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The influence of meteorological factors on *Ambrosia* pollen loads in Cracow, Poland, 1995–2006

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Abstract

Ambrosia is a highly allergenic, anemophilous genus of the Asteraceae family which is composed of about 40 species. We investigated a 12 year period of *Ambrosia* pollen occurrence to analyse annual totals, season starts, duration, peak days and the relationship between concentration and some meteorological factors. Analysis was performed on the basis of data collected in Cracow using the volumetric method in 1995–2006. *Ambrosia* pollen concentration showed seasonal fluctuation but no clear increasing tendency. In consecutive years the number of days with pollen increased, particularly in the category of < 10 pollen grains per day. Results of applied log-linear analysis indicated significant interaction between concentration and maximum temperature, and also significant interaction among independent variables. *Ambrosia* pollen has highest concentrations during the days with high values of maximum temperature ($T_{\max}$). The results of wind direction analysis showed that high pollen concentration occurred when wind blew from east (E) and east southeasterly (ESE) directions, which could have indicated long distance transport. When west (W) and west southwesterly (WSW) wind directions prevailed pollen could have been brought from local sources in the western part of Poland.

Keywords: Pollen concentration, meteorological factors, log-linear analysis, *Ambrosia*

The genus of *Ambrosia*, a member of the Asteraceae family, is composed of about 40 species. In Europe, five species of *Ambrosia* are recognised: *Ambrosia artemisiifolia* L. = *A. elatior* (short or common, annual ragweed), *Ambrosia trifida* L. (great or giant ragweed), *Ambrosia psilostachya* Torr. et Gray = *A. coronopifolia* (perennial ragweed), *Ambrosia tenuifolia* Spreng. (silver ragweed) (Hansen, 1976). However, short ragweed is the most widely spread of all (Járai-Komlódi & Juhász, 1993). *Ambrosia maritima* L. occurs in the Mediterranean region and is the only native species in Europe. The other four species probably have their origin in southern North America, from where they were introduced to Europe by importation of ragweed seeds with

American cereals. *Ambrosia* has evolved in response to a dry climate and open areas and from an entomophilous to an anemophilous pollination. In Western Europe four American species have already established because of easy and rapid spread, mainly due to the large production of seeds which may remain dormant in the ground for decades (Comtois, 1998; Dahl et al., 1999). *Ambrosia* also produces allergenic pollen in very large quantities. Each plant alone can produce millions of pollen grains which easily become airborne because of their small size and contain one of the most potent allergens known (Comtois, 1998). The presence of ragweed in Europe was recorded for the first time in the 19th century, although it became a real pest after

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the First World War (Juhász, 1998). In Europe the places most contaminated with ragweed are Hungary, Croatia and parts of France, but it is also spreading in northern Italy, Switzerland, Austria, the Czech Republic, Slovakia and Bulgaria (Dahl et al., 1998; Makovcová et al., 1998; Rybniček et al., 2000; Clot, 2003; Makra et al., 2004, 2005). The spread of ragweed seems to be limited by climate even if the human environment would allow its establishment (Comtois, 1998). In areas with a maritime climate, ragweed populations do not appear to thrive, and in Northern Europe the growing season is too short for seed maturation. Populations rely on the introduction of seeds from outside sources (Comtois, 1998; Dahl et al., 1999). In Poland, *Ambrosia* usually grows on disturbed soils, roadsides, and near harbours and cereal elevators. Ragweed is also common within the farmlands and other cultivated areas. *Ambrosia artemisiifolia* occurs more commonly and more densely in the western part of Poland. *Ambrosia psilostachya* appears to be less common and occurs in scattered stands in several regions in Poland, including the region of Cracow.

According to clinical studies in northern Italy, where the population of *Ambrosia* increased in recent years, its pollen provoked oculorhinitis and asthma symptoms from August to October (Zanon et al., 1998). Research in Austria analysed the relationship between *Ambrosia* pollen concentration and the immunological reaction of Vienna inhabitants. It was stated that within the higher *Ambrosia* pollen concentration, the higher the amount of ragweed pollen antibodies in the blood of patients suffering from inhalative allergy (Jäger & Litschauer, 1998).

