

Examining *Ambrosia* pollen episodes at Poznań (Poland) using back-trajectory analysis

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Abstract The pollen grains of *Ambrosia* spp. are considered to be important aeroallergens in parts of southern and central Europe. Back-trajectories have been analysed with the aim of finding the likely sources of *Ambrosia* pollen grains that arrived at Poznań (Poland). Temporal variations in *Ambrosia* pollen at Poznań from 1995–2005 were examined in order to identify *Ambrosia* pollen episodes suitable for further investigation using back-trajectory analysis. The trajectories were calculated using the transport model within the Lagrangian air pollution model, ACDEP (Atmospheric Chemistry and Deposition). Analysis identified two separate populations in *Ambrosia* pollen episodes, those that peaked in the early morning between 4 a.m. and 8 a.m., and those that peaked in the afternoon between 2 p.m. and 6 p.m.. Six *Ambrosia* pollen episodes between 2001 and 2005 were examined using back-trajectory analysis. The results showed that *Ambrosia* pollen episodes that peaked in the early morning usually arrived at Poznań from a southerly direction after passing over southern Poland, the Czech Republic, Slovakia and Hungary, whereas air masses that brought *Ambrosia* pollen

to Poznań during the afternoon arrived from a more easterly direction and predominantly stayed within the borders of Poland. Back-trajectory analysis has shown that there is a possibility that long-range transport brings *Ambrosia* pollen to Poznań from southern Poland, the Czech Republic, Slovakia and Hungary. There is also a likelihood that *Ambrosia* is present in Poland, as shown by the arrival of pollen during the afternoon that originated primarily from within the country.

Keywords Aerobiology · Ragweed · *Ambrosia* · Poznań · Back-trajectory analysis

Introduction

This study focuses on pollen grains from the genus *Ambrosia* spp. (Family Asteraceae). In Europe, the only native species of *Ambrosia* (ragweed) is *Ambrosia maritima* L. (Laaïdi and Laaïdi 1999; Laaïdi et al. 2003). Four other species have been accidentally introduced from North America, probably with imported cereals; these are *Ambrosia artemisiifolia* L. (= *Ambrosia elatior* L.), *Ambrosia trifida* L., *Ambrosia tenuifolia* Spreng. and *Ambrosia psilostachya* DC. (= *Ambrosia coronopifolia* Torr. & Gray) (Laaïdi and Laaïdi 1999; Stepalska et al. 2002; Makra et al. 2004; Tamaracaz et al. 2005). The distribution of *Ambrosia psilostachya* (perennial ragweed) is uncertain due to its confusion with other species (Rich 1994) and *Ambrosia tenuifolia* (silver ragweed) is present only in France and Spain (Tamaracaz et al. 2005). In Europe, *Ambrosia artemisiifolia* (common or short ragweed) is the most widespread and probably the most important species in terms of allergy, whereas *Ambrosia trifida* (giant ragweed) is important locally (Dahl et al. 1999; Rybníček et al. 2000; Makra et al. 2004).

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Ambrosia artemisiifolia is an annual species that produces entirely by seed (Rich 1994). Common ragweed spreads very quickly, colonising cultivated fields as well as riparian and ruderal habitats. Each plant can produce prodigious amounts of seed (from about 3,000 to around 60,000 seeds per plant) that can remain dormant for at least 39 years if conditions are unsuitable for germination (Rich 1994; Comtois 1998; Dahl et al. 1999; Peternel et al. 2005; Tamaracaz et al. 2005). The pollen of *Ambrosia* spp. are considered to be very potent aeroallergens; each plant can produce millions of pollen grains, but the threshold value for clinical symptoms for the majority of sensitised patients is below 20 ragweed pollen grains/m³ (Comtois 1998; Jäger 1998, 2000; Tamaracaz et al. 2005). Furthermore, *Ambrosia* pollen appears to induce asthma about twice as often as other pollen, and there is significant cross-reactivity between ragweed species within the *Ambrosia* genus as well as between the major allergens of *Ambrosia* and *Artemisia* (Dahl et al. 1999; Jäger 2000; White and Bernstein 2003; Tamaracaz et al. 2005).

Ambrosia artemisiifolia favours a warm continental climate and dry soils (Dahl et al. 1999; Stepalska et al. 2002; Peternel et al. 2005; Tamaracaz et al. 2005). The places in Europe most contaminated with ragweed are Hungary, Croatia, and parts of France (the Rhône-Alps region and Burgundy), but it is also spreading in areas such as northern Italy, Switzerland, Austria, the Czech Republic, Slovakia, Bulgaria, Bosnia, Serbia, Romania, Ukraine and European Russia (Makovcová et al. 1998; Dahl et al. 1999; Rybníček et al. 2000; Laaidi et al. 2003; Makra et al. 2004; Peternel et al. 2005; Tamaracaz et al. 2005). The spread of ragweed seems to be limited by climate (Comtois 1998; Saar et al. 2000). Ragweed populations do not appear to thrive in areas with a maritime climate, and in northern Europe the growing season is too short for seed maturation, so populations rely on the regular introduction of seeds from outside sources (Comtois 1998; Dahl et al. 1999; Saar et al. 2000). In Europe, *Ambrosia* has been recorded as far north as Poland, the Baltic States and even Sweden, but populations are often ephemeral and scattered (Dahl et al. 1999; Saar et al. 2000; Stepalska et al. 2002). *Ambrosia artemisiifolia* has been recorded in Poznań (Poland) in the past (Zukowski 1960; Jackowiak 1993), but recent surveys have shown that these areas are no longer populated (Stach 2005).

Trajectory analysis involves plotting the path an air parcel travels during a definite time interval. The technique has been used in aerobiology to investigate the movement of airborne pollen (Hjelmroos 1991, 1992; Smith et al. 2005), including studies of *Ambrosia* pollen episodes in Spain (Belmonte et al. 2000), Italy (Cecchi et al. 2006) and the Baltic States (Saar et al. 2000). The aim of this paper is to examine the path along which air masses have travelled,

in order to determine the likely sources of *Ambrosia* pollen grains that arrive at Poznań.

