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The influence of extreme high and low temperatures and precipitation totals on pollen seasons of *Ambrosia*, Poaceae and *Populus* in Szeged, southern Hungary

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Abstract
Extreme high and low temperatures and precipitation totals may have important effect on daily and annual pollen concentrations. The aim of this study is to analyse the associations between pollen characteristics and meteorological variables, furthermore between the rank of pollen characteristics and the rank of annual values of meteorological variables for Szeged, southern Hungary. Pollen characteristics include pollen count parameters (TPA, total annual pollen amount; APC, annual peak pollen concentration) and pollen season parameters (start, end and duration of the pollen season). Meteorological variables are temperature and precipitation. The data set used covers a 14-year period (1997–2010) and contains daily values of *Ambrosia* (ragweed), Poaceae (grasses) and *Populus* (poplar) pollen concentrations, as well as those of temperature and precipitation. Both Pearson and Spearman rank correlations were calculated, because the rank correlation is less sensitive than the correlation to outliers that are in the tails of the sample. Our results suggest that *Ambrosia* and *Populus* are reversely related to temperature (negative correlations), while Poaceae exhibit a parallel relationship with precipitation (positive correlations). On the whole, pollen count characteristics (TPA and APC) indicate a decrease for *Ambrosia* and Poaceae, while for *Populus* an increase is expected.

Keywords: Ambrosia*, Poaceae,* Populus*, pollen counts, pollen season*

Weather related daily variability of pollen concentrations has a wide literature, among them studies of the relationship of meteorological parameters and daily pollen concentrations (e.g. Bartková-Ščevková, 2003; Rodríguez-Rajo et al., 2005; Štefanič et al., 2005; Kasprzyk, 2008; Recio et al., 2010), while others, based on meteorological data, use different techniques for predicting pollen characteristics (e.g. Galán et al., 2001; Aznarte et al., 2007; García-Mozo et al., 2009).

The role of extreme weather events regarding daily pollen concentrations has received low attention so far. Frei (2004, 2006) studied the occurrences of extreme events (storms, floods or droughts) with extreme birch and grass pollen concentrations in the data set from Basel, Switzerland. The heat wave over Europe in summer 2003 substantially influenced pollen phenology and pollen production in Switzerland with its mean temperature exceeding the 1961–1990 mean by about 5 °C in June, July and August (Gehrig, 2006). The grass pollen season was most affected starting 1–2 weeks earlier and ending 7–33 days earlier than in general. Extreme high *Chenopodium*, *Plantago* and Poaceae daily pollen concentrations were measured in that pollen season. Cariñanos et al. (2000) analysed the yearly distribution and severity of *Artemisia* and Chenopodiaceae-Amaranthaceae pollen indicating the highest and particularly high pollen levels in a rural area with sub-desert climate and extreme dryness. Hart et al. (2007) studied the effect of the six warmest months on the pollen concentrations in Sydney, Australia.

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As a result of the recent climate change, variability of temperature and precipitation increases (Tank & Konnen, 2003) and extreme weather events (e.g. cold or hot days, as well as droughts or rainy periods) can be persistent and can keep up to several weeks and even they can be repeated several times. Global warming may facilitate the extension of certain herbaceous and arboreal plant habitats by contributing to the increase of pollen levels and to the exacerbation of their adverse effects, hence to the rise of pollen sensitivity and respiratory admissions due to a pollen allergy (d'Amato & Cecchi, 2008; Ariano et al., 2010; Ziska et al., 2011). Thus, the analysis of the effects of long-lasting extreme weather events on the daily or annual pollen concentrations is of ever increasing importance.

Our primary aim is to analyse the relationship between pollen characteristics of *Ambrosia*, Poaceae and *Populus* with meteorological variables, and, furthermore, between the rank of ordered pollen characteristics of these taxa and the rank of ordered annual values of meteorological variables, for Szeged in southern Hungary. On the basis of our results, a potential change in the pollen count characteristics of *Ambrosia*, Poaceae and *Populus* is concluded due to global warming.

Pollen concentration database of 24 taxa is available in Szeged. Taxa with the highest pollen levels include *Ambrosia* (32.3%), Poaceae (10.5%) and *Populus* (9.6%), which together account for 52.4% of the total pollen production in the city (Makra et al., 2011); therefore, these three earlier mentioned taxa were selected for this study.

Material and methods

Study locality and its climate

Szeged (46° 15′ N, 20° 10′ E), the largest settlement in southern Hungary, is located at the confluence of the rivers Tisza and Maros (Figure 1). The area is characterised by an extensive flat landscape of the Great Hungarian Plain with an elevation of 79 m above sea level. The city is the centre of the Szeged region with 203 000 inhabitants.

The climate of Szeged belongs to Köppen's Ca type (warm temperate climate) with relatively mild and short winters and hot summers (Köppen, 1931). According to the climate classification of Trewartha (1968), Szeged is associated with class D1 (continental climate with a long warm season). The climate of Szeged is characterised by hot summers and moderately cold winters. For the 30-year period 1981–2010, the distribution of rainfall is fairly uniform during the year with a contribution of 29% and 19% for the summer (June, July, August) and the winter (December, January, February), respectively. Mean daily summer temperatures are around 22.4 °C, while mean daily winter temperatures fluctuate around 2.3 °C. The irradiance exhibits an average of 656.1 and 133.1 MJ/m^2 in summer and winter days, respectively. The total annual precipitation amounts may fluctuate quite substantially. In this period, its extreme values for Szeged were minimum precipitation ($P_{\min}$) = 203 mm (2000) and maximum precipitation ($P_{\max}$) = 838 mm (2010). The most frequent winds blow along the north-northwest (NNW)–south-southeast (SSE) axis with prevailing air currents arriving from NNW (42.3%) and south-southwest (SSW) (24%) in the summer and from SSE (32.6%) and NNW (30.8%) during the winter. Due to its unique geographical position, Szeged is characterised by relatively low wind speeds with average daily summer and winter values of 2.8 and 3.5 m/s, respectively. The highest hourly wind speeds were recorded in spring with a rate of 5 m/s (Hungarian Meteorological Service, personal communication, 2011).

