

The occurrence of *Ambrosia* pollen in the atmosphere of Northwest Turkey: investigation of possible source regions

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Abstract *Ambrosia* pollen was first reported as an important allergen in North America at the end of the nineteenth century, and many European countries have recently reported its increasing significance for pollen allergy. The aims of this study were to determine whether the highly allergenic *Ambrosia* pollen recorded during the studied period could be the result of long-distance transport (LDT) and to identify the potential sources of *Ambrosia* pollen grains. The study investigates *Ambrosia* pollen episodes during the peak term of six yearly periods between 2010 and 2015 by examining source regions in *Ambrosia* pollen in Bursa, Turkey. A volumetric trap was used for collecting the pollen samples, and the back-trajectory model was used to identify a potential source of atmospheric *Ambrosia* pollen. The days when pollen levels exceeded 30 P m^{-3} were computed, and clusters were shown on the figures. The study indicates that the *Ambrosia* pollen grains recorded during the episode in Bursa were not produced by local sources but transported long distances from potential source regions around the Azov Sea in Russia and Ukraine, Black Sea region of Turkey, Romania, and Bulgaria. Note that atmospheric concentrations of *Ambrosia* pollen exceeded the clinical threshold during 28 days during the investigation period. Taking into consideration the high allergenicity of *Ambrosia* pollen, the present findings suggest that the number

of ragweed-sensitized individuals might increase in the near future in the region.

Keywords *Ambrosia* · Bursa · Diurnal variations · Invasive species · Long distance transport · Ragweed · Turkey

Introduction

The genus *Ambrosia* L. (Asteraceae) contains at least 40 species and numerous intraspecific taxa. Only one species, *Ambrosia maritima* L., is native to Europe (Rich 1994; Follak et al. 2013). Other species established in Europe were introduced from temperate region of the world (Essl et al. 2015). *Ambrosia artemisiifolia* (ragweed) was first recognized in Europe in the nineteenth century, and many European countries have recently reported its increasing significance for pollen allergy (Visiani 1842; Rich 1994; Jaeger 2000; Wayne et al. 2002; Behrendt 2009; Asero et al. 2014).

The most ragweed-infected places in Europe are the Pannonian Plain, the Rhone-Alps region of France, parts of Northern Italy, as well as Ukraine and some parts of Russia (Smith et al. 2014; Essl et al. 2015; Makra et al. 2015). The region around the Azov Sea, Georgia, and Black Sea Region of Turkey were identified as highly infested area (Reznik 2009; Bullock 2010; Sikoparija et al. 2016). The city of Bursa is located in an area considered to be free from large local *Ambrosia* populations, i.e., it is approximately 1000 km from the northeast edge and 400 km northwestern edge of *A. artemisiifolia* distribution (Onen et al. 2014; Ozaslan et al. 2016).

Ambrosia is one of the most important allergen plants for sensitized patients during the late summer (Essl et al. 2015; Smith et al. 2014; Smith et al. 2013), and *Ambrosia* pollen has been detected in many European countries (Peeters 2000;

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Peternel et al. 2003; Puc 2004; Milkovska et al. 2008; Smith et al. 2014). There is a cross reactivity between ragweed species and between the major allergens of *Ambrosia* and *Artemisia* (Dahl et al. 1999; Tamarcaz et al. 2005). Pollen grains of *A. artemisiifolia* are produced in huge amounts (Wayne et al. 2002; Albertemst and Nawrath 2008), and as a result, ragweed pollen is involved in episodes of long distance transport (Zauli et al. 2006; Cecchi et al. 2007; Stach et al. 2007; Šikoparija et al. 2009; Skjøth et al. 2010; Šikoparija et al. 2013). There is a specific diurnal periodicity in *Ambrosia* flowering time. The peak concentrations of ragweed pollen were noticed from 06:30 to around midday (Bianchi et al. 1959). *Ambrosia* pollen identified during night hours is more likely to originate from distant areas and monitoring of *Ambrosia* pollen grains can serve as an early warning system to prevent this invasive and highly allergenic plant from uninfected areas.

Sensitization of individuals to *Ambrosia* pollen allergens was reported from different regions with different threshold values (Juhász 1995; Comtois 1998; Jäger 1998; De Weger et al. 2013). Juhász (1995) suggests 50 P m^{-3} as the threshold value to hay fever sufferers. For pollen-sensitive patients, the threshold value of clinical symptoms was reported as 20 P m^{-3} by Jäger (1998) and 30 P m^{-3} by Basky (2009). Atmospheric concentrations of *Ambrosia* pollen reach levels high enough in Turkey to potentially cause clinical symptoms in sensitized individuals; however, rates of sensitization in the country are currently unknown.

The aims of this study were (i) to determine whether airborne *Ambrosia* pollen grains recorded in Bursa could be the result of LDT since local sources are not known to be present, and (ii) to identify the potential sources of airborne *Ambrosia* pollen recorded in Bursa during a 6-yearly period. In order to investigate this phenomenon, air mass trajectories and wind directions were analyzed. So as to determine the origin of measured pollen grains, diurnal variations were analyzed and bihourly course of daily pollen concentrations was used for identifying a daytime peak.

Material and methods

Sampling site

Bursa is situated at $41^{\circ} 11' \text{ N}$, $29^{\circ} 04' \text{ E}$ in northwest of Turkey (Fig. 1) at 100 m above the sea level, located on a plain flanked by the Uludag Mountain to the south and the Samanlı Range Mountains to the north, and it is a city with approximately three million inhabitants. Bursa has a Mediterranean vegetation with semi-continental climate with cold and wet winters, hot and dry summers. The plain near the district comprises agricultural land: vineyards, plum, quince, peach, olive groves, and land suitable for the growth of

sunflower, tobacco, etc. The long-term (1950–2015) average of annual temperature in Bursa is 14.5° C , and the mean annual precipitation amounts to 695 mm with snow during wintertime (www.mgm.gov.tr). The climate of Bursa is strongly influenced by the high elevation of the Uludag Mountain, and Mediterranean vegetation on the plain changes to deciduous forest characteristic of semi-humid regions with increasing altitude. Aerobiological monitoring station was located at $40^{\circ} 22' 33'' \text{ N}$, $28^{\circ} 86' 42'' \text{ E}$.

Pollen data

Airborne *Ambrosia* pollen was detected in Bursa during all the studied period, 2010–2015. A Hirst-type volumetric spore trap (Hirst 1952) was used for aerobiological sampling. The trap was located on the flat roof of Arts Faculty in the campus area of Uludag University. The trap was placed about 12 m above ground level and 106 m above sea level. Sampling and data analysis were performed in accordance with the standard protocol drawn up by the Spanish Aerobiology Network (REA) and the minimum recommendations of the European Aeroallergen Network (Galan et al. 2014). Daily average and bihourly pollen concentrations are stated as P m^{-3} . The beginning and ending of main pollen season were specified as occurring the days when the accumulated sum of daily average *Ambrosia* pollen concentrations achieved 1 and 99% of the annual pollen index. For the start (end) of the *Ambrosia* pollen season for sampling station, we used the first (last) date on which 1 P m^{-3} of air is recorded and at least five consecutive days also show one or more P m^{-3} (Galan et al. 2001).