Materials and methods

Site

Poznań (population 578,235) is the capital of Wielkopolska, an agricultural region situated in mid-western Poland (Stach 2000; GUS 2001). *Ambrosia* pollen data were collected in Poznań by a Burkard volumetric spore trap of the Hirst design (Hirst 1952) from 1995 to 2005. The trap in Poznań was originally situated (1995–1996) in an old district of the city at a height of 36 m (52°24'N, 16°55'E). However, from 1997–2005 the trap was sited on the roof of a 13-storey university students' dormitory (Esculap) at a height of about 33 m (52°24'N, 16°53'E), approximately 1 km south-west of the city centre (GUS 2001; Corden et al. 2002). These two *Ambrosia* pollen datasets from Poznań were spliced together to make a single dataset running from 1995 to 2005. In addition, *Ambrosia* pollen data were taken from a third trap that was erected in 2005 on the roof of the Faculty of Physics building (height 22 m) in Morasko campus on the northern outskirts of the city (52°27'N, 16°55'E). Morasko is situated in an area that is a mixture of open grassland and coniferous woodland, with isolated stands of deciduous trees. Pollen data from Morasko were examined in order to discover whether there were any spatial variations in the timing and magnitude of peak *Ambrosia* pollen concentration in Poznań.

Climate and meteorological data

Poland has a temperate continental climate, and so has cold winters and warm summers. However, as well as having a continental climate Poznań is located in an area of western circulation, and as a result, winds from the West and southwest predominate. Mean January and July temperatures in Poznań are -1.4°C and 19.2°C respectively, and mean annual precipitation is approximately 500 mm (Wos 1994; Stach 2000; Corden et al. 2002). Meteorological data for Poznań were recorded at the Institute of Meteorology and Water Management site at Ławica Airport (52°25'N 16°49'E) approximately 4.25 km west of the pollen monitoring site at Esculap.

Ambrosia pollen counts

Temporal (seasonal and diurnal) variations in *Ambrosia* pollen counts at Poznań were examined with the aim of identifying *Ambrosia* pollen episodes that were suitable for investigation using back-trajectory analysis. Two different

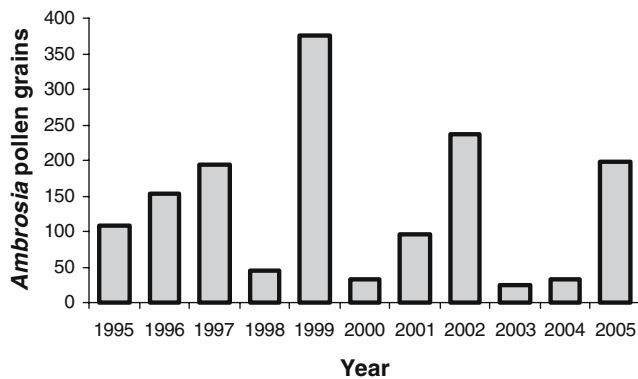
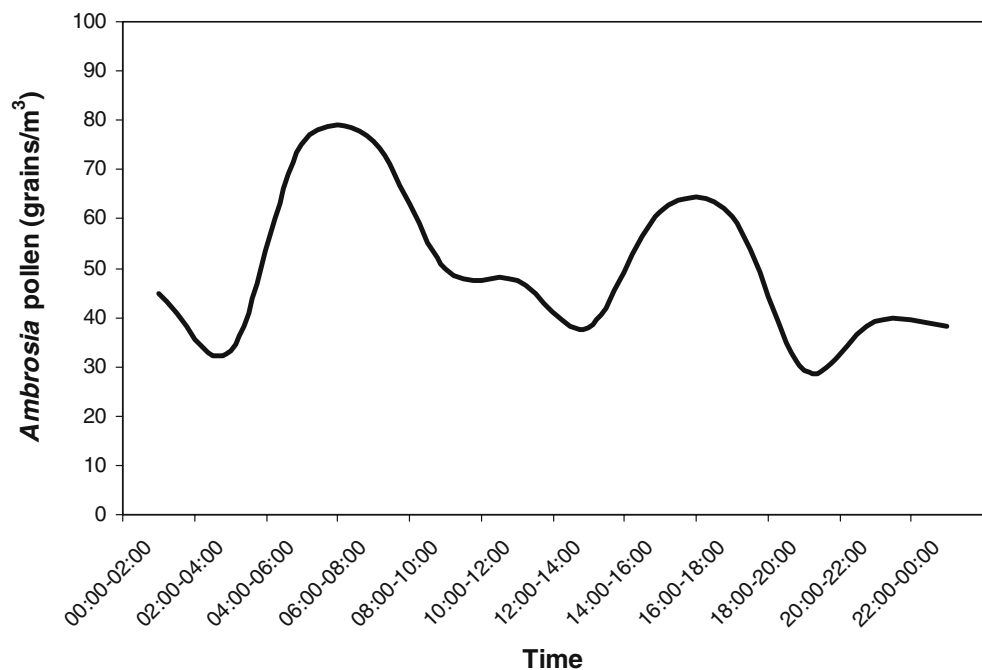


Fig. 1 Sum of *Ambrosia* pollen recorded annually at Poznań

counting methods have been employed at Poznań. From 1995 to 1999 pollen data were collected following the methods outlined by Stach (2000), whereby pollen grains were counted along 12 latitudinal transects. From 2000 to 2005 this method was changed, and pollen grains were counted along four longitudinal transects, which were divided into 2 mm (1-hourly) intervals. Daily average (00:00 to 00:00 hours) *Ambrosia* pollen counts are expressed as grains/m³.

The use of two different counting methods at Poznań meant that it was necessary to transform hourly counts (data from 2000 to 2005 were changed into two-hourly intervals) so that a direct comparison could be made between years. The *Ambrosia* pollen episodes identified for further analysis occurred in 2001, 2002 and 2005, it was therefore possible to run trajectories for the exact time that *Ambrosia* pollen counts peaked. Diurnal variations are also expressed as grains/m³.

Fig. 2 Mean diurnal variation of *Ambrosia* pollen episodes ≥ 20 grains/m³ recorded in the centre of Poznań (1995–2005)

