokat kb. három évtizeddel később publikálták (Declavijo et al., 1988; Emberlin and Norrishill, 1991; Peeters et al., 1994). Ez a tudományterület Magyarországon új. Az első pollenklimatológiai tárgyú publikációk a 2000-es évek elején jelentek meg hazánkban (Makra et al., 2004; 2005).

A parlagfűpollen koncentrációk és az időjárás kapcsolatának tanulmányozása nagy szakirodalommal rendelkezik, mivel az kiemelkedő gyakorlati jelentőséggel bír. Az ez irányú kutatások eredményei hatékonyan segíthetik a pollenérzékeny emberek felkészülését a magas pollenterhelésű időszakokra, ezzel megkönnyítve számukra az egészségügyi következmények elviselését.

A disszertáció eredményeit különböző statisztikai eljárások alkalmazása szolgáltatták. Ezek közül a faktoranalízist és speciális transzformációt ez idáig még nem alkalmazták ilyen típusú kapcsolatok feltárására. Ráadásul ezt az eljárást korábban még a nemzetközi szakirodalomban sem használták meteorológiai folyamatok tanulmányozására – eddig csak közgazdaságtani alkalmazásai ismertek. A jövőbeli napi parlagfűpollen koncentrációk előrejelzésére a mesterséges intelligencia módszereit alkalmaztuk a disszertációban. A napi parlagfűpollen koncentrációk és riasztási küszöbök előrejelzésére több fa alapú algoritmust (M5P, REPTree, DecisionStump és J48) használtunk. Ezeket az algoritmusokat eddig még nem alkalmazták a fenti feladatokra a nemzetközi szakirodalomban. Ezeket a modelleket Matlab környezetben fejlesztették ki a fenti algoritmusok WEKA implementációjával, (Hall et al., 2009).

A disszertáció legfontosabb eredményei a következők.

1) A szegedi régió meteorológiai elemektől függő parlagfű pollenszámai napi változékonyságának lehetséges okait elemezve, a meteorológiai változók napi eltéréseit (adott nap értéke minusz az előző nap értéke) hozzárendeltük az Ambrosia pollenszámok "A" napi arányaihoz (adott napi érték osztva az előző napi érték) a vizsgálat minden egyes napjára. Ily módon rendre három adatkészletet vizsgáltunk: (1) a teljes adatkészletet, (2) a meteorológiai változók azon napi eltéréseit, amelyekre A ≤ 1, és (3) azon napi eltéréseit,

amelyekre $A > 1$. Mindhárom adatkészlet esetében a vizsgált napokat 4-4 kategóriába soroltuk, mégpedig a következő módon: (a) csapadékos nap, melyet csapadékos nap előz meg, (b) csapadékos nap, melyet nemcsapadékos nap előz meg, (c) nemcsapadékos nap, melyet csapadékos nap előz meg, és (d) nemcsapadékos nap, melyet nemcsapadékos nap előz meg.

Egy ritkán alkalmazott eljárást, a faktoranalízist speciális transzformációval hajtottunk végre a napi meteorológiai és a parlagfűpollen adatokon annak érdekében, hogy meghatározzuk a meteorológiai paraméterek (magyarázó változók) és a parlagfűpollen (célváltozó) közötti kapcsolatok erősségét és előjelét.

Miután végrehajtottuk a faktoranalízist speciális transzformációval a három adatkészlet 4-4 kategóriájára, a szélsebesség (V), a csapadék (R), és a hőmérsékleti terjedelem (ΔT) bizonyultak a legfontosabb paramétereknek, melyek rendre 5 esetben (a teljes adatkészletre), 8 esetben (a meteorológiai paraméterek azon eltéréseire, melyeknél $A \leq 1$) és 4 esetben (a meteorológiai paraméterek azon eltéréseire, melyeknél $A > 1$) szignifikáns kapcsolatot mutattak az Ambrosia pollenszámok napi arányaival. Ugyanakkor a minimum hőmérséklet (Tmin) és globálsugárzás (I) voltak a legkevésbé fontos meteorológiai változók a célváltozó értékének meghatározásában. Miután a teljes adatkészletet két csoportra osztottuk, a meteorológiai változók és a pollenváltozó közötti erősebb kapcsolatra utaló tendenciát találtunk abban az adatkészletben, amelyben $A \leq 1{,}00$, szemben azzal az adatkészlettel, amelyben $A > 1$. Ez annak tulajdonítható, hogy a növény eltérő módon tűri az eltérő környezeti stresszt. Nevezetesen, az az adatkészlet, amelyre $A \leq 1{,}00$, alacsonyabb nyári hőmérsékletekhez kapcsolódik, amelyekhez optimum közeli fito-fiziológiai folyamatok társulnak. Ezzel szemben az a kategória, amelyre $A > 1{,}00$, magas és extrém magas hőmérsékletekkel jellemezhető, amelyek módosítják az életfunkciókat, s ebből adódóan a meteorológiai- és pollenváltozók kapcsolatrendszerét is (Csépe et al., 2012a; Matyasovszky et al., 2012; Makra et al., 2014c).