Meteorological data

The synoptic charts were downloaded from <http://www.wetterzentrale.de/topkarten/tkfaxbraar.htm>. Mean humidity (%), total daily precipitation amount (mm), mean temperature ($^{\circ} \text{ C}$), and average wind speed (km/h) were examined. Meteorological data from 2010 to 2015 were obtained from the Bursa meteorological station.

Statistical analysis

The conformity of the data to normal distribution was examined with the Shapiro-Wilk test. The data did not show normal distribution, so Spearman's correlation analysis was used to test relationships between the daily average concentrations of airborne *Ambrosia* pollen with meteorological data (not wind direction). The Wilcoxon test was used to compare the mean daily concentrations for each year separately. For all of these tests, statistical significance was accepted at the level of $p < 0.05$. All calculations were made using SPSS 23.00 software.



Fig. 1 The monitoring site (rectangle) and its surroundings on the map

Back-trajectory analysis

The air mass movement was simulated using the Hybrid Single-particle Lagrangian Integrated Trajectory model (HYSPLIT 4.9) developed by the National Oceanic and Atmospheric Administration (NOAA) (Stein et al. 2015). The data, which is maintained by the National Oceanic and Atmospheric Administration Air Resources Laboratory (NOAA ARL) as input having a temporal resolution of 6 h and a spatial resolution of 1° , from the Global Data Analysis System (GDAS) archives were used for the trajectory calculations. The elevation at arrival time was set to 500 m AGL as geographical barriers affecting north and northeast air masses coming from the Black Sea. To clearly justify this fact, a comparison between heights had been done and back-trajectories were computed for all episodes with a received height of 500, 1000, and 1500 m taking into account variations in air mass directions with increasing height in the atmosphere, but the elevation at arrival time when the hour daily peak level recorded was set to 500 m AGL as geographical barriers affecting north and northeast air masses coming from the Black Sea.

Although different values were identified around the different population for threshold (Juhász 1995; Jäger 1998; Comtois 1998; Basky 2009; De Weger et al. 2013), rates of sensitization in the investigated region are currently unknown. The threshold value, which is the closest value to the average of the thresholds given in the literature, was considered as the threshold that can cause sensitization in the investigated

region. We selected the days when *Ambrosia* pollen reached 30 P m^{-3} for analyses except the year 2012. These peaked days formed more prominent, certain, and consistent pollen clusters around the yearly values. In the year 2012, daily average pollen grains reached 14 P m^{-3} as a maximum value, and only this day was computed for back-trajectory analysis.

Specified trajectories were shown as a cluster on a map to determine potential sources of pollen grains. Local time was converted to Central European Summer Time (UTC), and UTC was used on back-trajectory analysis. The hours of the day for the back-trajectories run were selected when bihourly pollen grains reached the maximum daily peak level. The air mass path for the previous 48 h was specified in time steps of 6 h.

Results and discussion

Annual totals

The limits of the *Ambrosia* pollen seasons, the total annual pollen concentrations (the sum of daily and airborne ragweed pollen concentrations), the date of the peak, the peak value, and the number of days with daily average ragweed pollen concentrations $>30 \text{ P m}^{-3}$ are given in Table 1. The length of the *Ambrosia* pollen season and the annual total amount of *Ambrosia* pollen recorded in Bursa varied from year to year. The longest pollen season during the study period was

Table 1 Characteristics of *Ambrosia* pollen at sampling station during the studying period, 2010–2015

Year	<i>Ambrosia</i> pollen season	Yearly total (pollen/m ³)	Peak day	Peak value (P m ⁻³)	Number of the days with > 30 P m ⁻³
2010	09/08–27/09	878	13/09	314	2
2011	12/08–28/09	393	02/09	67	3
2012	04/08–20/09	174	08/09	14	-
2013	03/08–24/09	825	24/09	77	12
2014	02/08–21/09	317	10/09	47	2
2015	02/08–18/09	800	24/09	126	7

identified in 2013. Annual totals of *Ambrosia* pollen varied from 174 to 878 P m⁻³ (Table 1).

The Wilcoxon test was run, and the output indicated that the mean daily pollen concentration in 2010 was statistically significantly higher than in 2012 ($z = 0.0026$) and in 2014 ($z = 0.0153$). There was also a significant difference in the mean pollen concentration in 2013 compared to 2011 ($z = .0049$) and 2014 ($z = 0.0177$), and similarly, the mean daily pollen concentration in 2015 was statistically significantly higher than in 2012 ($z = 0.0017$) and in 2014 ($z = 0.0235$) (Table 2). The sum of daily average pollen concentrations monitored in the years 2011, 2012, and 2014 was considerably lower (393, 174, and 317 *Ambrosia* pollen grains, respectively) than the years 2010, 2013, and 2015 (878, 825, and 800 pollen grains, respectively).

In contrast to the reported diurnal variation and peak concentrations of ragweed pollen in the natural plant population, the ragweed pollen concentrations reached the lowest value around the middle of the day (Fig. 2b) and an irregular pattern was identified for the daily *Ambrosia* pollen peak for the studied region (Figs. 2a, 3, 4, 5, 6, 7, and 8a). This is one of the most important findings of evidence for the LDT of *Ambrosia* pollen to the investigated region.

The influence of meteorological data on *Ambrosia* pollen concentrations

Daily concentrations of *Ambrosia* pollen grains and daily mean temperature, humidity, and total precipitation are shown in Figs. 3, 4, 5, 6, 7, and 8a. Meteorological data (daily mean temperature, humidity, wind speed, and total precipitation) and daily *Ambrosia* pollen grains were analyzed using Spearman's correlation test for the peak days. The only significant correlation between daily average airborne pollen concentrations, and the meteorological data was the significant positive correlation with wind speed (Table 3). These findings suggest that there was no local population of *Ambrosia* plants. Dates with no or little airborne *Ambrosia* pollen (1–3 P m⁻³) recorded around the peak days were selected to detect the wind direction (31 August and 1–3 September 2010; 16 August and

14, 20 September 2011; 5, 6, and 14 September 2012; 28 August 2013; 22 August and 21–22 September 2014; 11, 18 August and 4, 6 September 2015), and back-trajectories were computed for midnight. These trajectories showed that air masses came from the west, northwest, south, or east of the region (Suppl. Figs. 1, 2, and 3).

In addition, wind direction was examined and wind roses were created for each examined pollen season (Fig. 9a–h). It can be seen in Fig. 9 that more than 60% of the wind during the years 2010 and 2011 arrived from a northerly direction where there are possible source regions of *Ambrosia* pollen. Wind roses for the daily average wind direction during August and September for the years 2010–2015 show that 67% of average frequency of winds were recorded from the north and northeast (Fig. 9g). It was noted that there was a significant frequency of winds from the east (10%) and west (10%) in 2012 which was the year with the lowest recorded amount of *Ambrosia* pollen (Fig. 9c).