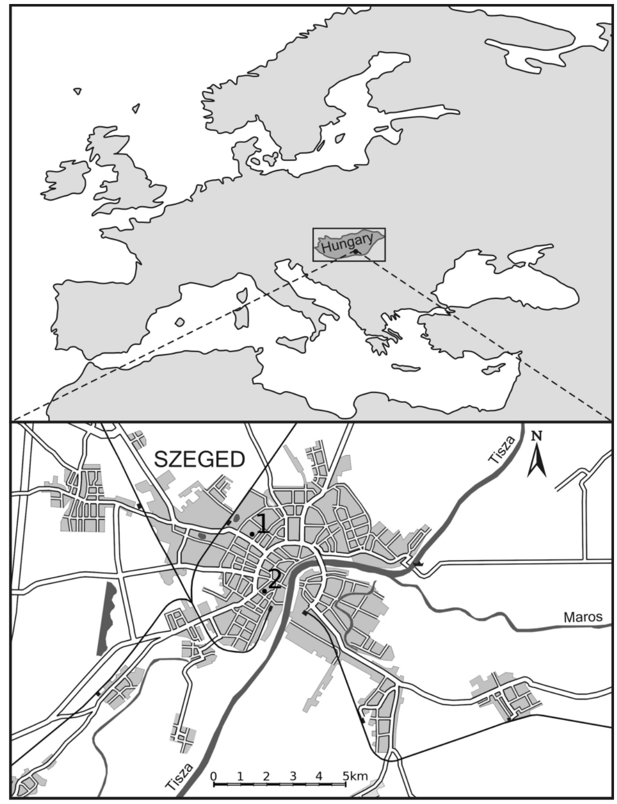

Figure 1. Maps of Europe and Hungary showing the study locality in the centre of Szeged with the positions of the data sources: 1 – meteorological monitoring station; 2 – aerobiological station.

Pollen sampling

In Szeged, the pollen content in the air has been measured since 1989 using a seven-day Hirst-type

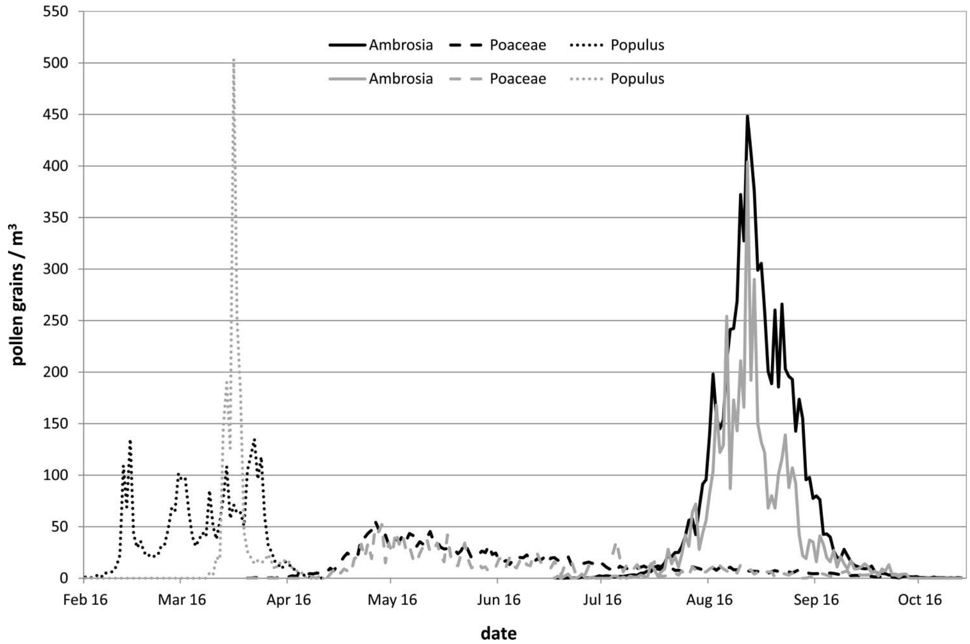

Figure 2. Daily pollen concentrations of *Ambrosia*, Poaceae and *Populus* in Szeged, Hungary, in the years 1997–2010 (black curves – mean daily pollen counts 1997–2010 except for 2003; grey curves – daily pollen counts 2003).

volumetric pollen trap Lanzoni VPS 2000 (Hirst, 1952). The air sampler is located on top of the building of the Faculty of Arts, University of Szeged (20 m above ground) in the downtown area (Figure 1; Makra et al., 2005). 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/min (= 14.4 m^3/day, which is corresponding to the daily requirement of an adult person) and was supplied with a timer, to which a rotating drum was fitted. The drum moved the adhesive tape (2 mm/h) 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 fuxin as a stain and put on 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 & Penttinen, 1981; Peternel et al., 2006*a*).

Meteorological data

Meteorological data were collected at the meteorological monitoring station (operating by the Environmental and Natural Protection and Water Conservancy Inspectorate of Lower-Tisza Region, Szeged) located in the downtown area of Szeged, about 10 m from the busiest main road (Figure 1).

In order to determine the relationship between extreme high and low temperatures and precipitation totals on the one hand and pollen counts of the three selected taxa on the other hand, the daily values of mean temperature, precipitation total and daily pollen concentrations of *Ambrosia* (ragweed), Poaceae (grasses) and *Populus* (poplar) were considered. The selection of these taxa is justified by their high or medium allergenicity [in a four-score scale to be find at Hungarian pollen index (www.pollenindex.hu), allergenicity of both *Ambrosia* and Poaceae is the highest indicated by score four, while that of *Populus* is medium indicated by score two] and by their more or less permanently high pollen concentrations (Figure 2).