Different studies have tried to define the threshold value of ragweed pollen concentration able to induce symptoms in sensitised patients. It should be stressed that the threshold values are different in different countries. The threshold value in France is 13 pollen grains per m^3 (p. m^{-3}) (Laaidi & Laaidi, 1999), 20 p. m^{-3} in Austria (Jäger, 1998), 30 p. m^{-3} (Makra et al., 2005) or 50 p. m^{-3} (Juhász & Gallowich, 1995) in Hungary. The aim of the study was to investigate for a 12 year period of *Ambrosia* pollen occurrence in Cracow, and to analyse annual totals, season starts, duration, peak days due to the possible relationship between its pollen concentration and some meteorological factors.

Material and methods

Study site

Ambrosia pollen concentrations in Cracow were investigated in 1995–2006. Cracow ($50^{\circ}04' \text{N}$,



Figure 1. The monitoring site locality map (Cracow, Poland).

$19^{\circ}58' \text{E}$; 220 m a.s.l.) is a relatively large city covering 327 km^2 area and with over 1 million inhabitants in the urbanised area. Located in southern Poland in the Malopolska (Lesser Poland) province (Figure 1), Cracow is surrounded by strongly nucleated and transformed farmlands and mutilated pro parte forests. To the north of Cracow there are farmlands with small forest communities; in the south and east of Cracow there are roughly equal areas of farmlands and forests and to the west of the city forest communities prevail (Kornaś & Medwecka-Kornaś, 1967). *Ambrosia artemisiifolia* is more widespread than *Ambrosia psilostachya*, particularly to the west of Cracow (Figures 2 and 3).

Pollen concentration has been monitored using a Burkard trap located on the roof (ca. 25 m above ground level) of the university building of Sniadecki's Collegium, situated in the centre of Cracow. Airborne pollen grains were sampled continuously, 12 months a year during 1995–2006. The Melinex tape used for catching pollen grains was replaced every Tuesday at 8 a.m. and cut into segments corresponding to 24 h periods. Daily average pollen counts were expressed as pollen grains per cubic meter of air.

Climate and meteorological data

Cracow and Poland are influenced by the air masses of the polar-maritime origin coming from over the Northern Atlantic which bring thaw, an increase in

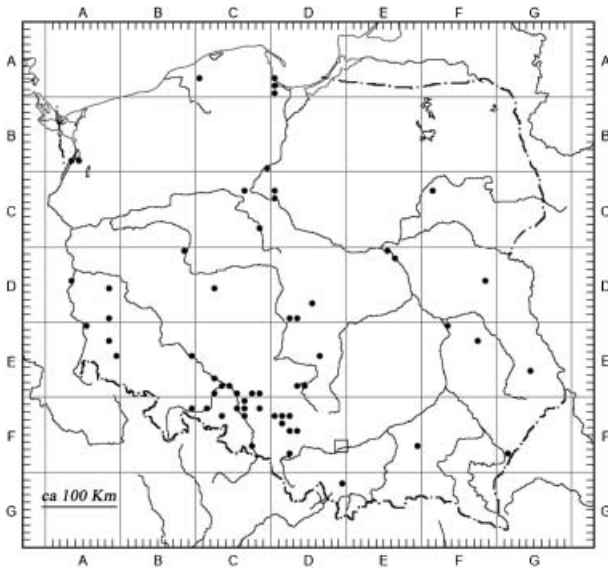


Figure 2. Distribution of *Ambrosia artemisiifolia* in Poland (square frame indicates locality of Cracow). Adapted from original map of B. Tokarska-Guzik in: Zajac, A. & Zajac, M. (2001).

cloudiness and snow in Winter and chilling, an increase in cloudiness and rainfall in Summer. Mean January and July temperatures in Cracow are -3.4°C and 17.6°C respectively, and mean annual sunshine duration per day is 3.9 hours, although from April to September it is 5.7 hours (Woś, 1999). Mean annual precipitation is approximately 700 mm. The highest rainfall level is recorded in Summer (June, July, and August). In the annual cycle about 40% of rain falls in these months in Poland (Dynowska, 1991). Mean annual humidity is 79% and wind from a westerly direction prevails. Mean wind velocity is relatively low, ca. 2.9 ms^{-1} (Woś, 1999). The Department of