Selection and daily cycles of *Ambrosia* peak periods

Pollen grains of *Ambrosia* were recorded over 6 years in the investigated region. During the study period, airborne concentrations exceeded 30 P m⁻³ daily average on 2 days in 2010, 3 days in 2011, 12 days in 2013, 2 days in 2014, and 7 days in 2015 (Table 1). Bihourly concentrations of airborne *Ambrosia*

Table 2 Results of Wilcoxon test (z) used to compare the mean of daily pollen concentrations for the year 2010–2015

Year	2010	2011	2012	2013	2014
2010	–				
2011	0.0615	–			
2012	0.0026*	0.0887	–		
2013	0.0638	0.0049*	2.036	–	
2014	0.0153*	0.3198	0.0799	0.0177*	–
2015	0.6420	0.0578	0.0017*	0.2614	0.0235*

*significantly different

$p < 0.05$

Fig. 2 Diurnal variation (a) and average bihourly mean of peak days (b) of *Ambrosia* pollen concentrations for Bursa (main pollen season defined using 98% method)

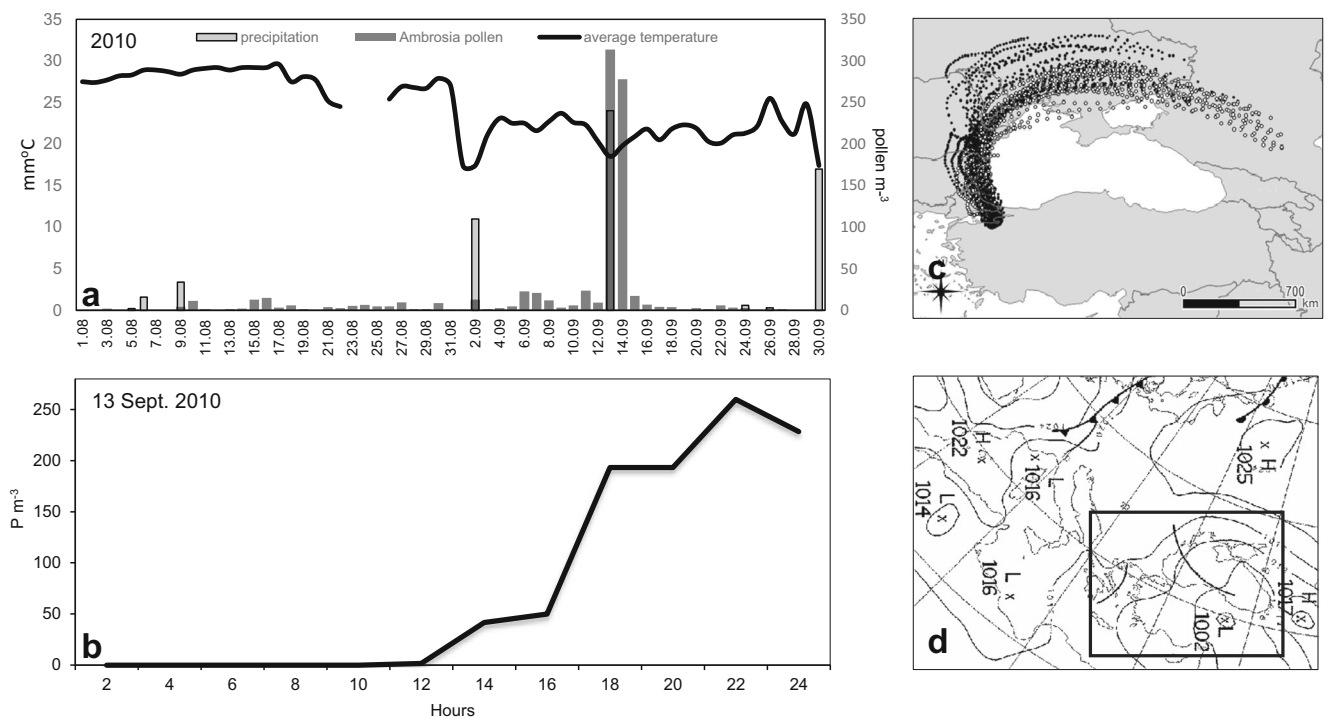
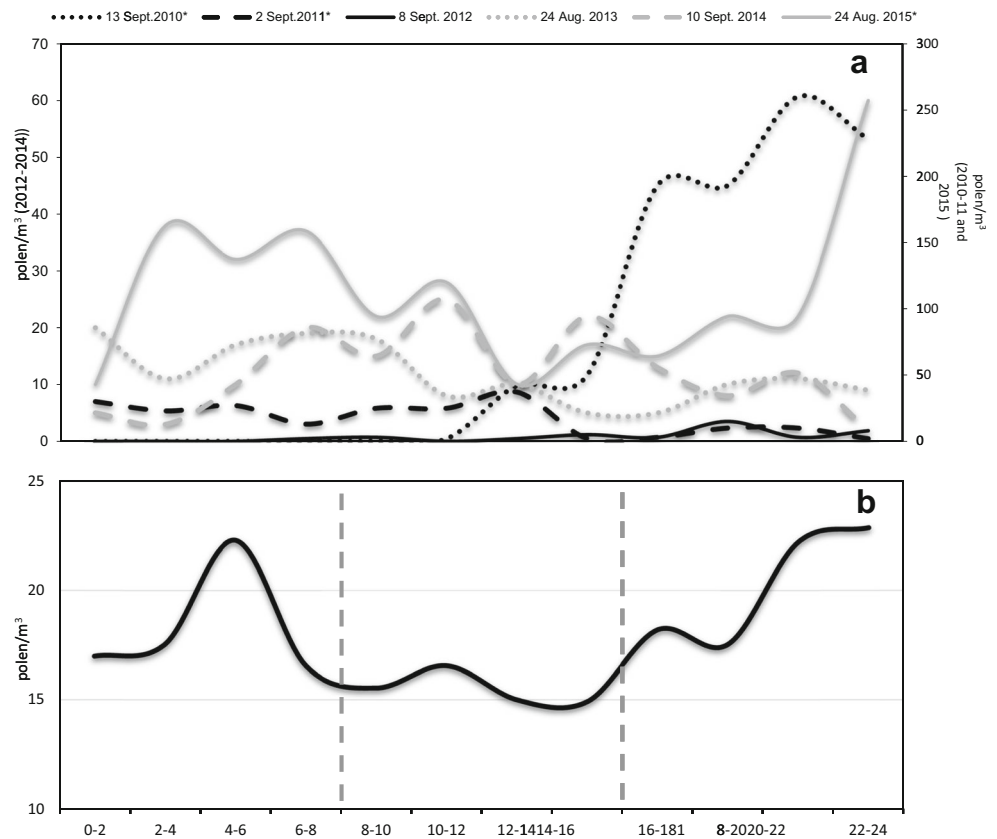