Considered taxa and accompanying flora

Regarding the taxa to the highest pollen concentrations, *Ambrosia* is presented by only one species, namely *Ambrosia artemisiifolia* L. (Common Ragweed) in the Szeged region appearing both in the urban environment and in the countryside. Ragweed especially frequently occurs in the western part of the city. The dominant north-western winds can easily transport pollen into the city. *Ambrosia* can spread unchecked in the sandy region (northwest of Szeged), because stubble stripping is not necessary for ground-clearance due to the mechanical properties of sandy soils. Owing to newly-built motorways

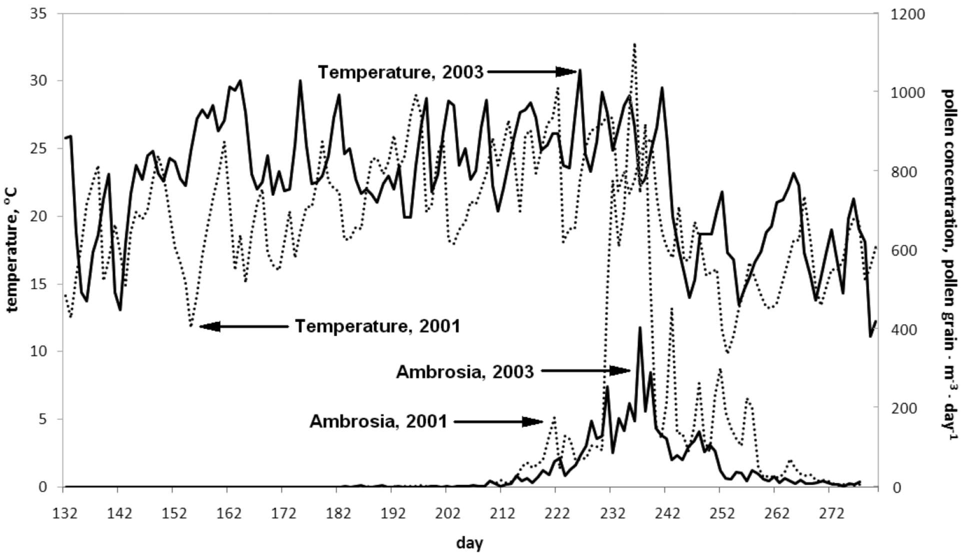

Figure 3. Daily pollen concentrations of *Ambrosia* in years with extreme temperature (warmest year: 2003, coldest year: 2001); examination period of the years: days 132–280.

around Szeged, several farmland areas have been left untouched for a long time, which also favours the expansion of *Ambrosia*. Several species of Poaceae family are common in and around Szeged: namely *Agropyron repens* (L.) P.Beauv. (Common Couch), *Poa trivialis* L. (Rough Meadow-grass), *Cynodon dactylon* (L.) Pers. (Bermuda grass), *Bromus* sp. (Brome species) as well as *Poa bulbosa* L. (Bulbous Meadow-grass) and *Poa angustifolia* L. (Narrow-leaved Meadow-grass). They are typical in weedy dry grasslands, while *Echinochloa crus-galli* (L.) P.Beauv. (Cockspur) is common in wet weedy grasslands of inland-water covered depressions of fallows converted into arable lands. Several grasslands remained around Szeged both in sand and loess and floodplain landscapes – now mainly connected to the depressions – that are dominated by the representatives of Poaceae. *Alopecurus pratensis* L. (Meadow Foxtail) is the main grass of floodplain meadows, which covers also the dykes in Szeged. Fescue species (mainly *Festuca pseudovina* Hack. ex Wiesb. and *F. rupicola* Heuff.) prevailing sand, loess and short-grass alkali steppe grassland types, whereas *Molinia hungarica* Milk. (Hungarian Purple Moor-grass) forms the rare *Molinia* fens in those depressions of Kiskunságian Sandland where upwelling-points of groundwater are found. *Dactylis glomerata* L. (Cocksfoot) is common in sand steppe grasslands and regenerating sandy fallows. *Agrostis stolonifera* L. (Creeping Bent) is the most common grass of the sandland-type saline meadows, whereas *Puccinellia limosa* Homlb. (Common Saltmarsh Grass) forms the *Puccinellia* swards and grasslands with surface salt-accumulation, appearing mainly in the Kiskunságian Sandlands. Swamps, artificial lakes, oxbow lakes and channels are surrounded by *Phragmites communis* Trin. (Common Reed) prevailing all landscape types around Szeged. Furthermore cereals, i.e. wheat (*Triticum aestivum* L.), maize (*Zea mays* L.) and barley (*Hordeum vulgare* L.) also belong to Poaceae that cover a huge proportion of the landscape surrounding Szeged as arable lands, thus being the most common habitats of all landscape types in this region.

For *Populus*, natural species of *Populus alba* L. (White Poplar) and *P. canescens* Sm. (Grey Poplar), as well as cultivated poplars such as I-273 Poplar and *P. canadensis* Castigl. (*P. deltoides* × *P. nigra*; Canadian Poplar) and its variants, are the most frequent in the city. They also dominate the natural and planted forests of floodplains and are common in the sandland as well, because they were planted intensively both in active floodplains and in sandlands during the last decades.

The analysis was performed for the 14-year period 1997–2010. 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 one pollen grain/m^3 air is recorded and at least five consecutive (preceding) days also show one or more pollen grains/m^3 air (Galán et al., 2001). Evidently, the pollen season for all three pollen types varies from year to year.