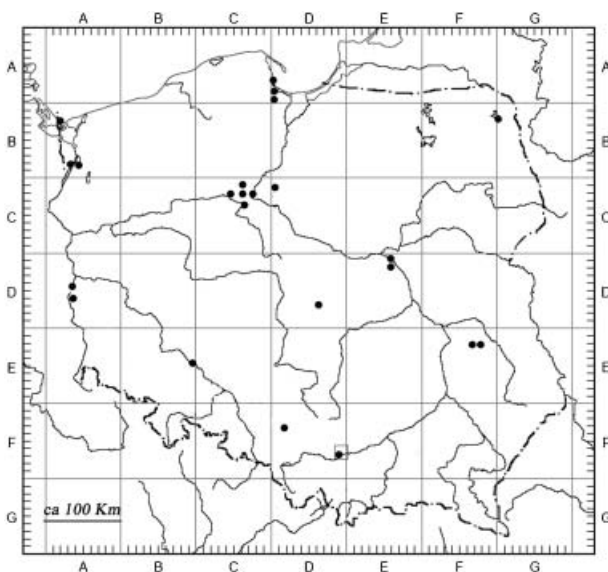


Figure 3. Distribution of *Ambrosia psilostachya* in Poland (square frame indicates locality of Cracow). Adapted from original map of B. Tokarska-Guzik in: Zajac, A. & Zajac, M. (2001).

Climatology at Jagiellonian University provided us with meteorological data recorded at the weather station located in the immediate vicinity of the monitoring site.

Palynological data and statistics

Analysis of *Ambrosia* pollen concentrations was performed on the basis of data collected in Cracow using the volumetric method. Two different counting methods have been employed. From 1995 to 1999 pollen grains were counted along 12 latitudinal transects. From 2000 to 2006 this method was changed into counting along four longitudinal transects on the basis of the method used by the Spanish Aerobiology Network (REA). Cariñanos et al. (2000) concluded that proportion of analysed surfaces is 11.25% of the total surface for the transverse method, and 12.85% for the longitudinal method. Pollen seasons were calculated using the 90% method. The start of the season was defined as the date when 5% of the seasonal cumulative pollen count was trapped and the end of the season as the date when 95% of the seasonal cumulative pollen count was reached (Nilsson & Persson, 1981). To define the relationship between concentration and meteorological parameters, log-linear analysis was performed, using the Statistica program version 7.0.

Results

The study on *Ambrosia* pollen indicated variation in concentrations (Figure 4A–D; Table I). The lowest annual sum was 19 p. m^{-3} , recorded in 1996 and the highest annual sum 310 p. m^{-3} in 1999. The highest daily count was 85 p. m^{-3} which was noted on September 3, 1999. Periods of pollen occurrence were defined as the periods of 90% of the total catch. Start dates were found in the first half of August (4 years) or in the second half of August (7 years). In 1999 the season started on September 3 and was very short and intensive. Start dates were similar for 4 years and also for 7 years, although duration and intensity of the seasons were different, especially comparing 7 years.

Ambrosia pollen grains are considered to be important aeroallergens. Days with a number of pollen grains over 13 p. m^{-3} (which is accepted in France as threshold value for clinical symptoms; see Laaidi & Laaidi, 1999) and with over 20 p. m^{-3} (assumed as similar threshold in Austria; see Jäger, 1998) are demonstrated (Table I). In the years examined in Cracow, the number of days when the threshold value was exceeded was low. The highest value was seen for 5 days in 1999.