Fig. 3 Seasonal dynamics of *Ambrosia* pollen concentrations recorded in sampling station in 2010. **a** Diurnal variation of *Ambrosia* pollen grains, precipitation, and average temperature for 1/08 and 30/09. **b** Intradiurnal variation of *Ambrosia* pollen grains in the peak day. **c** Back-trajectories

arriving to Bursa 500 m AGL for the days $>30 \text{ P m}^{-3}$ in 13 and 14 September 2010, white: 13 September, black: 14 September. **d** Synoptic map for peak day (study area is indicated by black rectangle)

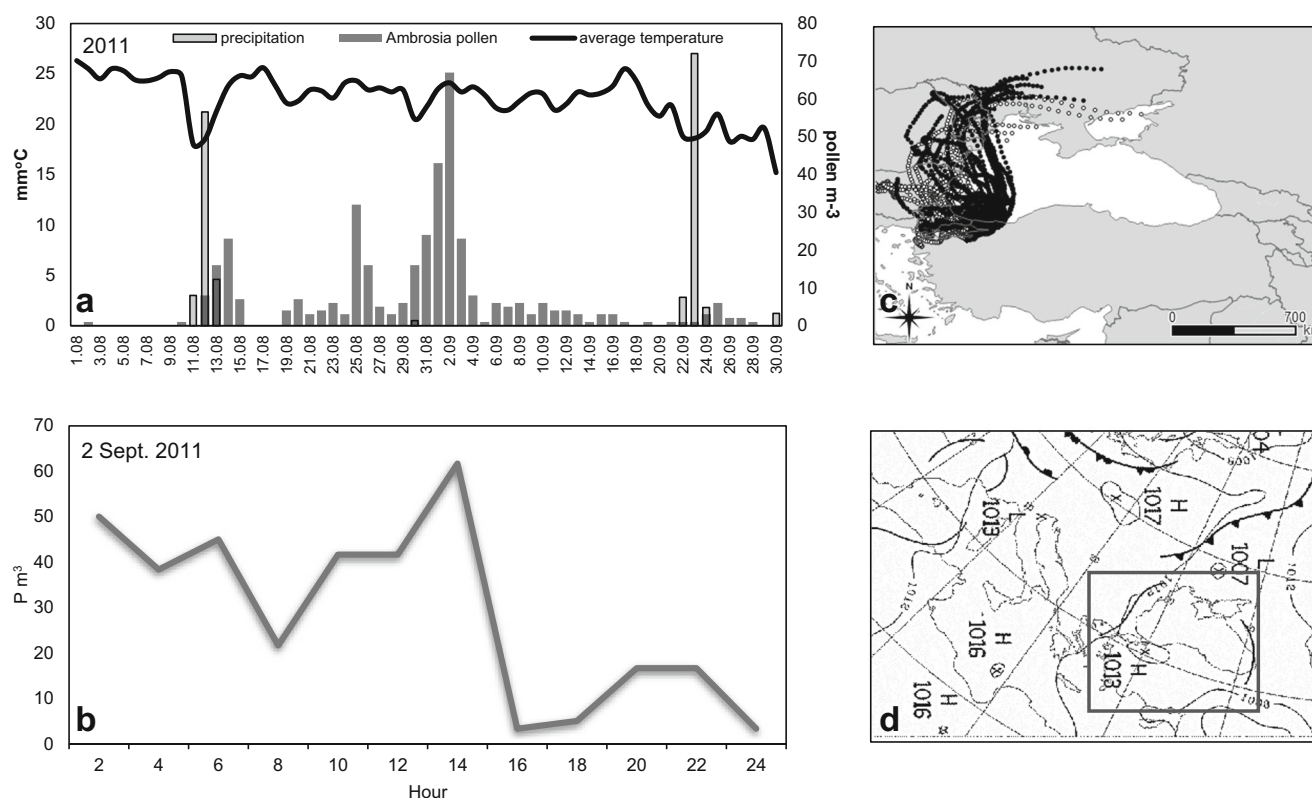


Fig. 4 Seasonal dynamics and effects of meteorological conditions to *Ambrosia* pollen concentrations recorded in sampling station in 2011. **a** Diurnal variation of *Ambrosia* pollen grains, precipitation, and average temperature for 1/08 and 30/09. **b** Intradiurnal variation of *Ambrosia*

pollen grains in the peak day. **c** Back-trajectories arriving to Bursa 500 m AGL for the days $>30 \text{ P m}^{-3}$ in 1 and 2 September 2011, white: 1 September, black: 2 September. **d** Synoptic map for peak day (study area is indicated by black rectangle)

pollen reached peak values during the night or early morning on a total of 19 days (73% of dates when daily concentrations exceeded 30 P m^{-3}) during the studied period (Table 4).

A total of 314 and 278 *Ambrosia* pollen grains per cubic meter of air were recorded on 13 and 14 September 2010, respectively (Fig. 3a). These were the only days when atmospheric *Ambrosia* pollen concentrations exceeded a 30 P m^{-3} daily average in 2010. Although *Ambrosia* pollen grains were not detected from 00:00 to 12:00 on 13 September 2010, a total of 581 P m^{-3} were measured between 12:00 and 24:00. The back-trajectory was calculated consistent with the highest concentrations made at 19:00 (UTC, Fig. 3b). The calculated trajectory for 13 September at 19:00 (UTC) showed that the air masses originated from the northeast. During the 48 h before arrival, the air masses passed over Russia, Moldova, Ukraine, and in the last 24 h, over the coastal regions of Romania and Bulgaria, arriving in the Bursa region at 19:00 (UTC) when the peak value was recorded as 314 P m^{-3} at the station (Fig. 3c). Atmospheric pollen concentrations peaked at 00:00 (UTC) on 14 September 2010.

In 2011, the highest atmospheric *Ambrosia* pollen concentrations were recorded on 25 August and 1 and 2 September as 32, 43, and $67 \text{ Ambrosia P m}^{-3}$, respectively (Fig. 4a). These were the only dates when the daily average *Ambrosia* pollen

exceeded 30 P m^{-3} in 2011 (Fig. 4a). Diurnal variations on 25 August 2011 showed that airborne *Ambrosia* pollen concentrations reached a maximum level at 21:00 (UTC). Back-trajectories were run for the measured highest atmospheric pollen concentrations (at 21:00 UTC), and the trajectory of air masses for 25 August 2011 showed that the air masses arrived from the south of Ukraine where the most important habitat of ragweed plants (Rodinkova et al. 2012). Atmospheric *Ambrosia* pollen concentrations peaked on 1 September 2011 at 13:00 (UTC) (Fig. 4b). The back-trajectory computed for 1 and 2 September 2011 (Fig. 4c) showed that the air masses arrived from the southern part of Romania, then over the Sofia where *Ambrosia* has extended habitat (Yankova et al. 1996; Dimitrov and Tzonev 2002; Ianovici and Sirbu 2007; Ianovici et al. 2013).