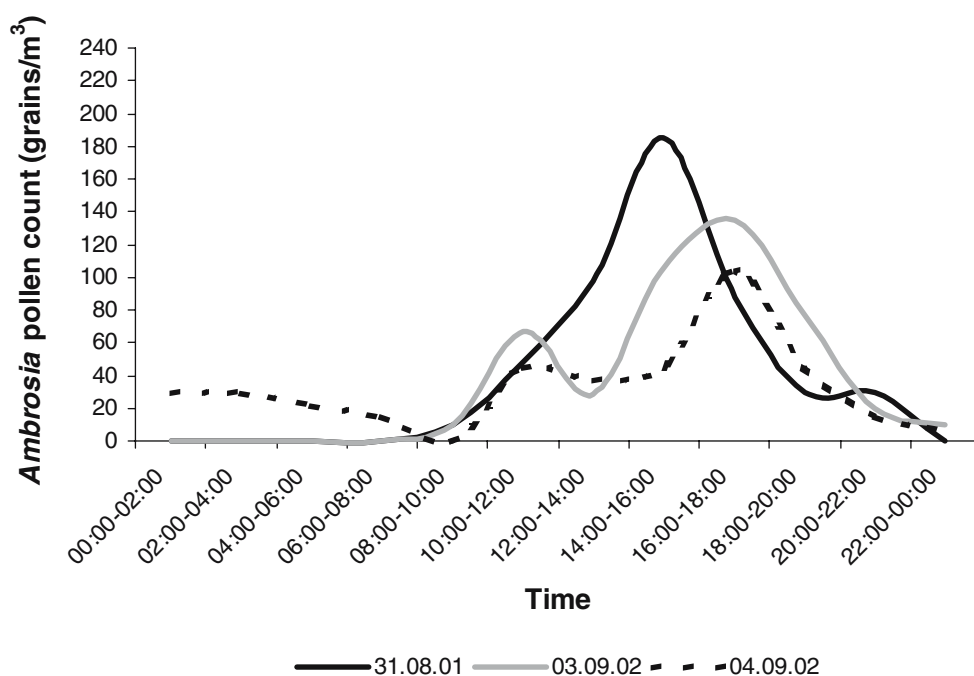


Back-trajectory analysis

The back-trajectories were calculated at the National Environmental Research Institute (NERI) in Denmark. Trajectory calculations were carried out using the transport model within the Lagrangian air pollution model ACDEP (Atmospheric Chemistry and Deposition) (Hertel et al. 1995), which during the period 1999–2004 was applied in connection with the national Background Air Quality Monitoring Programme (Ellermann et al. 2002; Skjæth et al. 2002). For each hour during the measuring time, the transport of air parcels is computed along trajectories starting 96 hours back in time, following the σ -level 0.925 wind (approximately 800 m above the surface). Trajectory calculations involve an amount of uncertainty, and this uncertainty increases exponentially with time. Therefore, to account for this uncertainty, ensembles based on nine trajectories with receptor points placed 16 km apart were calculated. Trajectories of the ensemble will be closely related until the trajectories reach a certain area, where even small variations in meteorology will create large variations in the transport path of the individual trajectories. Where the ensembles of trajectories diverge, the trajectories are considered uncertain and not used in the analysis. The trajectories examined in this study showed little variation with respect to transport path. Therefore, to simplify visualization, only single back-trajectories are shown in the graphics included in this paper.

The meteorological data were obtained from the Eta weather forecast model (Nickovic et al. 1998) included in the THOR model system (Brandt et al. 2000, 2001a–c). The model uses the hydrostatic approximation, and has, in

Fig. 3 Diurnal variation of *Ambrosia* pollen on 31 August 2001 and 3 and 4 September 2002 at Esculap (Poznań city centre)



the NERI setup, 32 vertical levels in a step mountain vertical coordinate system (Mesinger et al. 1988). The horizontal grid is defined as a rotated latitude/longitude staggered Arakawa E grid (Nickovic et al. 1998) with a resolution of $0.25^\circ \times 0.25^\circ$, which corresponds to approximately 39 km horizontal grid resolution over Denmark. The centre of the model domain is the National Environmental Research Institute in Denmark, with 25.7 degrees to the western/eastern boundary and 21.7 degrees to the northern/southern boundary. This corresponds to 174×103 grid cells for the entire horizontal model domain. The model domain covers Europe, some northeastern parts of the Atlantic Ocean, much of the Mediterranean and parts of North Africa. The time step in the operational model is 90 seconds.

Based on data from the Global Forecast System (GFS) from the National Centre for Environmental Prediction (NCEP) in the USA, the Eta model is run four times each day at NERI, producing 72-hour forecasts. Each time a new model run is initiated, the last data set is overwritten except

for the first 6 hours of the forecast series from the previous run, which are stored in the THOR data base. Meteorological fields with hourly resolution are therefore available for trajectory calculation for the period 1998 to the present.

Results

Temporal variations in *Ambrosia* pollen counts

The amount of *Ambrosia* pollen recorded at Poznań varies annually (Fig. 1). The lowest amount of *Ambrosia* pollen recorded in the city centre in a year was 25 grains in 2003 and the highest amount was 375 grains in 1999. The highest daily count was 109 *Ambrosia* pollen grains/ m^3 , which was recorded on 5 September 1999. In the years examined, there were only 18 days with daily average ragweed pollen counts ≥ 20 grains/ m^3 . Note that, for the days in question, the wind always arrived at Poznań from the south or from an easterly direction.

Table 1 Weather data recorded at Poznań (00:00–00:00 hours)

Date	Maximum daily temperature (°C)	Average daily temperature (°C)	Daily rainfall (mm)	Humidity (%)	Wind velocity (m/s)	Wind direction	Wind direction frequency (%)
31/08/2001	23.9	17.6	0.6	65	4.2	SE	39.6
03/09/2002	24.7	18.0	*	69	4.6	E	60.4
04/09/2002	28.0	22.1	*	59	4.2	SE	62.5
07/09/2005	27.3	21.1	*	54	3.4	S	72.9
08/09/2005	30.0	21.0	*	57	1.8	S	62.5
10/09/2005	28.5	23.3	*	57	1.6	E	43.8

*Asterisk shows that there was rainfall but not enough to be recorded

Mean diurnal variations of these 18 *Ambrosia* pollen episodes were examined and two distinct peaks were found; a peak in the early morning between 4 a.m. and 8 a.m., and a peak in the afternoon between 2 p.m. and 6 p.m. (Fig. 2). A total of six *Ambrosia* pollen episodes (three from each of these two populations) were selected for further investigation using back-trajectory analysis. These were: 31 August 2001, 3 September 2002, 4 September 2002, 7 September 2005, 8 September 2005 and 10 September 2005.