Statistical treatment of recorded data

The periods examined for the three taxa are indicated by the days of the year: *Ambrosia* days 132–280, Poaceae days 62–282 and *Populus* days 35–113. The end of these periods was selected according to the average end date of the annually varying pollen seasons. Choosing the starting days (132, 62 and 35, respectively) is slightly more complicated. When

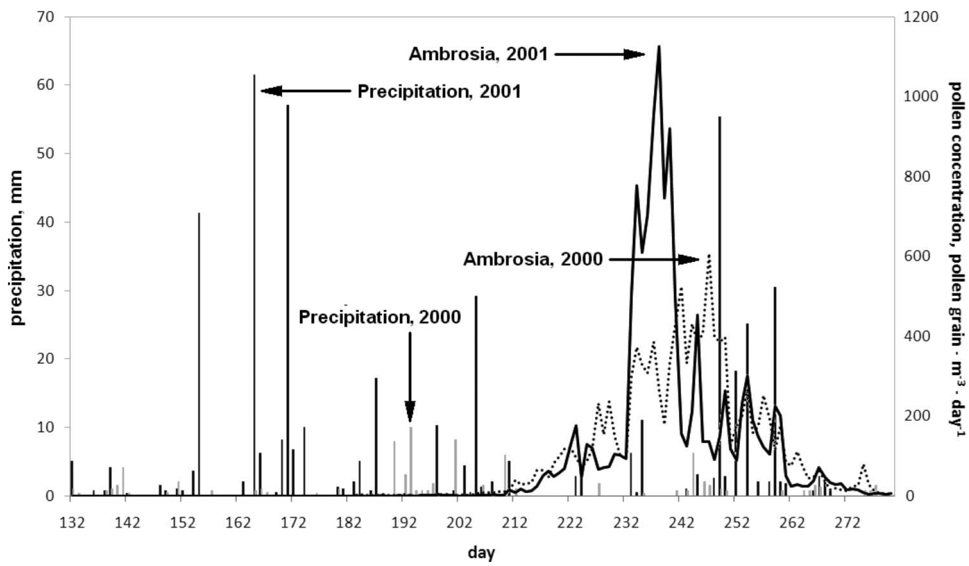

Figure 4. Daily pollen concentrations of *Ambrosia* in years with extreme precipitation (wettest year: 2001, driest year: 2000); Examination period of the years: days 132–280.

analysing pollen count characteristics, it is a frequent task to predict the starting date of the pollen season using meteorological information. A generally used technique includes the method of accumulated temperatures when daily mean temperatures are cumulated from a starting date. Specifically, if the actual cumulated temperature amount exceeds a given threshold on a day the start of the pollen season is identified with that day. The threshold and the starting day of temperature accumulation are estimated from an available data set as to minimise the mean squared error of estimated pollen season starts (Laaidi et al., 2003). Our starting days mentioned earlier were taken equal to starting days obtained from the procedure of cumulated daily mean temperatures.

Daily mean temperatures and daily precipitation amounts were cumulated over the earlier mentioned periods for every year separately, regarding the three taxa. These quantities were then related to annual pollen characteristics via correlations. Additionally, the annual course of both daily mean temperature and daily precipitation amount was described by fitting sine and cosine waves of one year and half year periods to the entire 14-year data set. The half year period was used to reproduce the asymmetry of the annual cycle. The mean squared deviation (MSD) between the actual daily mean temperature/precipitation amounts and the annual course was calculated for each year separately and for the periods corresponding to the three taxa. Years with the highest annual MSD values were then taken as extreme years. An extreme year is warm/cold (wet/dry) if its cumulated temperature (precipitation) is above/below the 14-year mean cumulated temperature (precipitation). Years (extreme years) were ordered from the highest to the lowest cumulated values, and these ranks of years were related to the ranks of ordered annual pollen characteristics via correlations (Spearman rank correlation).

As the number of data for calculating correlations is very small (14 or just six in some cases), the commonly used approximation to the probability distributions of estimated correlations with *t*-distributions is not advisable. Therefore, the interval for accepting the null-hypothesis of zero correlation was determined by a permutation test as follows. The N number values of meteorological variables (cumulated temperature, cumulated precipitation, ranks) corresponding to the N years were reordered while keeping the pollen characteristics. Correlation between these two new data sets was then calculated. Reordering and computation of the correlation were done in every possible case except for the original non-reordered case. Having ($N!-1$) number of correlations, the interval to be found for a significance level $\varepsilon \cdot 100\%$ is $(q_{\varepsilon/2}, q_{1-\varepsilon/2})$, where q_ε is the ε-quantile of these correlations.

Results

The pollen season for *Ambrosia artemisiifolia* in Hungary begins between 13 July and 4 August and lasts for almost three months. The maximum pollen release of flowers appears 1–1.5 weeks after their blossom (Szigetvári & Benkő, 2004). Pollination of Poaceae is species-dependent. The pollination peak of Poaceae species represented in the Szeged region begins in late spring (especially in May) and can last for almost the whole summer (mainly June–July), but a time-shift can be observed in the

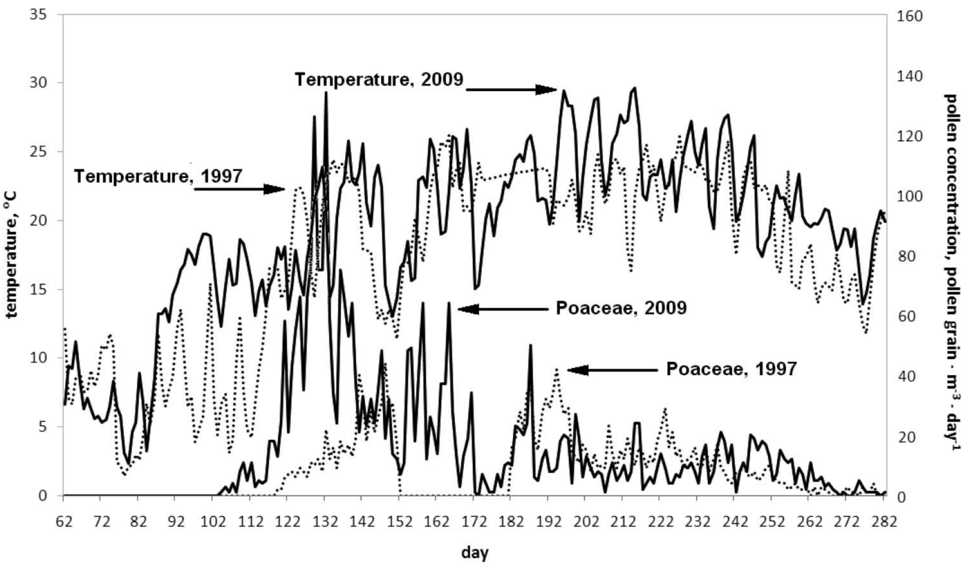

Figure 5. Daily pollen concentrations of Poaceae in years with extreme temperature (warmest year: 2009, coldest year: 1997); examination period of the years: days 62–282.