Interestingly, *Ambrosia* pollen grains did not exceed 30 P m^{-3} on any day in 2012. The highest daily average *Ambrosia* pollen concentrations recorded in the year were 14 P m^{-3} on 8 September (Fig. 5b), 12 P m^{-3} on 8 August, and 10 P m^{-3} on 4, 7, and 9 September 2012 (Fig. 5a).

The *Ambrosia* pollen season was the longest in 2013 during the investigated period, and airborne *Ambrosia* pollen concentrations exceeded 30 P m^{-3} daily average in 12 days between 12 and 27 August (Fig. 6a). Diurnal analyses for 7 of the 12 days

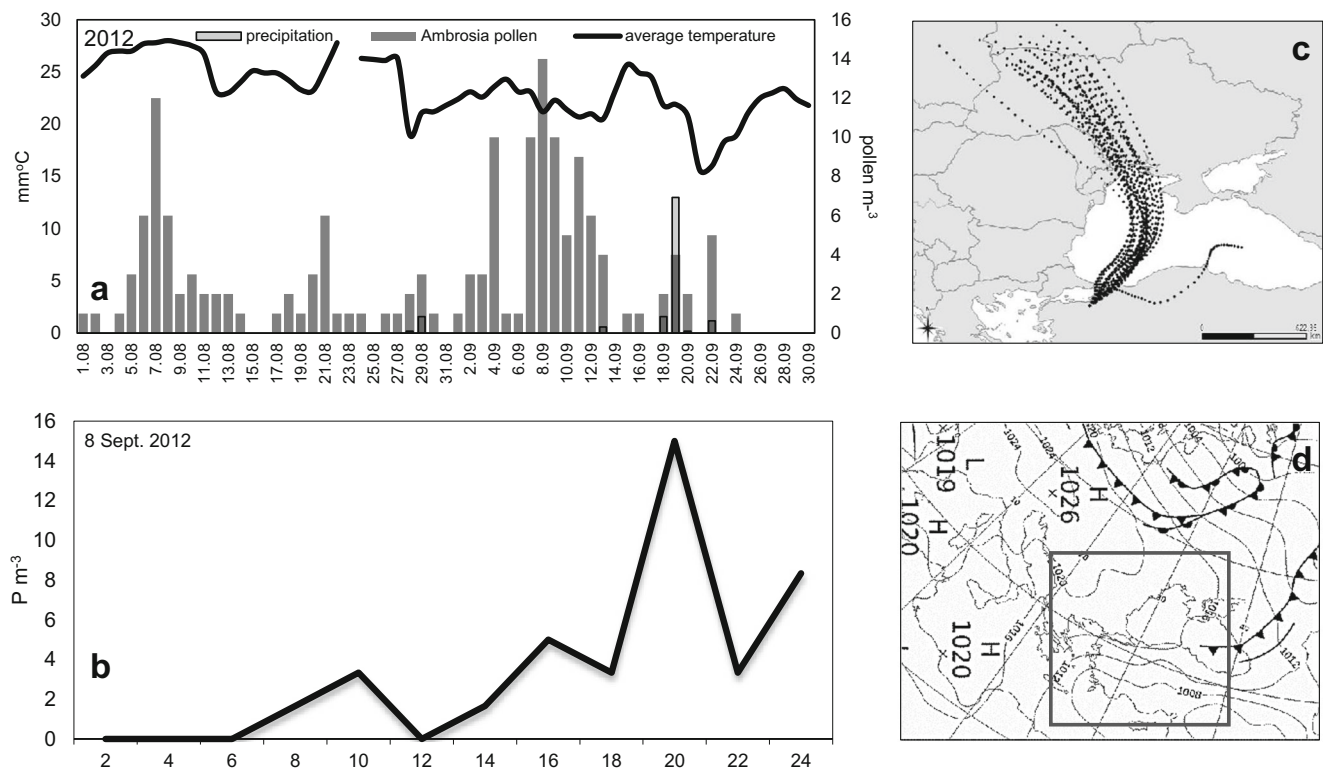


Fig. 5 Seasonal dynamics of *Ambrosia* pollen concentrations recorded in sampling station in 2012. **a** Diurnal variation of *Ambrosia* pollen grains, precipitation, and average temperature between 1/08 and 30/09. **b**

Intradiurnal variation of *Ambrosia* pollen grains in the peak day. **c** Back-trajectories arriving to Bursa 500 m AGL in 8 September 2012. **d** Synoptic map for peak day (study area is indicated by black rectangle)

Ambrosia pollen were recorded between 19:00 and 01:00 (UTC). Bi-hourly value of atmospheric *Ambrosia* pollen concentrations peaked at 20:00 (UTC) on 24 August 2013, when the highest pollen level was also identified (Fig. 6b). Daily average *Ambrosia*

pollen reached more than 40 P m^{-3} between 21 and 24 of August and was identified as 45, 63, 76, and 77 P m^{-3} , respectively (Fig. 6a). The analysis of diurnal variations in airborne *Ambrosia* pollen concentrations on these days shows that peak

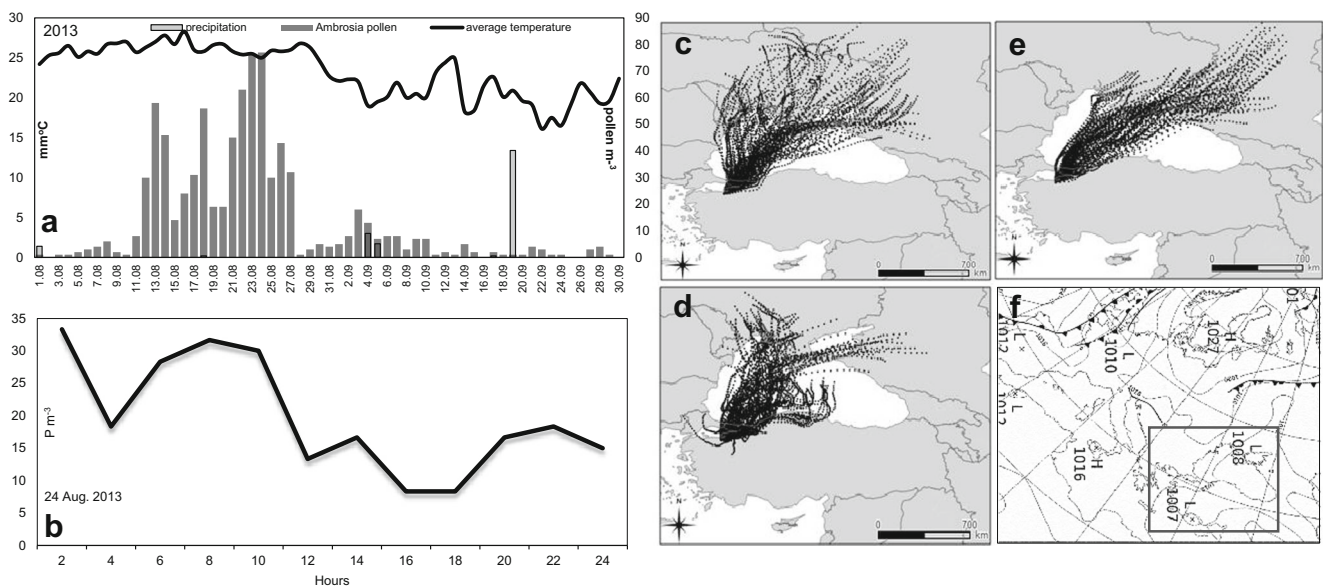


Fig. 6 Seasonal dynamics of *Ambrosia* pollen concentrations recorded in sampling station in 2013. **a** Diurnal variation of *Ambrosia* pollen grains, precipitation, and average temperature between 1/08 and 30/09. **b** Intradiurnal variation of *Ambrosia* pollen grains in the peak day. **c–e**