Back-trajectory analysis for 31 August 2001

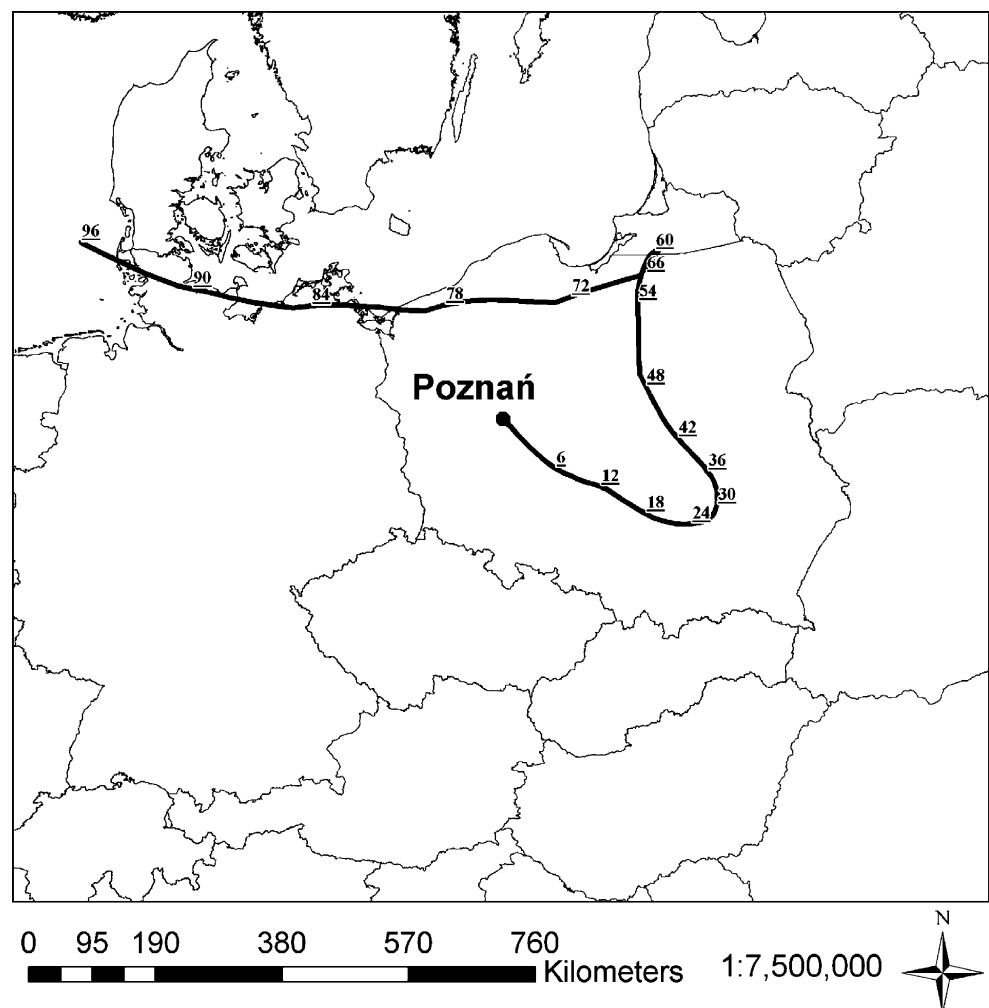
The daily average *Ambrosia* pollen count for 31 August 2001 was 41 grains/m³; counts peaked at 3 p.m. (Fig. 3). In Northern Europe, from 30 to 31 August 2001, there were a number of lows and highs in the range 1000 hPa to 1020 hPa that resulted in generally low wind speeds. Near to Poznań, a relatively weak low pressure system moved from the Netherlands to Denmark and high pressure moved from the Baltic to the area of Saint Petersburg in Russia. The daily average temperature and daily rainfall for 31

August 2001 recorded at Poznań were 17.6°C and 0.6 mm respectively, which were 1.2°C and 2.7 mm below the 10-year (1996–2005) mean for the month (Table 1). The back-trajectory shows that the air mass approached Poznań from the southeast and spent several days over eastern Poland (Fig. 4).

Back-trajectory analysis for 3 September 2002

The daily average *Ambrosia* pollen count for 3 September 2002 was 38 grains/m³. Diurnal variation of *Ambrosia* pollen counts for this day show there were two peaks, one small peak at around midday and a second higher peak at 4 p.m. (Fig. 3). The synoptic situation for 3 September 2002 was characterised by a deep low-pressure system that had moved north and east from Iceland toward Svalbard (north of mainland Scandinavia), and a corresponding high pressure to the north of Poland over the Baltic region. The daily average temperature for this day was 18°C, which was 4.1°C above the 10-year monthly mean. There was some rainfall on 3 September, but not enough to be

Fig. 4 Back-trajectory analysis; start of run 1500 hours on 31 August 2001



recorded, although humidity was 69% (Table 1). The back-trajectory (Fig. 5) shows that the air mass arrived from an easterly direction and spent 2 days over eastern Poland and parts of Russia and Lithuania.

Back-trajectory analysis for 4 September 2002

The daily average *Ambrosia* pollen count for 4 September 2002 was 33 grains/m³. The diurnal variation followed a similar pattern to that of the previous day, with a small peak around midday and a second higher peak at 5 p.m. (Fig. 3). The synoptic situation for 4 September 2002 was similar to 3 September, the main difference being that the low pressure had moved further east toward Arctic Russia. The average daily temperature for 4 September 2002 (22.1°C) was 8.2°C above the 10-year mean. Not enough rain fell during the day to be recorded, and relative humidity was 59% (Table 1). The air mass arrived at Poznań from the southeast after spending more than 3 days over southern and eastern Poland (Fig. 6).

Back-trajectory analysis for 7 September 2005

The daily average *Ambrosia* pollen count for 7 September 2005 was 53 grains/m³ at Esculap and 49 grains/m³ at Morasko. Diurnal variation of *Ambrosia* pollen counts show that counts at Esculap peaked sharply at 5 a.m., followed by a smaller peak at around midday (Fig. 7). The peak recorded at Morasko was lower and flatter and somewhat later, starting around 4 a.m. and finishing around midday (Fig. 8). During the period 6 to 10 September 2005, a series of low-pressure centres and fronts moved in towards the British Isles and Scandinavia from the Atlantic, while a generally stable area of high pressure remained situated over central Europe, which caused the winds over Poland to come from the south. At Poznań, the average daily temperature (21.1°C) was 7.2°C above the 10-year mean, whereas rainfall and humidity were low. Wind was mainly from the south (Table 1). The air mass started in southwestern Ukraine and traversed Hungary, Slovakia, Czech Republic and southern Poland before eventually reaching Poznań (Fig. 9).