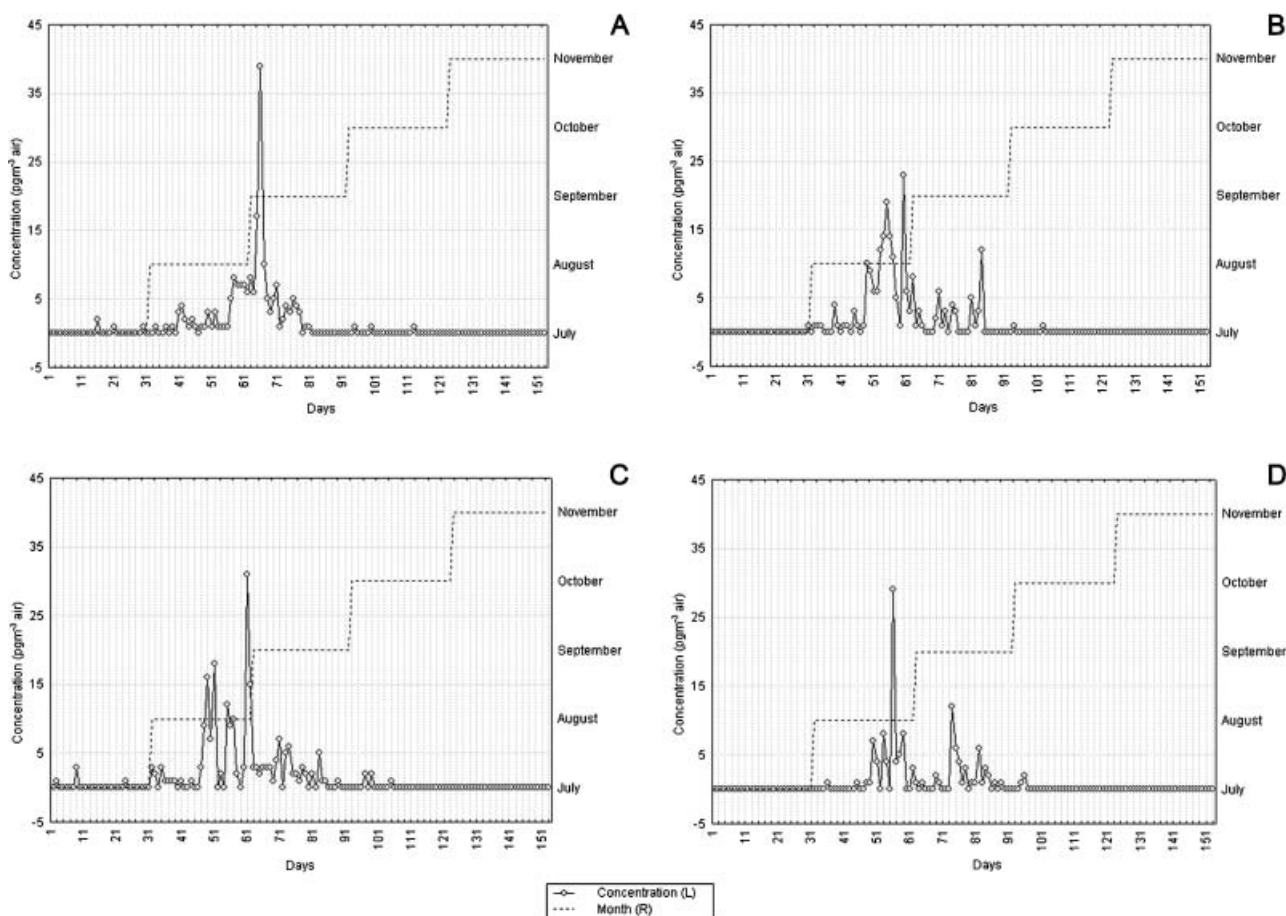


Figure 4. Variation in *Ambrosia* pollen concentration in selected years (1 July – 30 November): **A.** 2002; **B.** 2003; **C.** 2004; **D.** 2005.

A linear trend for annual concentrations of *Ambrosia* pollen in 1995–2006 is significant at probability level $p=0.0115$. The adjusted determination coefficient (R^2_{adj}) multiplied by 100% gives the percentage of concentration changes explained by time (Figure 5). However, it must be remembered that there is no direct relationship between

concentration and time, but between concentration and meteorological factors changing with time. In the context of trend analysis it is not clear exactly which meteorological factors influence pollen concentration of *Ambrosia*. To answer this question, regression analysis for categorical data (log-linear analysis) was performed.

Table I. The selected data of the *Ambrosia* pollen presence in Cracow during 1995–2006.