Back-trajectories arriving to Bursa 500 m AGL for the days $>30 \text{ P m}^{-3}$ in 2013. **c** Episode I: 12–14 and 17–18 August. **d** Episode III: 25–27 August. **e** Episode II: 21–24 August. **f** Synoptic map for peak day (study area is indicated by black rectangle)

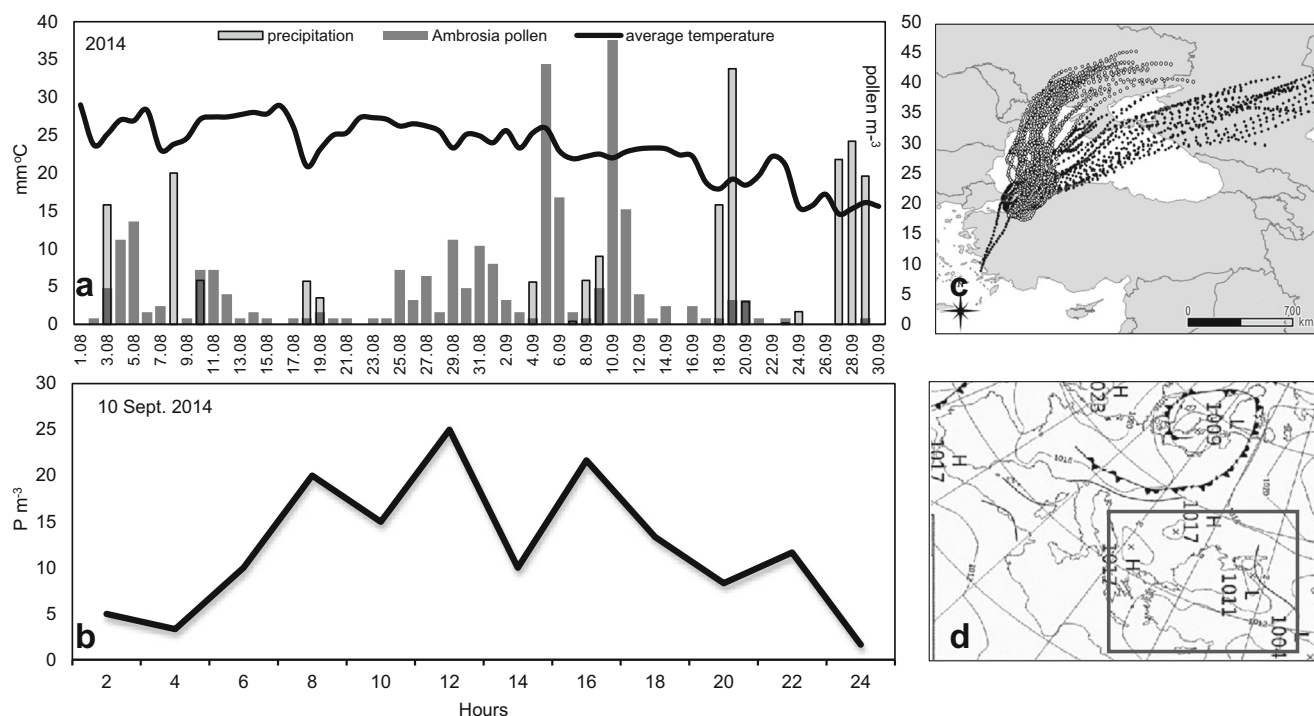


Fig. 7 Seasonal dynamics and effects of meteorological conditions to *Ambrosia* pollen concentrations recorded in sampling station in 2014. **a** Diurnal variation of *Ambrosia* pollen grains, precipitation, and average temperature for 1/08 and 30/09. **b** Intradiurnal variation of *Ambrosia*

pollen grains in the peak day. **c** Back-trajectories arriving to Bursa 500 m AGL for the days $>30 \text{ P m}^{-3}$ in 2014, white: 5 September 2014, black: 10 September. **d** Synoptic map of peak day (study area is indicated by black rectangle)