Fig. 5 Back-trajectory analysis; start of run 1600 hours on 3 September 2002

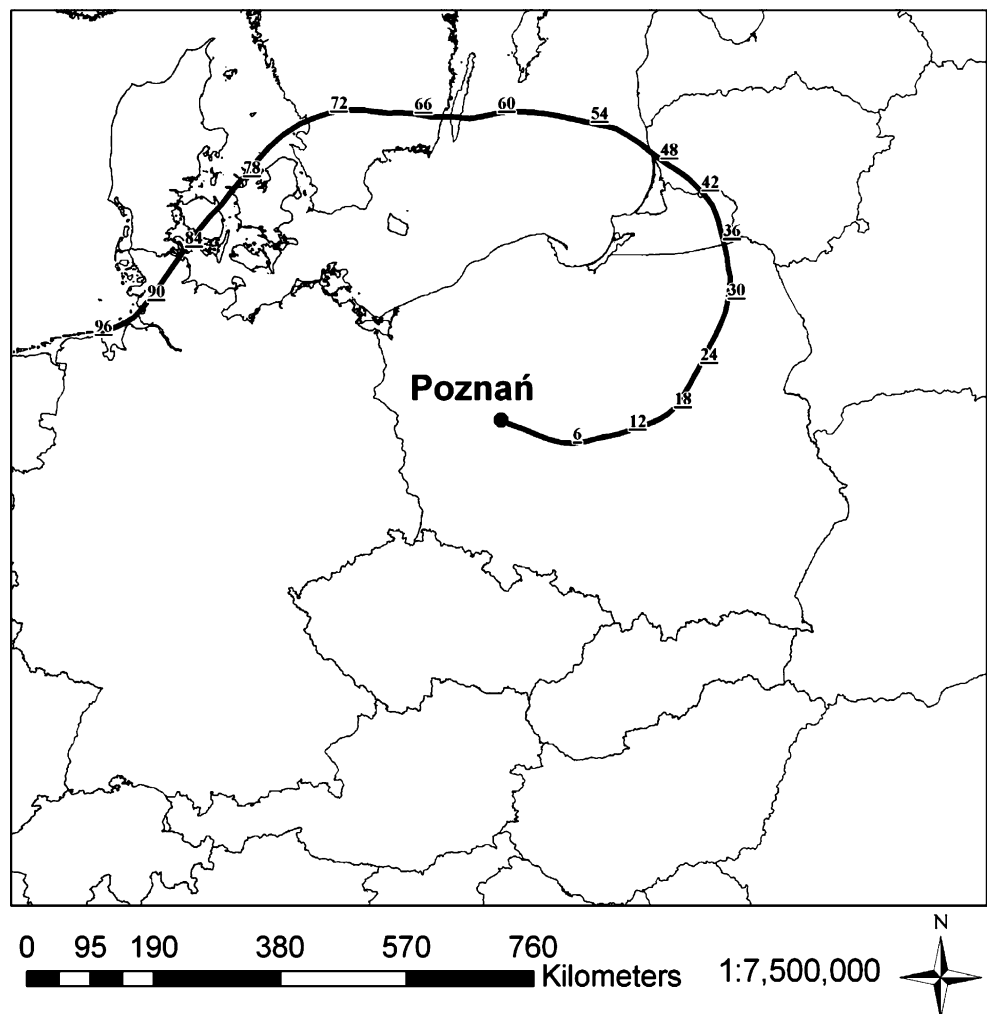


Fig. 6 Back-trajectory analysis; start of run 1700 hours on 4 September 2002

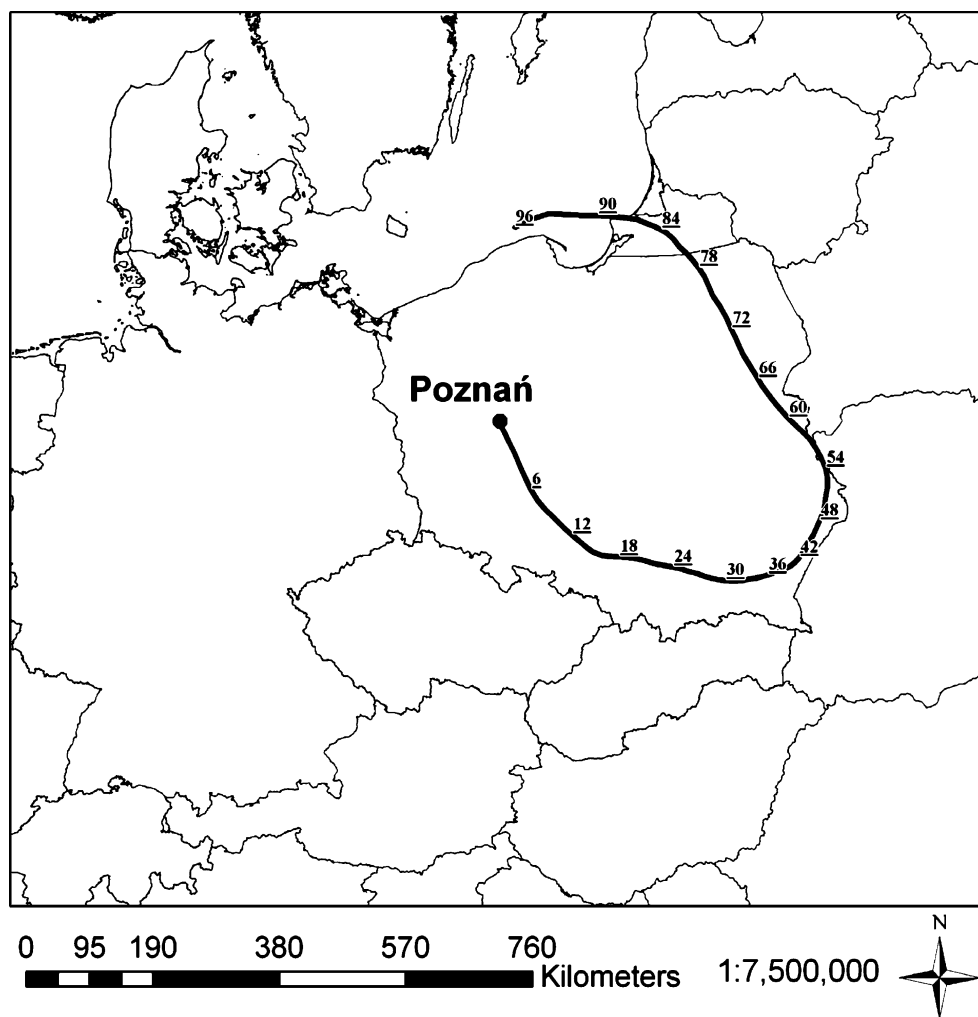


Fig. 7 Diurnal variation of *Ambrosia* pollen on 7, 8 and 10 September 2005 at Esculap (Poznań city centre)