Year	Period of occurrence ^a	Season duration (days)	Annual sum of pollen grains (p. m ⁻³)	Peak day	Concentration in a peak day	No. of days with over 13 p. m ⁻³	No. of days with over 20 p. m ⁻³
1995	18.08–19.11	94	22	18.08	11	0	0
1996	19.08–03.09	16	19	03.09	12	0	0
1997	16.08–23.09	39	34	25.08	6	0	0
1998	22.08–13.09	23	71	12.09	47	1	1
1999	03.09–07.09	5	310	03.09	85	5	5
2000	04.08–11.09	39	60	19.08	14	1	0
2001	15.08–02.10	49	141	17.08	34	1	1
2002	10.08–14.09	36	200	04.09	39	2	1
2003	12.08–21.09	41	210	29.08	23	4	1
2004	04.08–21.09	49	221	30.08	31	4	1
2005	19.08–23.09	36	126	25.08	29	1	1
2006	19.08–30.09	43	100	25.09	14	1	0

^a90% Method.

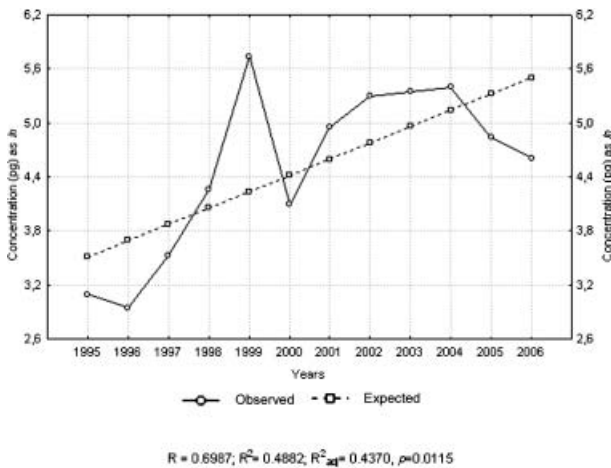


Figure 5. Trend-line for annual concentrations of *Ambrosia* pollen during 1995–2006.

It was observed that the number of days with *Ambrosia* pollen gradually increased from 1995 to 2006 (Table II). Most of the days were days with low pollen concentration, below 10 p. m^{-3} per day. In this group the increase in number of days was clearly seen.

Due to low and variable *Ambrosia* pollen concentrations, usually short seasons and many zero values, multiple regression analysis failed to detect a statistically significant trend. In this case we accepted log-linear analysis which could be treated as multiple regression analysis for categorical data. All quantitative data (dependent and independent variables) were transformed into categorical data. For log-linear analysis, the following categorical data were taken:

1. Pollen concentration – 2 categories: ‘YES’ and ‘NO’;

Table II. Days with *Ambrosia* pollen grains (YES) in different concentration categories and days without (NO).

YES						
Years	Days Total	Days by category (p. m ⁻³)				NO
		<10	10–19	20–49	≥50	
1995	9	8	1	0	0	356
1996	5	4	1	0	0	361
1997	20	20	0	0	0	345
1998	18	17	0	1	0	347
1999	17	12	0	2	3	348
2000	17	15	2	0	0	349
2001	46	45	0	1	0	319
2002	48	45	2	1	0	317
2003	41	33	7	1	0	324
2004	49	43	5	1	0	317
2005	32	30	1	1	0	333
2006	40	39	1	0	0	325
Total	342	311	20	8	3	4041

2. Maximum day temperature ($T_{\max}$ –3) categories: low temperature ($T_{\max} < 10^\circ\text{C}$), moderate temperature ($10^\circ \leq T_{\max} < 20^\circ\text{C}$), high temperature ($T_{\max} \geq 20^\circ\text{C}$);
3. Wind direction at noon – 17 categories;
4. Rainfall – 2 categories: ‘YES’ and ‘NO’.

Results of log-linear analysis indicated significant interaction between concentration and maximum temperature and also significant interaction among independent variables which did not interact with concentration variable (Table III). The high p -value showed that the model fits well empirical data.

The distribution of day numbers with *Ambrosia* pollen concentration dependent on maximum temperature is presented (Table IV). The relation of days with moderate temperatures and pollen presented, and all days within these temperatures is ca. 15.5 times higher than similar relations within low temperatures. The same relation is 42.5 among the high and low temperatures examined.