pollination of the different species resulting in a pollen season that can continue until early autumn even until September and October. In this way, different species are responsible for the measured pollen concentrations during the vegetation period. *Alopcurus pratensis* – being dominant in the flood-plain meadows, dykes and *Crisicum* type of secondary saline meadows of saved-side former inundated areas – and *Poa bulbosa* (species of disturbed grasslands) begin the pollen season for Poaceae in April. The pollen season of *Alopecurus pratensis* lasts until July, whereas that of *Poa bulbosa* keeps up just until June. For most of the grass species, pollen season begins in May, but it can last for different periods. The shortest pollen period can be detected for the main dry grassland species of *Festuca* spp. and the semi-wet, somewhat disturbed condition favouring *Poa angustifolia* that pollinates just for one month until June. Albeit the disturbed grassland favouring *Bromus* species, namely, *Poa trivialis* and some main cereals (wheat and barley) pollinate until July, the grass of the disturbed grassland (i.e. *Agropyron repens*) pollinates until September, whereas *Dactylis glomerata* (grass of sand steppe grasslands and regenerating fallows) even until October. The pollen season for the grasses of the sandland-type saline grasslands begins in early summer, in June and for the most halophytic *Puccinellia limosa*, it lasts just for one month, until July, whereas for *Agrostis stolonifera* it lasts until August. Maize starts its one-month pollination in July. As the continental precipitation peak in June is essential for the growth of the main grass of *Molinia* fens (the wettest moor-type vegetation in the surroundings of Szeged) in this way, the pollen season of *Molinia hungarica* starts in July and can last until September. The pollination of *Echinochloa crus-gallii* begins at the end of July and lasts even until October. *Phragmites communis* has the latest pollen season beginning in August and finishing in October. The pollination of all poplar species is short term and concentrates on the spring period between March and April without any plant-specific exceptions (Figure 2). Correlations between the pollen characteristics and the cumulated daily values of meteorological variables (temperature and precipitation) are summarised in Table I.

Table I. Correlations between daily pollen characteristics and cumulated daily values of meteorological variables.

Pollen characteristics, taxa	Temperature		Precipitation	
	Every year	Six years[a]	Every year	Six years[a]
TPA, *Ambrosia*	−0.39	−0.88 (1.8%)*	0.24	0.28
APC, *Ambrosia*	−0.51 (6%)*	−0.97 (0.2%)*	0.38	0.61
SPS, *Ambrosia*	0.20	0.09	0.17	0.26
EPS, *Ambrosia*	−0.27	−0.07	−0.07	−0.02
DPS, *Ambrosia*	−0.35	−0.20	−0.15	−0.20
TPA, Poaceae	−0.2	0.24	0.24	0.71
APC, Poaceae	−0.15	0.10	0.48 (8%)*	0.68
SPS, Poaceae	−0.41	−0.70	−0.19	−0.55
EPS, Poaceae	0.20	0.51	−0.18	0.00
DPS, Poaceae	0.30	0.68	0.01	0.52
TPA, *Populus*	0.22	0.11	0.16	0.42
APC, *Populus*	0.12	−0.16	0.14	0.31
SPS, *Populus*	−0.59 (3%)*	−0.72 (10%)*	−0.07	−0.21
EPS, *Populus*	−0.36	−0.77 (8%)*	−0.15	−0.10
DPS, *Populus*	0.46 (10%)*	0.56	0.00	0.33

Note: TPA – total pollen amount during the pollen season; APC – annual peak concentration; SPS – start of the pollen season; EPS – end of the pollen season; DPS – duration of the pollen season.
[a]The three warmest/coldest and the three wettest/driest years, respectively.
*Significance levels for correlations being non-zero are shown for levels no higher than 10% (in parentheses).

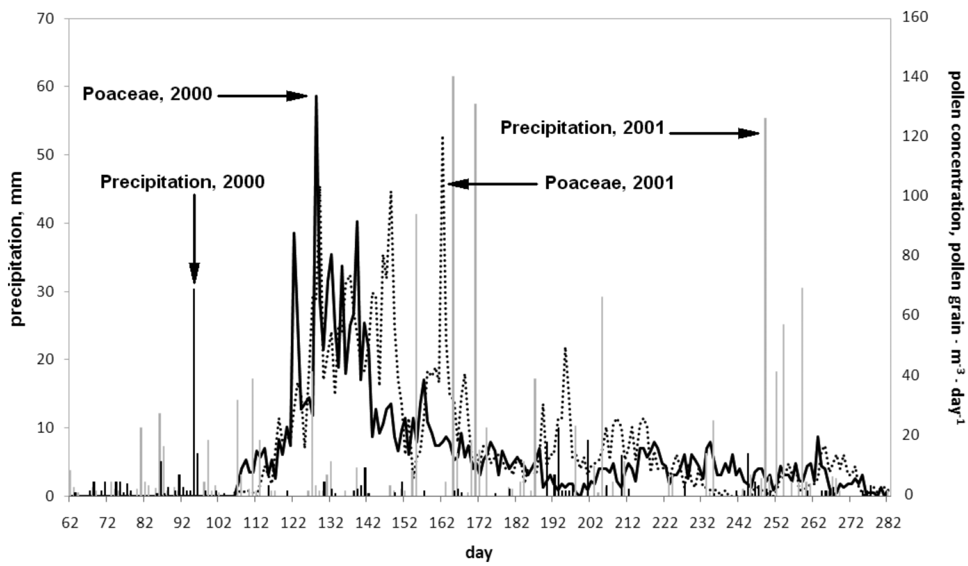

Figure 6. Daily pollen concentrations of Poaceae in years with extreme precipitation (wettest year: 2001, driest year: 2000); examination period of the years: days 62–282.