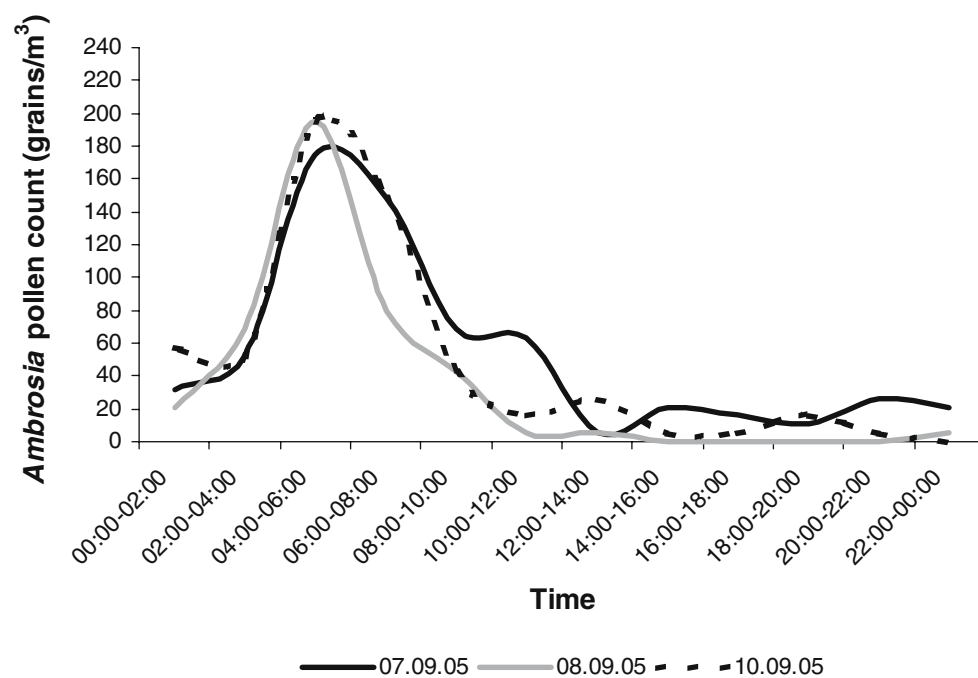


Fig. 8 Diurnal variation of *Ambrosia* pollen on 7, 8 and 10 September 2005 at Morasko (outskirts of the city)

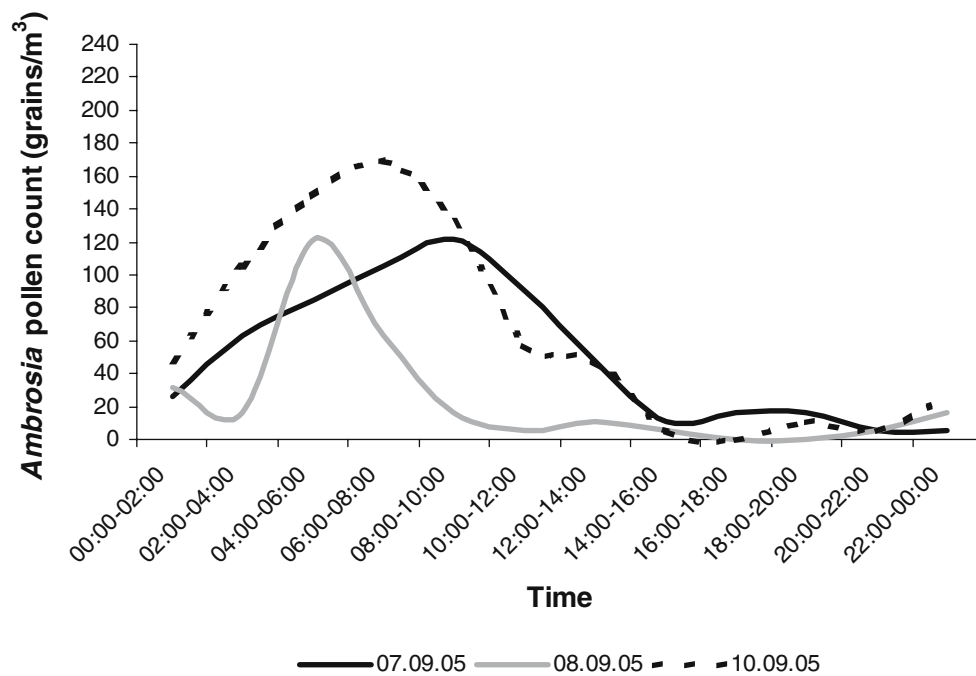
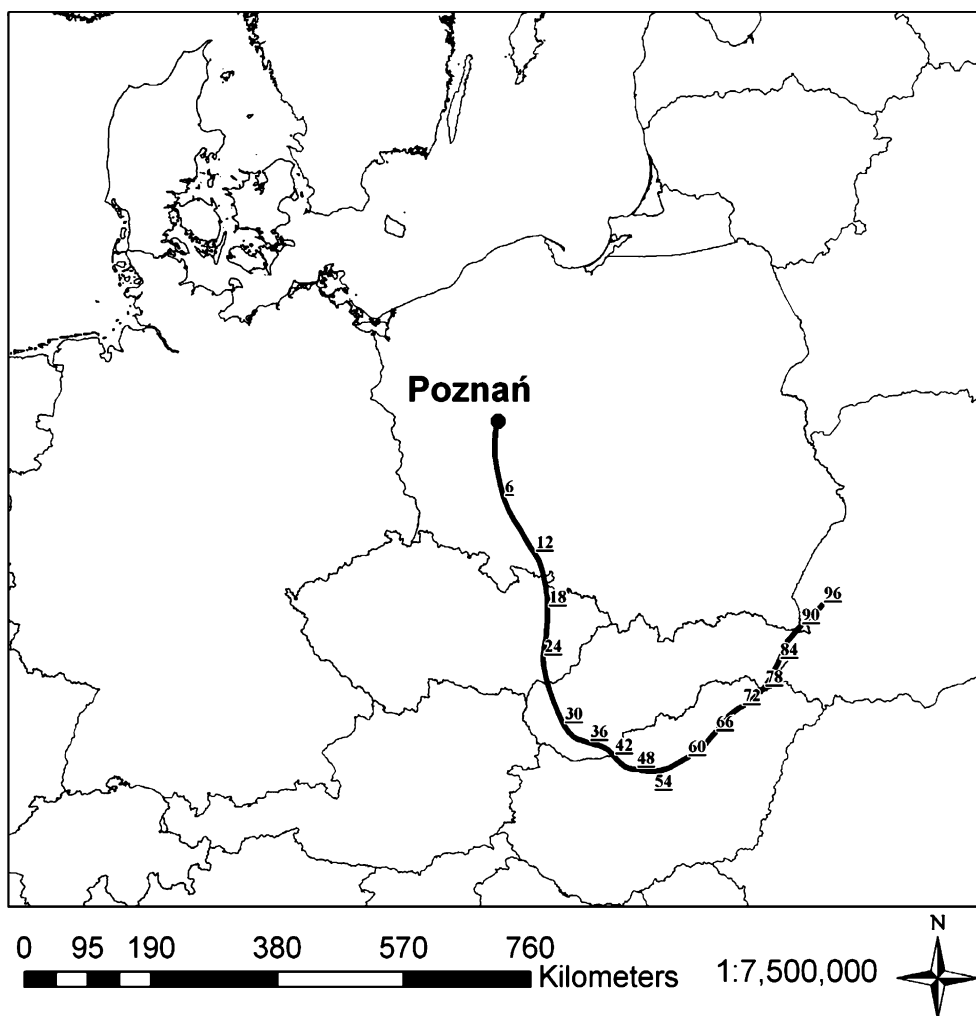