Analysing 17 wind directions, the number of days with defined wind direction was calculated. Eight wind directions, those most often occurring, were selected for detailed analysis (Table V). When wind blew from easterly (E) and east-southeasterly (ESE) directions, which occurred the most often during *Ambrosia* pollen season, a higher percentage of days with pollen was observed than days with no pollen (% was calculated along a horizontal line). Wind from a west southwesterly (WSW) direction also had a slightly high percentage of days with pollen. Wind from a westerly (W) direction is most frequent in Cracow, but not during the *Ambrosia* pollen season, which explains the lower percentage of days with pollen than days with no pollen.

Table III. Results of log-linear analysis of the *Ambrosia* pollen occurrence in Cracow during 1995–2006.

Test	χ^2	df	p
Maximum likelihood chi-squared	85.757	99	0.82607
Pearson chi-squared	91.157	99	0.70025

Table IV. Distribution of days with the *Ambrosia* pollen in Cracow during 1995–2006, dependent on $T_{\max}$.

$T_{\max}$	Concentration		Days Total	YES/Total %
	NO	YES		
Low	1596	7	1603	0,4
Moderate	1202	80	1282	6,2
High	1243	255	1498	17,0
Total	4041	342	4383	–

Table V. Analysis of days with 'NO' and 'YES' *Ambrosia* pollen according to analysed 17 wind directions in Cracow during 1995–2006.

	WSW	W	E	NE	WNW	ESE	NW	N	Total ^b
NO ^a	320	848	360	174	537	230	172	128	4041
NO %	7.92	20.99	8.91	4.31	13.29	5.69	4.26	3.17	
YES ^a	29	61	41	6	46	43	6	6	342
YES %	8.48	17.84	11.99	1.75	13.45	12.57	1.75	1.75	
Total	349	909	401	180	583	273	178	134	4383

^aNo. of days; Bold numbers - higher percentage in 'YES' days than 'NO' days ^bTotal=number of all days calculated for analysed 17 wind directions.

It is likely that *Ambrosia* pollen resulted from long distance transport associated with E and ESE wind directions, suggesting transport from the Czech Republic, Slovakia, Hungary and Ukraine. On the other hand, W and WSW wind directions could bring pollen from local sources in the western region of Poland.

Discussion

A 12 year study on *Ambrosia* pollen occurrence in Cracow showed that the linear trend for annual concentrations was significant. Other authors observed a similar trend in *Ambrosia* pollen concentration in another Polish city and European countries (Albasser, 1992; Pizzulin Sauli et al., 1992; Pozzi et al., 1992; Jäger & Litschauer, 1998; Laaidi & Laaidi, 1999; Clot, 2003; Puc, 2004). Generally the *Ambrosia* pollen concentration in Cracow is low and does not usually exceed threshold value. According to some authors, the threshold value is concentration at which 60–80% of people allergic to ragweed pollen react with acute symptoms of pollinosis (Járai-Komlódi, 1998; Laaidi & Laaidi, 1999; Bass et al., 2000). In Cracow, the highest number of days when the threshold value given by Laaidi & Laadi (1999) and Jäger (1998) was exceeded was 5 days in 1999. Similarly to Cracow, the very short period of a few days when the concentration was higher than the threshold value was noted in Szczecin, Poland (Puc, 2004). According to reports in Hungary there are 25–30 days in the critical period with daily pollen counts over the allergological threshold value (Járai-Komlódi, 1998). In spite of this, almost half of the patients suffering from pollen allergy in Cracow revealed a positive skin prick test to *Ambrosia* pollen (Obtułowicz et al., 1995). Similar results were reported by Rybniček et al. (2000) in the Czech Republic, where despite low ragweed pollen concentration high sensitisation (over 20%) of population allergic to ragweed has occurred.

A different situation was observed in Genoa (Italy), where *Ambrosia* pollen has been rising since 1989 and reached a maximum pollen count in 1995–

1997 although skin prick test positivity was very rare (about 0.5%) without any evident increase (Valtolini et al., 2000). Carosso & Gallesio (2000) stated a low percentage of sensitisation to ragweed pollen in Turin (Italy). One of the reasons could be the low percentage of *Ambrosia* pollen in the atmosphere.