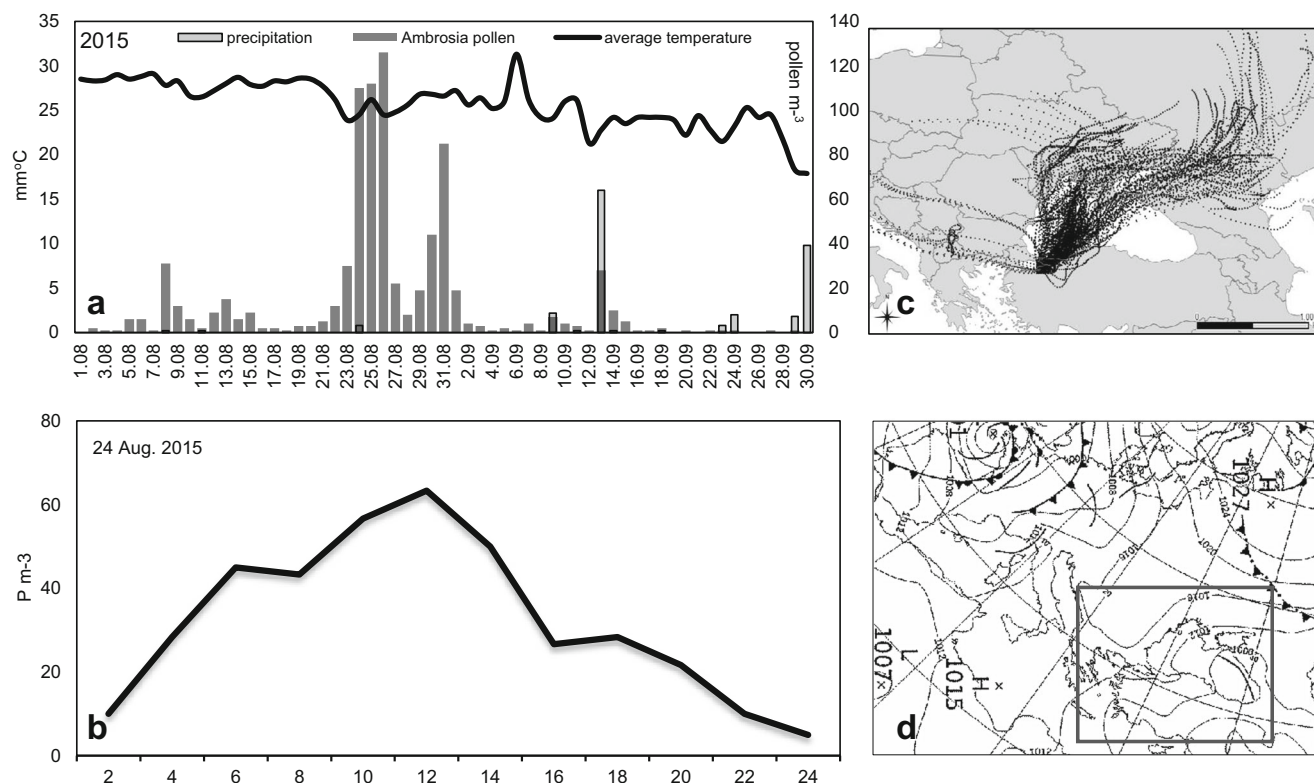


Fig. 8 Seasonal dynamics and effects of meteorological conditions to *Ambrosia* pollen concentrations recorded in sampling station in 2015. **a** Diurnal variation of *Ambrosia* pollen grains, precipitation, and average temperature for 1/08 and 30/09. **b** Intradiurnal variation of *Ambrosia*

pollen grains in the peak day. **c** Back-trajectories arriving to Bursa 500 m AGL for the days $>30 \text{ P m}^{-3}$ in 2015. **d** Synoptic map for peak day (study area is indicated by black rectangle)

Table 3 Arrival time of each back-trajectories

Year	Date of the peak	Arriving time for back-trajectories (UTC)
2010	13 September	19:00
2010	14 September	00:00
2011	25 August	21:00
2011	01 September	13:00
2011	02 September	06:00
2012	08 September	17:00
2013	12 August	20:00
2013	13 August	04:00
2013	14 August	22:00
2013	17 August	20:00
2013	18 August	16:00
2013	21 August	18:00
2013	22 August	18:00
2013	23 August	16:00
2013	24 August	20:00
2013	25 August	22:00
2013	26 August	22:00
2013	27 August	00:00
2014	05 September	17:00
2014	10 September	09:00
2015	08 August	10:00
2015	23 August	21:00
2015	24 August	21:00
2015	25 August	21:00
2015	26 August	16:00
2015	30 August	21:00
2015	31 August	02:00

levels were recorded between 19:00 and 23:00 (UTC). Back-trajectories computed for 21–24 August show that the air masses came from the north around the Azov Sea (Fig. 6e).

Daily average value of *Ambrosia* pollen concentrations reached 43 and 47 grains $P\ m^{-3}$ on the 5 and 10 September 2014, respectively (Fig. 7a). These were the only days when daily average *Ambrosia* pollen concentrations exceeded 30 $P\ m^{-3}$ in the year 2014. Atmospheric *Ambrosia* pollen concentrations on the 5 and 10 September in Bursa peaked at 17:00 and 09:00 (UTC), respectively (Fig. 7b). Back-trajectories calculated for the trajectory for 5 and 10 September 2014 show that the air masses come from Ukraine and Russia (Fig. 7c). At 48 h before arrival, the air masses passed over the Black Sea and arrived to the sampling station between the hours 17:00 and 09:00 (UTC) when the peak values were recorded as 43 and 47 $P\ m^{-3}$, respectively, on these days.

The daily average atmospheric *Ambrosia* pollen concentrations exceeded 30 $P\ m^{-3}$ on 7 days between 8 and 31 August 2015, and ranged between 30 and 126 $P\ m^{-3}$ (Fig. 8a). Analysis of diurnal concentrations showed that a peak level

of *Ambrosia* pollen occurred at 21:00 (UTC) on four of these days. Peak levels were recorded on 24 August 2015 at midday (Fig. 8b). Back-trajectories showed that the air masses came from around the Azov Sea (Fig. 8c).

Air mass patterns of *Ambrosia* peak periods

During the peak periods of 2010, the synoptic situation was dominated by low-pressure systems (1002–1012 hPa) residing the northern side of the Black Sea in an east to west direction. This area is to the northwest of Turkey and a trough of low pressure developed over the region, which gave a wind direction of north to south and marked the same route taken by the pollen (Fig. 3d).

The synoptic situation on 1 and 2 September 2011 was characterized by low-pressure systems (1006–1012 hPa) residing over the upper side of Black Sea in a north to south direction to the northwest of Turkey (Fig. 4d). This low-pressure system ran the wind from north to south and marked the same direction taken by the ragweed pollen. The average daily temperature for 1 and 2 September 2011 (24 °C) was 9.5 °C above the 65-yearly average, no rainfall was recorded, and relative humidity was 51% (Fig. 4a). An occlusion was characterized over Romania and Bulgaria on 1 and 2 September 2011 (Fig. 4d). This occluded front generally marked the route taken by the pollen.

Atmospheric *Ambrosia* pollen concentrations peaked between 15:00 and 17:00 (UTC) on 8 Sept. 2012 (Fig. 5b). The computed back-trajectory at 17:00 UTC on the 8 September shows that the air masses that arrived in Bursa was over Ukraine 48 h before and passed through the country (Fig. 5c). The synoptic situation was characterized by high-pressure systems (1016 hPa) over the upper side of the Black Sea in a north to south direction to the northwest of Turkey (Fig. 5d).

Peak days in 2013 were separated into three clusters:

1. Episode I: pollen grains > 30 $P\ m^{-3}$ before the yearly peak level

Pollen grains of *Ambrosia* reached 30 $P\ m^{-3}$ on 12 August and were then recorded as 58 and 46 $P\ m^{-3}$ on the following days (Fig. 6a). The synoptic situation was dominated by low-pressure systems (1008–1012 hPa) which passed over Ukraine on 12 August and over Bulgaria on 13 September, then reached the sampling station (Fig. 6c). Back-trajectories were computed for 17–18 August when the synoptic situation was again under a low-pressure system (1006–1012 hPa) rising around the south of the Azov Sea (Fig. 6c). The average daily temperature for 17 and 18 August 2013 was 26 °C, no rainfall was recorded, and relative humidity was 57.5% (Fig. 6c).