Fig. 9 Back-trajectory analysis; start of run 0500 hrs on 7 September 2005



Back-trajectory analysis for 8 September 2005

Daily average *Ambrosia* pollen counts for 8 September 2005 were 35 grains/m³ at Esculap and 24 grains/m³ at Morasko. The diurnal pattern of *Ambrosia* pollen counts was similar at the two sites (peaking at 5 a.m.), although the peak was lower at Morasko (Figs. 7 and 8). The weather on 8 September 2005 was similar to that of the previous day, with higher than average temperatures, low rainfall and humidity and the majority of wind from the south (Table 1). The back-trajectory showed that before getting to Poznań the air mass passed over Hungary, Slovakia, Austria, Czech Republic and southern Poland (Fig. 10).

Back-trajectory analysis for 10 September 2005

The daily average *Ambrosia* pollen count for 10 September 2005 was 48 grains/m³ at Esculap and 63 grains/m³ at Morasko. *Ambrosia* pollen counts at Esculap peaked sharply at 6 a.m., whilst at Morasko counts followed a similar pattern to that seen on 7 September 2005, the peak

being slightly later and lower but more prolonged (Figs. 7 and 8). The daily average temperature for 10 September 2005 was again hotter than the 10-year mean (23.3°C), and rainfall and humidity were also low, but the wind had backed to the east (Table 1). The air mass traversed parts of Rumania, Hungary, Slovakia and southern Poland before arriving at Poznań (Fig. 11).

Discussion

Members of the genus *Ambrosia* spp. are probably the most noxious hay fever plants in the world (Rich 1994). *Ambrosia artemisiiflora* is an effective coloniser but rarely reaches maturity in northern latitudes, and the continued presence of the species often relies on the frequent introduction of seed, or on seed banks that can remain dormant in the soil for decades waiting for the right conditions for germination (Dahl et al. 1999; Laaidi and Laaidi 1999; Saar et al. 2000). It should be noted, however, that populations of *Ambrosia psilostachyo* have been

Fig. 10 Back-trajectory analysis; start of run 0500 hours on 8 September 2005

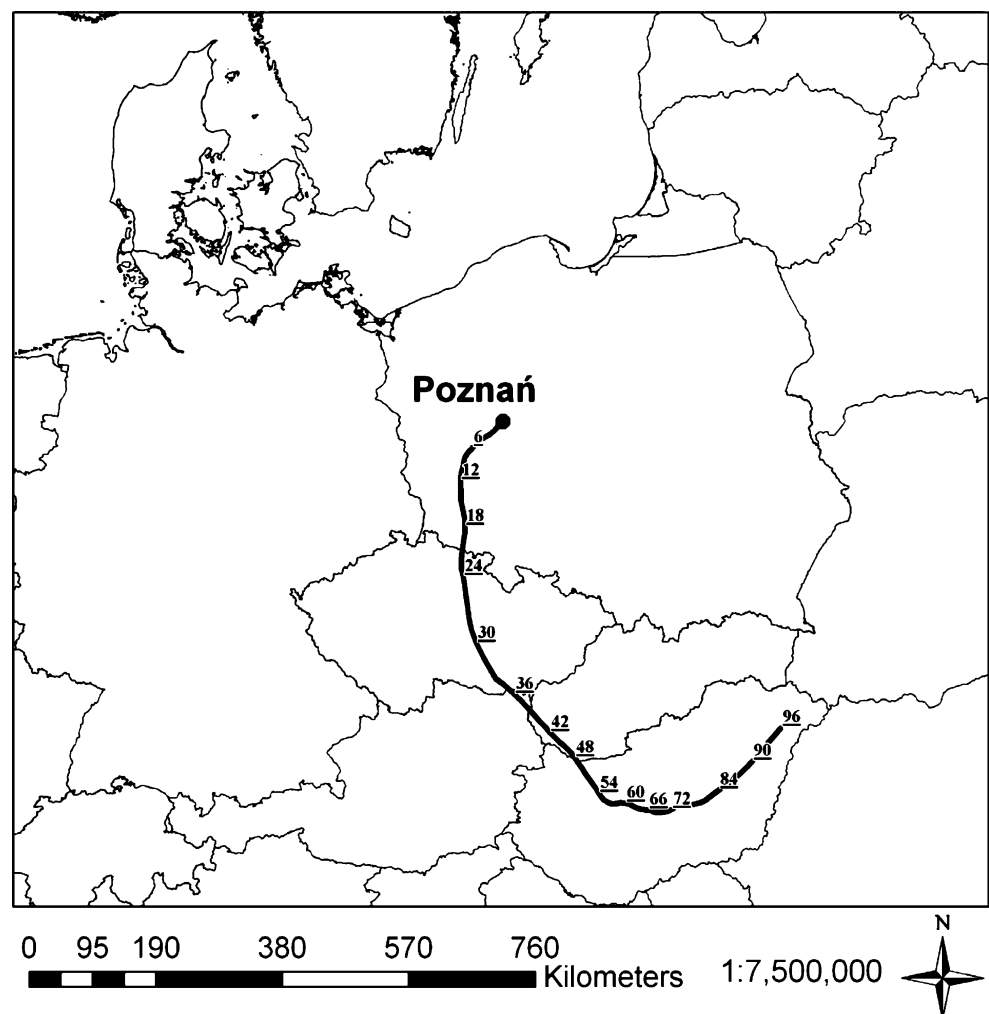
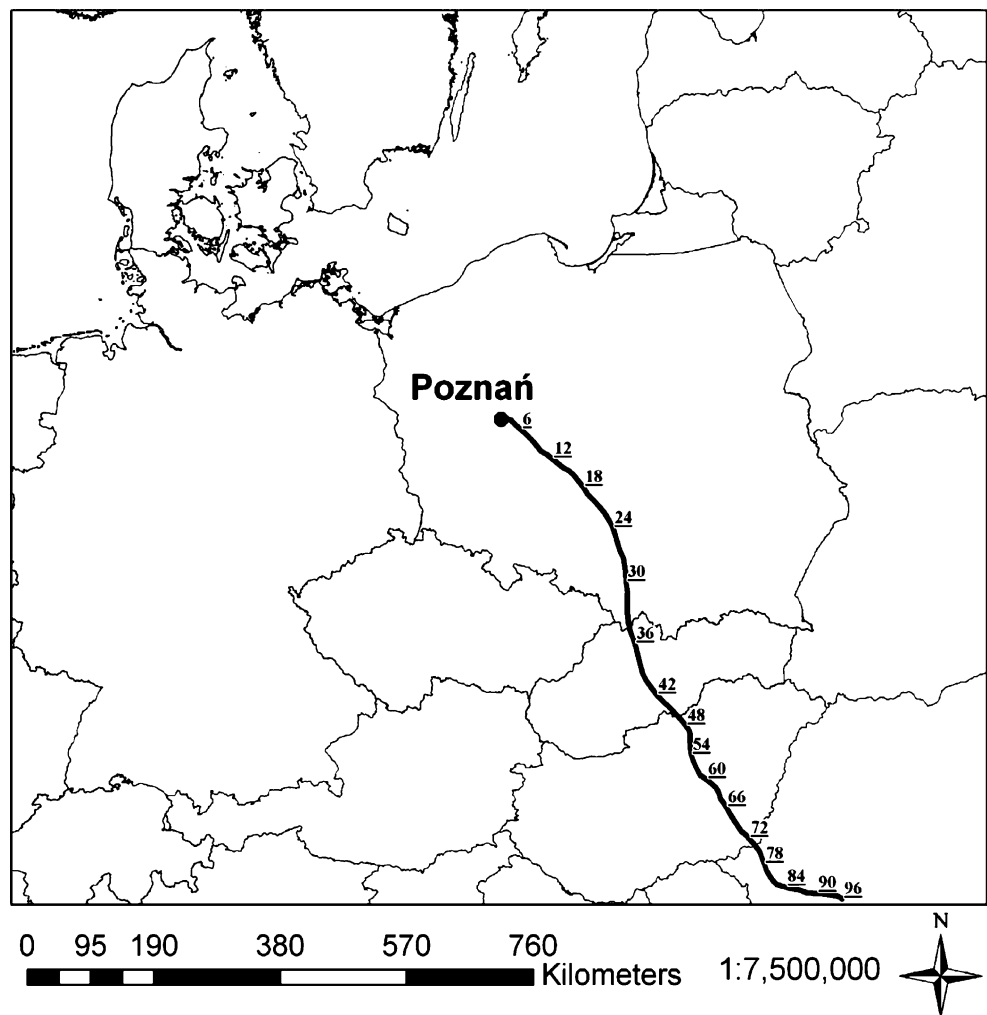