For *Ambrosia*, only temperature related associations are important. In a first approach, correlations were determined for every year, and then computed for the three warmest and coldest as well as for the three wettest and driest years (extreme years), respectively (Table I). 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 six 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 APC are in substantial negative connection with temperature (Figures 3, 4, Table I).

For Poaceae, considering every year, the APC is positively correlated with precipitation. However, there is no significant association between this pollen variable and temperature (Figures 5, 6, Table I).

For *Populus*, precipitation based associations are irrelevant, but for the extreme years, the end of the pollen season (EPS) is in significant negative correlation with temperature (Figures 7, 8, Table I).

Correlations between the rank of pollen characteristics and the rank of years based on cumulated temperature and precipitation were calculated for all three taxa 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 five significant correlations can be observed (Table I), but eight rank correlations are significant (Table II). 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 APC is inversely proportional to the rank of the annual temperature data. However, for the extreme years, the ranks of both TPA and APC are negatively associated with the rank of the annual

Table II. Correlations between the rank of daily pollen characteristics and the rank of years based on cumulated daily values of temperature and precipitation.

Pollen characteristics, taxa	Temperature: Every year	Temperature: Six years[a]	Precipitation: Every year	Precipitation: Six years[a]
TPA, *Ambrosia*	−0.39	−0.81(5%)*	0.15	0.14
APC, *Ambrosia*	−0.49(8%)*	−0.90(1%)*	0.43	0.67
SPS, *Ambrosia*	0.16	0.05	0.39	0.56
EPS, *Ambrosia*	−0.25	−0.22	0.00	0.06
DPS, *Ambrosia*	−0.28	−0.32	−0.23	−0.42
TPA, Poaceae	−0.21	0.29	0.37	0.67
APC, Poaceae	−0.17	0.21	0.45(10%)*	0.57
SPS, Poaceae	−0.40	−0.62	−0.14	−0.39
EPS, Poaceae	0.28	0.54	−0.12	−0.06
DPS, Poaceae	0.43	0.70	0.01	0.29
TPA, *Populus*	0.20	−0.09	0.20	0.61
APC, *Populus*	0.13	−0.37	−0.04	0.39
SPS, *Populus*	−0.04	−0.71	−0.07	−0.26
EPS, *Populus*	−0.16	−0.81(5%)*	−0.16	0.01
DPS, *Populus*	−0.08	0.56	−0.08	0.36

Note: TPA – total pollen amount during the pollen season; APC – annual peak concentration; SPS – start of the pollen season; EPS – end of the pollen season; DPS – duration of the pollen season.
[a]The three warmest/coldest and the three wettest/driest years, respectively.
*Significance levels for correlations being non-zero are shown for levels no higher than 10% (in parentheses).

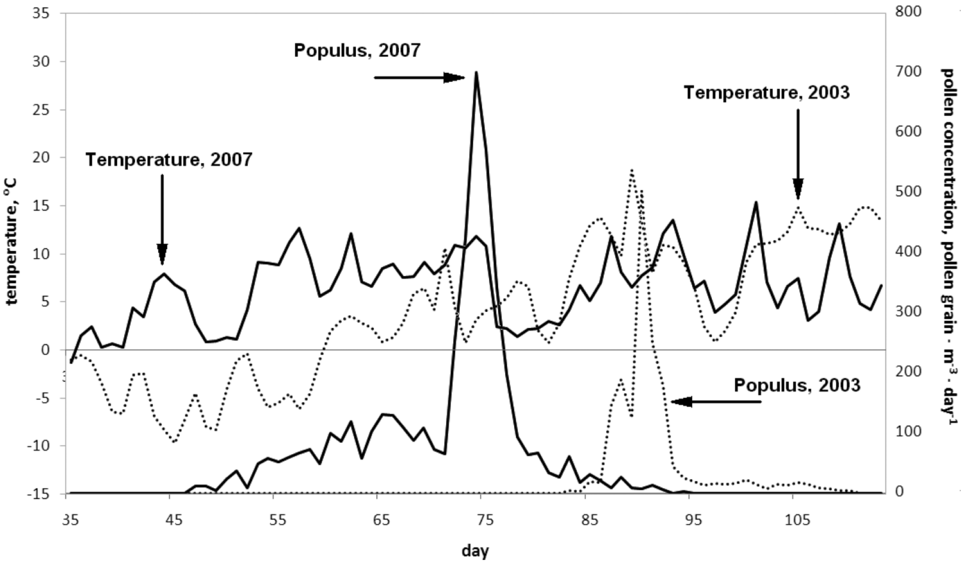

Figure 7. Daily pollen concentrations of *Populus* in years with extreme temperature (warmest year: 2007, coldest year: 2003); examination period of the years: days 35–113.

temperature data. In more detail, in the warmest year (2003), the TPA was the second smallest and the APC was the third smallest. In the coldest year (2001), the TPA was the second highest and the APC was the third highest (Figures 3, 4, Table II).

For Poaceae, considering every year, the rank of the APC is proportional to the rank of years based on precipitation. However, there is no significant association between the rank of any pollen characteristics and the rank of the extreme years based on either temperature or precipitation (Figures 5, 6, Table II).

For *Populus*, only temperature related substantial correlations have been detected. When regarding every year, the ranks for both the start of the pollen season (SPS) and the duration of the pollen season (DPS) are associated with the rank of the annual temperature data. Taking into account only the extreme years, the ranks of both the SPS and the EPS are inversely proportional to the rank of the annual temperature data. In more detail, in the warmest year (2007), the DPS was the third longest, while in the coldest year (2003), it was the fifth shortest. In the coldest year (2003), the SPS was the second latest, while in the warmest year (2007), it was the earliest (Figures 7, 8, Table II).