2) A meteorológiai paraméterek (magyarázó változók) faktorsúlyainak a célváltozóra (a parlagfű pollen 3 kategóriája) gyakorolt fontossági sorrendjét elemezve az alábbi eredményeket kaptuk.

Az Ambrosia pollen a hőmérsékletre, vagy a csapadékra reagál érzékenyen. Ugyanakkor fordítottan kapcsolódik a hőmérséklethez (negatív korrelációk). Összességében – a melegedő és szárazodó klímának köszönhetően – a kvantitatív pollenkarakterisztikák (az évi összes pollenmennyiség és a napi maximális pollenkoncentráció az év során) a parlagfű pollenszámok csökkenését jelzik.

A szélsőséges hőmérsékletekhez és csapadékmennyiségekhez kapcsolódó parlagfű pollenszámok alapján megállapítottuk, hogy a leghidegebb és a legcsapadékosabb évek nagymértékben elősegítik a pollentermelést.

Az emelkedő hőmérséklet hozzájárulhat a parlagfű nagyobb területen történő pollenszórásához, valamint a pollenkoncentráció jelentős növekedéséhez, míg a csapadék hiánya gátolja a pollentermelést és -kibocsátást. Bár a parlagfű pollenszámok trendjei részben magyarázhatók a tájhasználat változásával, a szezonális változások olyan időjárási körülményeket tükröznek, amelyek javíthatják vagy elnyomhatják (elrejthetik, tompíthatják) az általános tendenciákat. A parlagfű genetikai háttere különleges választ ad a változó időjárási körülményekre, amely utóbbiak meghatározhatják a növénynek a tájhasználattól is függő potenciális térbeli eloszlását (Csépe et al., 2012b; Makra et al., 2012b).

3) Annak meghatározásához, hogy a meteorológiai elemek előző napi értékei miként befolyásolják az extrém parlagfűpollen terhelés aktuális napi értékeit, faktoranalízist hajtottunk végre speciális transzformációval, s azt tapasztaltuk, hogy négy meteorológiai változó (a középhőmérséklet, a globálsugárzás, a relatív páratartalom és a tengerszinti légnyomás átlagos napi értékei) kivéve az átlagos napi szélsebességet, szignifikáns kapcsolatot mutat a parlagfűpollen terheléssel. A hőmérséklet és a globálsugárzás egyenesen, míg a tengerszinti légnyomás és a relatív páratartalom fordítottan arányos a parlagfűpollen terheléssel. A parlagfűpollen terhelést befolyásoló magyarázó változók fontosságuk csökkenő sorrendjében a következők: hőmérséklet, tengerszinti légnyomás, globálsugárzás és relatív páratartalom.

A faktoranalízis egy előzetes betekintést nyújtott a kvantitatív pollenváltozók és a meteorológiai változók kapcsolatrendszerébe, s a t-próba azt jelezte, hogy meg lehet különböztetni az extrém és nem-extrém kvantitatív pollenváltozókat, a meteorológiai elemek, mint magyarázó változók felhasználásával. A parlagfű pollen valószínűségi eloszlásaihoz kapcsolódó, néhány kiválasztott alacsony és magas kvantilis alkalmazásával a pollenterhelések kvantilis és kvantilis alatti átlagait összhasonlítottuk és értékeltük. Ennek eredményeképpen a 90%-os kvantilist meghaladó események száma és a 10%-ot nem meghaladó események száma erősen alábecsült. Ugyanakkor az eljárás jól működik a

20%-os és a 80%-os kvantilisek esetében, és még jobban a 30%-os és a 70%-os kvantilisek esetében.

Egy nearest neighbour (NN) (legközelebbi szomszéd) technikát alkalmaztunk az extrém és nem-extrém pollen események megkülönböztetésére, amelynek során a meteorológiai elemeket magyarázó változókként használtuk. Azt találtuk, hogy a parlagfűpollen terhelésre ható magyarázó változók fontosságuk csökkenő sorrendjében a következők: hőmérséklet, globálsugárzás, relatív páratartalom, tengerszinti légnyomás és szélsebesség. Ezenkívül a különböző kvantiliseket meghaladó / nem meghaladó jó döntések relatív gyakorisága azt mutatja, hogy a fenti öt meteorológiai elem, mint magyarázó változó, megfelelő mértékben informatívak ahhoz, hogy megkülönböztessük az extrém és nem-extrém pollen eseményeket. Ugyanakkor fontos megjegyeznünk, hogy minél nagyobb százalékos értékek fordulnak elő a 9. és a 10. táblázat "above-above" és "below-below" sor-oszlop metszeteinek celláiban, annál jobb az NN technikával kapott becslés (Csépe et al., 2012c).