Fig. 11 Back-trajectory analysis; start of run 0600 hours on 10 September 2005



reported in Szczecin in northwestern Poland (Puc 2004). *Ambrosia psilostachyo* is a perennial plant that can form large populations in ruderal habitats; seed set is low but it sprouts from rhizomes and reproduces mainly vegetatively (Rich 1994; Belmonte et al. 2000).

Ambrosia pollen counts in Poznań are intermittent, and relatively low compared to the magnitude of counts experienced in places such as Hungary, where annual sums of ragweed pollen grains can reach almost 20 thousand (3 to 5 thousand in Budapest), and where daily average ragweed pollen counts of 2000 pollen grains/m³ have been experienced in the south of the country and 500 pollen grains/m³ in Budapest (Járai-Komlódi 2000). However, as the threshold value for clinical symptoms is below 20 grains/m³, even small numbers are important with respect to allergy. In more northern latitudes, *Ambrosia* may germinate but plants might not necessarily flower every year (Saar et al. 2000) and so the occurrence of *Ambrosia* pollen in Poznań may be reliant on conditions being appropriate for germination and pollination. Similarly, the

intermittent nature of *Ambrosia* pollen counts in Poznań might be associated with the incidence of suitable conditions for the long-range transport of ragweed pollen from regions that have established ragweed populations. In Poznań, all ragweed pollen counts ≥ 20 grains/m³ occurred when the wind was from the south or from an easterly direction, indicating transport from areas with larger populations of *Ambrosia*.

Jones et al. (2006) found that the maximum ragweed pollen count was recorded during the middle of the day, and the minimum was during the early hours of the morning. The study of diurnal variations of *Ambrosia* pollen episodes ≥ 20 grains/m³ in Poznań showed the presence of two different populations; one where counts peak in the early morning, and the other where counts peak in the afternoon. The presence of *Ambrosia* pollen grains in the early morning suggests that the pollen grains were released the previous day (or preceding days) and arrived in Poznań via long-range transport. A peak in the early morning may be related to nighttime cooling, which would deposit pollen

grains that had been kept airborne during the day by convection (Faegri and Iversen 1992). The study of back-trajectories for 7, 8 and 10 September 2005 show that air masses arrived at Poznań from a southerly direction after passing over southern Poland, the Czech Republic, Slovakia and Hungary. Similarly, Cecchi et al. (2006) also studied synoptic weather conditions and back-trajectories, and suggested that an area around southern Hungary was the possible source of *Ambrosia* pollen recorded in central Italy.

Diurnal variations in *Ambrosia* pollen counts in 2005 also showed that the peak generally occurred slightly later in Morasko than Esculap and that it was usually lower and flatter. Hart et al. (1994) found that pollen concentrations decreased with increased height above ground level. The trap at Esculap is located more than 10 m higher than the one at Morasko, and so the difference in counts between the two sites may be greater than shown. Morasko is situated on the northern outskirts of the city, and air masses arriving from the South would have had to pass over the city (where Esculap is situated) before reaching the trap, which may explain the delayed peak at Morasko.

The presence of *Ambrosia* pollen grains in the air during the afternoon might be the result of pollen being released into the air from a more local source, possibly during the same day. The study of back-trajectories for 31 August 2001 and 3 and 4 September 2002 showed that the air masses arrived from a more easterly direction than those that arrived in the early morning of 7, 8 and 10 September 2005, and that these air masses generally remained within the borders of Poland for 24 hours or longer. This strengthens the argument that the pollen was from sources inside the country.

Conclusion

Ragweed produces large quantities of pollen grains that are small (18–22 µm) and suitable for long-range transport (Dahl et al. 1999; Tamaracaz et al. 2005; Cecchi et al. 2006). Back-trajectory analysis has shown that there is a possibility that long-range transport brings *Ambrosia* pollen to Poznań from southern Poland, Czech Republic, Slovakia and Hungary, and that increased levels may be obtained during the morning. *Ambrosia* may also be present in Poland, as shown by the arrival of pollen during the afternoon that resulted from atmospheric transport within the country.

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