In New South Wales, Australia ragweed pollen grains were present in the air in sufficient numbers and for a sufficient length of time to both sensitise and cause late Summer respiratory symptoms (hay fever, asthma) (Bass et al., 2000). Pollen is greatly influenced by the meteorological parameters which determine the pollen count in the air. The most important factors include primary factors (sunshine or temperature) which influence the growth and development of specimens and control the pollen production, secondary factors (rainfall, relative humidity) which influence the opening of anthers and so the release of pollen grains, then tertiary factors (mostly wind) causing the grains to be distributed in the atmosphere (Laaidi, 2001).

Results of log-linear analysis performed in Cracow showed significant interaction between *Ambrosia* pollen concentration and maximum temperature. Similar positive correlation between the pollen amount in the air and the maximum day temperature ($T_{\max}$) has been found in Poznań (Stach, 2002) and Szczecin (Puc, 2004, 2006) both in Poland. A statistically significant effect of temperature on the ragweed pollen concentration was reported also by Barnes et al. (2001) in the USA.

Analysis of wind directions occurring the most often in Cracow showed pollen concentrations associated to E, ESE, W, and WSW wind directions which indicated long distance transport (the Czech Republic, Slovakia, Hungary, Ukraine) and also local sources in the western region of Poland. Earlier studies on *Ambrosia* pollen occurrence in Cracow confirm the possibility of long distance transport from those wind directions (Stepalska et al., 2002). A few studies have shown that long distance transport of ragweed pollen has occurred in other European countries. In Switzerland the presence of *Ambrosia* pollen is often noticed in cases of a strong

west or south-west wind blowing, probably coming from the Rhone Valley and the Bresse in France, and the Po Valley in Italy (Peeters, 2000).

A research study performed in Catalonia, Spain showed a considerable, although temporary, increase in *Ambrosia* pollen concentration in 1996 in a single day. It was attributed to long distance transport, caused by unusual conditions of atmospheric circulation from the Lyon region in France where the species is abundant (Belmonte et al., 2000). In southern Sweden, investigation of pollen from 1995 to 1998 was associated with the air coming from Eastern Europe (Dahl et al., 1999). Saar et al. (2000) concluded that Eastern European countries (Russia, Hungary and Ukraine) might be the possible source of *Ambrosia* pollen in the Baltic countries, i.e. regions close to southern Sweden. A highly statistically significant relationship between daily prevailing wind direction and pollen count was found in Florence and Pistoia, Italy. The path of back trajectories suggested the area around southern Hungary as a possible source of *Ambrosia* pollen (Cecchi et al. 2005). *Ambrosia* pollen episodes studied in Poznań by Stach et al. (2007) using back trajectories showed that those episodes which peaked in the early morning usually arrived at Poznań from a southerly direction after passing over southern Poland, the Czech Republic, Slovakia and Hungary. This confirms the results presented in this paper. Air masses bringing *Ambrosia* pollen to Poznań during the afternoon arrived from an easterly direction, and it is likely that they originated from within the country. To sum up, further studies are needed to control *Ambrosia* pollen concentration from an allergological point of view and also to recognise pollen sources using back trajectory analysis.

Conclusions

A 12 year study on *Ambrosia* pollen occurrence in Cracow during 1995–2006 showed that *Ambrosia* pollen annual totals and season duration differed from year to year. Start dates were found in August except in 1999 when the season started on September 3. The number of days when threshold values were overrun (over 13 and 20 p. m⁻³) was low during the studied period. The highest number of those days was 5 in 1999. Trend analysis showed that the linear trend for annual concentration was significant. Results of log-linear analysis indicated significant interaction between concentration and maximum temperature and also significant interaction among independent variables. In view of our observation it is likely that *Ambrosia* pollen resulted from long distance transport associated to E and

ESE wind directions (the Czech Republic, Slovakia, Hungary, and Ukraine). W and WSW wind directions could have brought pollen from local sources in the western part of Poland.

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