4) Jóllehet számos tanulmányt publikáltak már a meteorológiai feltételek és a pollenterhelések, továbbá a múlt időjárási viszonyai és különböző taxonok bizonyos fenológiai fázisai közötti összefüggések feltárására, egyik sem foglalkozott azzal, hogy megkülönböztesse a jelen és a múltbeli időjárás hatását az aktuális pollenkoncentrációkra. Ebben a részben szétválasztottuk a jelen és a múltbeli éghajlati viszonyok súlyát, hogy meghatározzuk, e két hatás miként érvényesül az aktuális napi parlagfűpollen koncentrációkban a szegedi régióban. Erre a célra két eljárást alkalmaztunk: a többszörös korrelációt és a faktoranalízist speciális transzformációval.

A fenti két módszer alkalmazásával az eredmények jellegzetes hasonlóságokat tártak fel. A parlagfű esetében a kontinentális csapadékcsúcs és a tenyészidőszak során fellépő helyi záporok erősíthetik a jelen meteorológiai elemek súlyát. Ugyanakkor a csapadék hatására nagymennyiségű víz tározódhat a talajban, amely a száraz időszakokban hozzájárulhat a múltbeli klimaelemek hatásához. A parlagfű – mint fűfélékhez tartozó taxon – nagyfokú klímaérzékenysége (különösen vízérzékenysége) egyértelműen megállapítható.

Megállapítottuk, hogy a jelen és a múltbeli időjárási tényezők hatásainak szélsőséges eltérései, amelyeket a szürke különböző árnyalatai jelölnek (Fig. 12 / 12. ábra), markáns egyebeeséseket mutatnak. Ez alapján feltételezhető, hogy valós összefüggések vannak egyrészről a fitofiziológiai folyamatok, másrészről pedig az év egyes részeinek aktuális és múltbeli meteorológiai tényezői, valamint a napok felhalmozódási hossza. között.

A tanulmányban bemutatott jelen és múltbeli éghajlati viszonyok súlyának szétválasztása különböző taxonok esetében gyakorlati jelentőséggel bír nemcsak a pollenérzékeny emberek számára, hanem a mezőgazdasági termelés szempontjából is. Nevezetesen, a múltbeli időjárás taxon-specifikus hatásainak ismerete segíthet a jövőbeni pollenkoncentrációk megfelelő időben történő előrejelzésében; ezenkívül hozzájárulhat a mezőgazdasági termelés időjárástól való függésének csökkentéséhez is (Matyasovszky et al., 2014a; 2014b).

5) Előrejelzéseket készítettünk azon célból, hogy megbecsüljük a parlagfűpollen koncentrációját néhány napra előre. Evégett a szakterület nemzetközi irodalmában egy új módszert alkalmaztunk: faktoranalízist speciális transzformációval annak érdekében, hogy kiderítsük a magyarázó változók fontossági sorrendjét a pollenkoncentrációk 1-7 napos előrejelzésében. Ezenkívül további eljárásokat is alkalmaztunk, úgy mint (1) adat-vezérelt modellezési módszereket, beleértve a neurális hálózatokat is, amelyeket ez idáig még nem használták a napi parlagfűpollen koncentráció előrejelzésére, (2) napi riasztási küszöbértékeket, melyeket első alkalommal jeleztük előre a nemzetközi levegőbiológiai szakirodalomban, továbbá (3) a J48 algoritmust, mely szintén első alkalommal került felhasználásra a palinológiai előrejelzések nemzetközi szakirodalmában.