Interestingly, the pollen season of *Ambrosia* falls to the driest period of summer in Hungary. An extreme warm condition can limit the pollination of *Ambrosia* especially the lack of water, since 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 (Figures 3, 4).

A warmer spring can help both growth of Poaceae and their earlier flowering. If sufficient water is available, the late spring pollen peak can be high even in semi-wet or dry conditions. This is the case even if the early spring temperatures are higher than the average. As low spring temperatures can hinder the growth of these warm-tolerant continental grass species, they require proper temperatures. If the spring is cool and the early summer precipitation is high (accompanied with low temperatures), the pollen grains can be washed out from the air and pollen production can be reduced to its minimum. These cool and wet conditions, however, can enhance the late summer flowering and favour grass species such as *Molinia* and *Agrostis* spp., as well as maize, which, consequently, produces a higher number of pollen grains. The warm and cool years do not influence the number of pollen grains substantially for Poaceae during the warmest July–August months, because their pollen production decreases below the late spring peak in order to preserve water for survival. At the same time, there are exemptions for some salt-tolerant species and for those favouring early summer precipitation (see earlier) that is mainly responsible for the pollen production in the late summer period. Nevertheless, they produce less pollen than those species flowering in late spring. In this

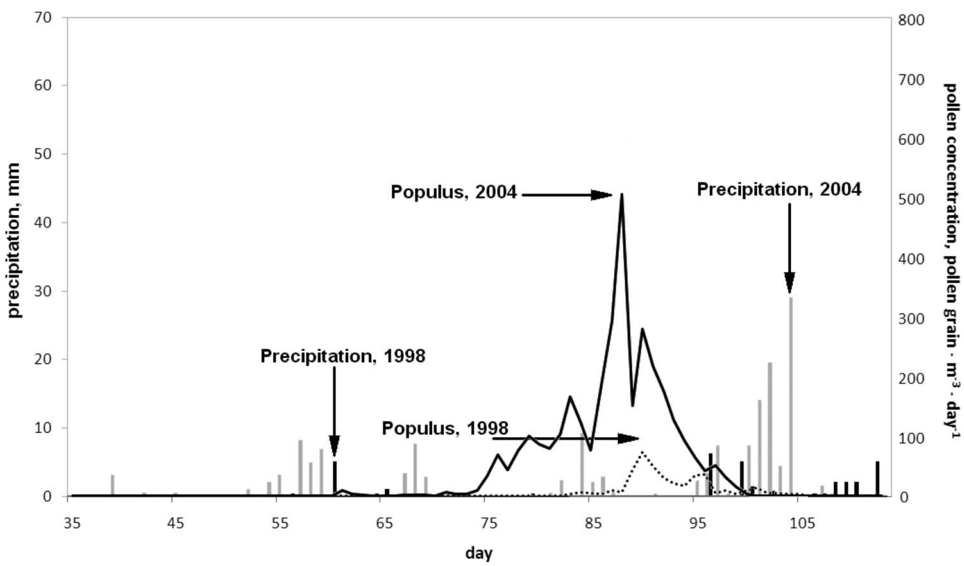

Figure 8. Daily pollen concentrations of *Populus* in years with extreme precipitation (wettest year: 2004, driest year: 1998); examination period of the years: days 35–113.

way, Poaceae living in salt meadows and Molinia fens can be less responsible for allergenic diseases (Figures 5, 6).

High early spring temperatures can enhance the growth of *Populus* and its pollen production can begin earlier due to the earlier start of its vegetative period. These warm conditions do not limit water resources for these species, especially for those stocks living in active floodplains receiving mass inundation during early spring floods. In this way, sufficient water with higher spring temperatures can help earlier blossoming of poplars resulting in higher pollen counts. In the case of a cool spring, even if there is no inundation in the floodplain areas, their pollen production is reduced because the metabolism of these species can slow down. If the beginning of the spring is cool, poplars must wait until the daily average temperatures increases above 0 °C, since a freeze-free period is required for their metabolism and pollen production. If temperatures are below 0 °C for a long time at the beginning of the year, the pollen season will begin later and shift to a later period. Consequently, it will last several days longer and daily peak pollen concentration will be smaller, compared to those in warm years. As poplars produce pollen in early spring, only a short warm period is available to start their annual life-cycle. In this way, a fast and early warming following the winter can be essential to produce more pollen. The faster this warming is and the higher the early spring temperatures can be, the most effective and higher pollen-production happens. Precipitation and inundation can also substantially influence the pollen production of poplars and can be even higher limitation factors for *Populus*. Even moderate but frequent rainfalls combined with floods can help poplars to reach very high pollen production. If precipitation is small and it falls rarely, the pollination period is much shorter and the pollen production is much smaller, especially if there is no flood. Later precipitation can help these species less as they are genetically adapted to spring pollen production. It means that no time-shift or secondary peak can be expected if the conditions are unfavourable (i.e. no rain, no flood during the early spring period; Figures 7, 8).

Discussion

A moderate warming is favourable for *Ambrosia* (Ziska et al., 2011). The increase of the 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 I, II). 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).

Poaceae can produce high biomass in years with higher than usual rainfall, which is in accordance with higher pollen production (Tables I, II). On their present diverse habitats – from sand steppes to floodplain meadows – rainfall increases biomass. Significant habitat changes and grassland-zone shifts are detected (Deák, 2010) between the neighbouring zones in wet years. Accordingly, wetter communities with higher biomass can appear on formerly drier places, so steppe grasslands can shift into meadows both in sand, loess and saline grassland dominated areas. These habitat-shifts are led by grasses; they appear first in the neighbouring habitats several times. Taller grasses like *Molinia* and *Alopecurus* have higher pollen-producing capacity compared with *Festuca*. However, actual grasses of habitats can also produce more pollen without habitat shift, as a result of higher rainfall. Similarly, cultivated crops (like wheat or maize) can have higher biomass due to increased rainfall, which means higher pollen production in their cases, as well (Tables I, II; Recio et al., 2010; Sicard et al., 2010). Poaceae show high sensitivity to the amount of available water (Tables I, II). High temperatures can be limits for them and can cause regional decreases. Nevertheless, as the species-pool of this family is the widest among the studied plant groups, there will be species to substitute the actual grasses. Even species from the Mediterranean and more continental areas will be able to reach the Carpathian-basin in the future. Although, in this case, the present species will be at risk; however, intra-taxonic re-assemblage could solve the problem. Shortage of water (Tables I, II) and too high temperatures can cause lower pollen production of natural grasslands and also in arable lands. This is why certain species in certain time periods and places can suffer from climate change. Nevertheless, the change in species composition will give a good chance for the survival of this family. Based on our data, Poaceae is sensitive to precipitation changes, while is indifferent to temperature variations.

Plantation of *Populus* species has not yet stopped during the last ten years. Besides locust-tree (*Robinia pseudoacacia* L.), they are the most favoured trees of afforestation in the Szeged region. The stocks planted during the last decades have grown up and are in mature state, so they can pollinate on high level. Warmer, moderately humid weather in the spring also favours their pollination. Since *Populus* has both wet and dry tolerant species from floodplains to bare sand, they have high environmental tolerance. Furthermore, they have low climate sensitivity (i.e. wide range of tolerance for climate conditions; Deák, 2010). However, the discrepancy between their low climate sensitivity on the one hand and a remarkably earlier start (Table II), later end (Tables I, II) and longer duration (Table II) of their pollen season on the other hand should be justified. A warming and drying climate is more favourable for them in general, facilitating their higher pollen release. Hence, a changing climate (warming and drying) may partly contribute to an extension of the pollen season (Tables I, II; Caramiello et al., 1994).

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 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 zero to three days). The duration of the pollen season was predicted by a regression model producing errors ranging from zero to seven 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).

Deen (1998) showed that the rate of development of common ragweed increased with temperature. Furthermore, strong associations of *Ambrosia*, Poaceae and *Populus* 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*a*; Piotrowska & Weryszko-Chmielewska, 2006; Kasprzyk, 2008; Ščevková et al., 2010) and for Poaceae (Bartková-Ščevková, 2003; Peternel et al., 2006*b*; 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 the one hand and the annual cycles of the daily slopes of mean temperature trends on the other hand. This measure is positive between the earlier 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. High daily mean Poaceae pollen levels are facilitated by anticyclone ridge weather situations (influenced by high mean values of temperature and air pressure as well as low relative humidity and wind speed) in accordance with expectations (Matyasovszky et al., 2011). Of the three taxa investigated, only Poaceae show a significant increase during the pollen season. Although *Populus* does not have any change concerning its pollen season, both the TPA and APC are definitely rising. Regarding the pollen season of

Ambrosia, a tendency for a later start can be observed (Makra et al., 2011).

For *Populus*, one should consider that weather conditions in the summer and/or autumn months of the previous year might have a major influence on the pollen production, since pollen grain formation in tree species begins much earlier (Van der Knaap et al., 2010). Therefore, correlations and rank correlations between the pollen characteristics and the cumulated daily values of meteorological variables (temperature and precipitation) were calculated with one-year shift as well. Relating pollen characteristics to previous-year meteorological variables, several periods within an entire period from early summer to middle autumn were selected to calculate cumulated daily temperatures and precipitation amounts. Correlations, in general, were remarkably higher (in absolute value) than those in Tables I and II. However, none of them were statistically significant (at least at 10% level) in contrast to values shown in Table I and, especially, in Table II.

The heat wave 2003 analysed by e.g. Gehrig (2006) modified the start, end and the duration of the pollen season only by 1–2 days for all three taxa, but influenced the pollen concentrations substantially in Szeged (Figure 2). Compared to the mean values of the remaining years, sizeable reduction of annual total pollen counts of *Ambrosia* (–41.6%), Poaceae (–25.0%) and *Populus* (–40.1%) can be observed for the year 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%) and Poaceae (–7.1%) a slight decrease, while for *Populus* a sharp increase (+373.3%), was recorded (Figure 2).

Based on our data set, all three taxa are 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* and Poaceae, while for *Populus* an increase is expected. Concerning *Ambrosia*, its habitat 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, forestry, 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 (EEA, 2010) and, hence, such a statistical procedure cannot be performed.

Conclusion

Correlation analysis between the original variables and between their ranks was performed in the study. Both Pearson and Spearman rank correlations were calculated. *Ambrosia* and *Populus* are reversely related to temperature (negative correlations), while Poaceae exhibits a parallel relationship with precipitation (positive correlations). On the whole, due to a warming and drying climate, pollen count characteristics (TPA and APC) indicate a decrease for *Ambrosia* and Poaceae, while for *Populus* an increase is expected.

Based on the daily pollen counts for *Ambrosia*, the coldest and the wettest years highly facilitate pollen production, while both for Poaceae and *Populus*, the warmest and wettest years favour higher pollen release.

Concerning spatial distribution, abundance and pollen release of the three taxa examined, the 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. With regard to *Ambrosia*, increasing temperature may benefit the first two, while it interferes with pollen production owing to the lack of rainfall. Concerning Poaceae, the situation is more complicated due to the extremely large number of its species. Generally, a moderate increase in temperature and precipitation is favourable for the pollen production of the spring species, while they have a smaller influence on summer species. For *Populus*, the amount of winter precipitation is much more important. Otherwise, the role of both temperature and precipitation is similar to the pollen production of Poaceae. If landscape use alters, the potential abundance and distribution of the taxa can substantially modify. Nevertheless, each taxon can give a special response to the yearly changing weather conditions. Although overall trends of their pollen counts can be explained partly by landscape-use changes, seasonal changes reflect weather conditions, which can enhance or suppress the overall trends. The genetic background of the three taxa examined gives a special response to the changing weather conditions that can determine their potential distribution influenced by landscape use.

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