Mesterséges intelligencia (CI = Computational Intelligence) eljárásokat alkalmaztunk az Ambrosia pollenkoncentrációk és riasztási küszöbök napi értékeinek előrejelzéséhez Szegedre (Magyarország) és Lyonra (Franciaország). Noha nehézséget jelentett a napi pollenkoncentráció adatok elérhetősége (csak heti egy alkalommal állnak rendelkezésre az előző hét napjaira), a napi parlagfűpollen koncentrációk és riasztási küszöbök 1-7 napos előrejelzései mindkét város esetében sikeresek voltak. Elemeztük a magyarázó változók (a nap éven belüli sorszáma, meteorológiai és a pollenváltozók) fontosságát a célváltozó (pollenszintek, vagy riasztási küszöbök 1-7 napra előre) meghatározásában. A parlagfűpollen koncentráció súlyai rendkívüli módon kiemelkednek az összes változó közül, ezzel is jelezve, hogy nagy jelentőséggel bírnak a pollenkoncentrációk (riasztási szintek) 1-7 nappal előre történő meghatározásában mindkét város esetében. A többi magyarázó változó súlyai eltérőek a két városra. Pl. Szegedre a legfontosabb magyarázó változók hőmérsékleti változók, míg Lyonra a relatív páratartalom és a szélsebesség játsszák a legfontosabb szerepet a pollenkoncentráció alakításában.

Szegedre a Multi-Layer Perceptron modellek hasonló eredményeket mutatnak, mint a fa alapú modellek a pollenkoncentráció egy-, illetve kétnapos előrejelzésében, míg a több mint kétnapos előrejelzésekben jobb eredményeket érnek el, mint a fa alapú modellek. Lyon esetében csak a Multi-Layer Perceptron nyújt elfogadható eredményt a pollenkoncentráció egy-, illetve kétnapos előrejelzésében. Ami a riasztási szinteket illeti, az eljárások hatékonysága jelentősen eltér egymástól.

Amikor a modelleket a legmagasabb pollenkoncentrációkkal rendelkező napokhoz illesztettük, a komplexebb CI módszerek mindkét város esetében jobbnak bizonyultak. Az MLP és az M5P módszerek nyújtották a legjobb eredményeket Szegeden és Lyonban is. Kimutattuk, hogy az optimális módszer kiválasztása az éghajlattól függ, amely a földrajzi elhelyezkedés és a domborzat függvénye.

A kapott eredmények hasznosíthatók a nemzeti polleninformációs szolgálatok számára. A parlagfű pollen által okozott összes egészségügyi költségek lényegesen csökkenthetők, ha az arra érzékenyek időben felkészülhetnek a súlyos parlagfűpollen terhelésű időszakokra. A döntéshozók felelősek azért, hogy megfelelő szabályozásokat és intézkedéseket vezessenek be, amelyekkel a parlagfű pollen által okozott problémákat hatékonyan kezelni lehet. Továbbá az aerobiológusok felelőssége, hogy személyre szabott információs szolgáltatásokat fejlesszenek ki, amelyekkel a pollenérzékeny emberek általános életminőségét javítani lehet. Fontos azonban megjegyezni, hogy az alkalmazott mintavételi eljárás korlátai (a napi pollenszámok csak minden hétnapos időszakot követően állnak rendelkezésre az előző hét napjaira), az itt bemutatott módszerek alkalmazhatósága operatív célokra korlátozott. Ennek megfelelően az itt bemutatott módszertant csak az eredeti előrejelzési módszerek (modellek) támogatásaként lehet felhasználni. Ez a probléma csak akkor oldható meg, ha teljesen új elven alapuló, alacsony költségű automata pollenmintavevők kerülnek bevezetésre, amelyek révén azonnal (in situ) megoldható a pollenszámoknak a befogott pollenfajták szerinti meghatározása.

A disszertációban alkalmazott módszerek érzékenyek a magyarázó változók számára. További cél az, hogy sokkal több magyarázó változót (pl. további meteorológiai paraméterek, kémiai légszennyező anyagok, tájhasználat, domborzat, stb.) alkalmazzunk egy olyan általános modell kidolgozására, amely különböző helyszíneken is jól használható (Csépe et al., 2014a; 2014b).

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TÉMAVEZETŐI NYILATKOZAT

Alulírott Makra László, mint Csépe Zoltán témavezetője nyilatkozom, hogy a következő tanulmányokban:

Matyasovszky, I., Makra, L., Csépe, Z., 2012: Associations between weather conditions and ragweed pollen variations in Szeged, Hungary. *Archives of Industrial Hygiene and Toxicology* (Arhiv Za Higijenu Rada I Toksikologiju), **63**(3), 311-320.

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szerzőtársakkal közösen publikált közlemények a meteorológiai elemek és a pollenkoncentráció kapcsolatának vizsgálatára vonatkozó eredményeiben Csépe Zoltán jelölt szerepe meghatározó fontosságú, és az értekezésben felhasznált eredmények tükrözik a jelölt hozzájárulását.

Szakmai szempontból Csépe Zoltán értekezés anyagát támogathatónak ítélem meg.

Szeged, 2018. 02. 25.

……………………………….

Dr. Makra László