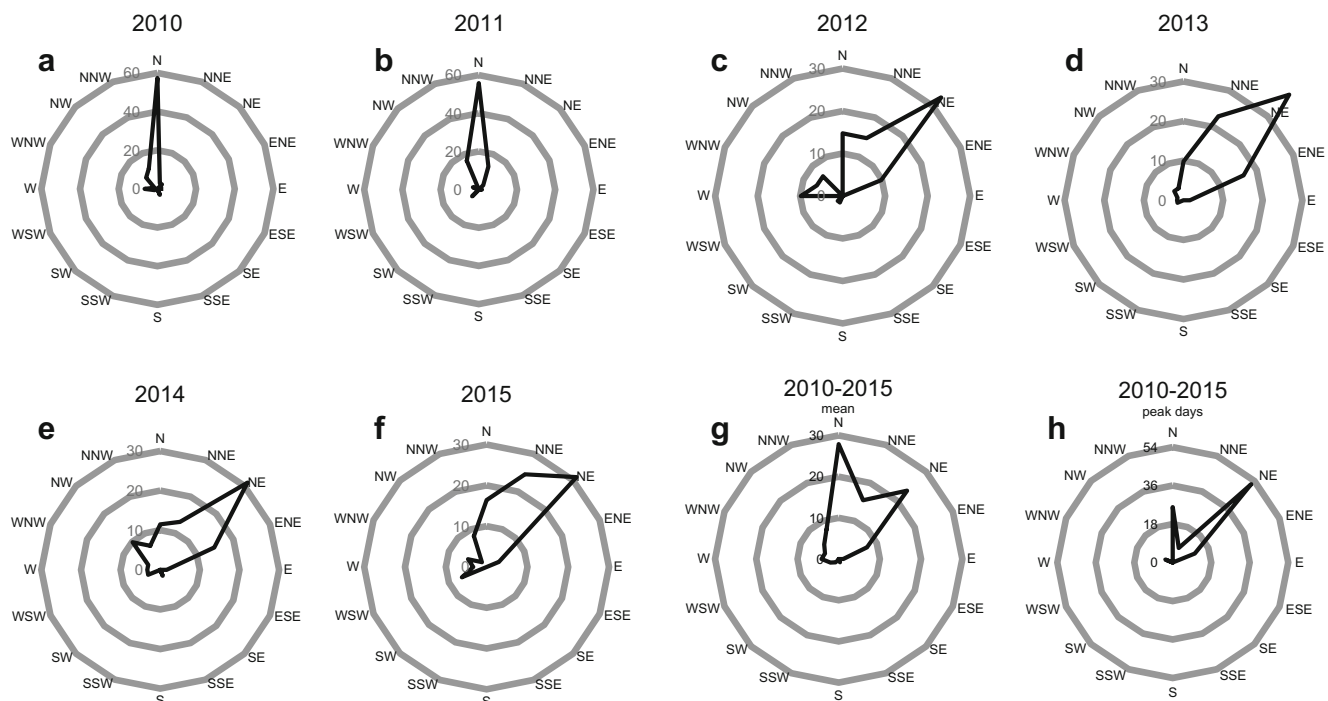


Fig. 9 Wind roses for investigated period, showing the frequency of daily average wind directions recorded at Bursa meteorological station during August and September in 2010–2015: **a** 2010; **b** 2011; **c** 2012; **d** 2013; **e** 2014; **f** 2015; **g** 2010–2015 mean; **h** 2010–2015 peak days

2. Episode II: pollen grains $> 40 \text{ P m}^{-3}$

Ambrosia pollens reached $>40 \text{ P m}^{-3}$ between 21 and 24 of August and were identified as 45, 63, 76, and 77 P m^{-3} , respectively (Fig. 6a). A series of high-pressure systems (1012–1016 hPa) passed to the south of Ukraine and Russia (around the Azov Sea) from the Black Sea toward Bursa and the air masses moved toward the pollen monitoring station from a northerly direction at midnight (local time) of 21–24 August

2013 (Fig. 6e). The average daily temperature from 21 to 24 August 2013 was 26°C , no rainfall was recorded, and average relative humidity was 54% (Fig. 6a).

The air masses continued to arrive from south of Europe. Back-trajectory analysis shows that possible sources of *Ambrosia* pollen on these dates included the southeast of Ukraine and Russia (Fig. 6c–e).

3. Episode III: pollen grains $> 30 \text{ P m}^{-3}$ after the yearly peak level

Back-trajectories were run for the days after the yearly peak level was identified and pollen grains exceeded 30 P m^{-3} (Fig. 6a). Back-trajectories and synoptic charts showed that between 25 and 27 August, air masses came from the Black Sea regions of Turkey (Fig. 6d). During 25–27 August, the synoptic situation was dominated by low-pressure systems (1009–1012 hPa) extending from the east of Turkey to the western side. This low-pressure system ran the wind from northeast to northwest and possibly marked the same route taken by the pollen. The average daily temperature between 25 and 27 August 2013 was 26°C , no rainfall was recorded, and relative humidity was 56% (Fig. 6a). As a result, air masses from this direction arrived with the pollen grains of *Ambrosia*. Interestingly, this direction was a Black Sea region of Turkey. The ragweed population was identified on the coast road of the Black Sea in 2012 (personal observation). This direction was identified during the studied period only in the

Table 4 Spearman's rank correlation analysis of daily meteorological data and *Ambrosia* pollen concentrations (meteorological data: daily mean humidity (%), daily total precipitation amount (mm), daily mean temperature ($^\circ\text{C}$), and daily mean wind speed (km/h))

Year	Humidity	Precipitation	Temperature	Wind speed
2010	0.170	−0.042	−0.298*	0.179
2011	−0.053	0.016	−0.194	0.171
2012	−0.059	0.264*	−0.024	0.304*
2013	0.037	−0.068	0.368**	0.361**
2014	−0.189	−0.165	0.264*	0.184
2015	−0.478**	0.030	0.255*	0.402**
^a	0.679	0.282	−0.157	0.820

*Correlation is significant at the 0.05 level (two-tailed); **correlation is significant at the 0.01 level (two-tailed)

^a Peak days $\geq 30 \text{ P m}^{-3}$ for the years 2010–2015

year 2013, and this caused an increase in the number of the days exceeding the threshold value in the year 2013.

In 2014, *Ambrosia* pollen exceeded 30 P m^{-3} for only 2 days (5 and 10 September 2014) and pollen counts peaked at 20:00 or 12:00 (local time) (Fig. 7b). Although no known local *Ambrosia* plant population was identified, it should be noted that an identified pollen peak at midday (local time) in these dates could indicate the most likely local plant population. The average daily temperature on 5 September 2014 was 26°C , and no rainfall was recorded despite relative humidity of 72%. Similarly, the daily average temperature on 10 September 2014 was recorded as 22°C , and relative humidity was recorded as 62% (Fig. 7a). However, the back-trajectory and synoptic situation featured low-pressure systems (1008–1012 hPa) coming from the east of the Azov Sea and passed over the Black Sea toward Bursa (Fig. 7d).

Daily average *Ambrosia* pollen concentrations exceeded 30 P m^{-3} for 7 days between 8 and 31 August 2015. Pollen grains of *Ambrosia* were recorded between 30 and 126 P m^{-3} on these days. The average daily temperature on 30 and 31 August 2015 was 27°C , no rainfall was recorded, and average relative humidity was 52.5% (Fig. 8a). The peak level was recorded on 24 August 2015 at midday (Fig. 8b). Back-trajectories were computed with the hours when the highest daily concentrations were measured, and all calculated trajectories for over the threshold values in 2015 showed that the air masses came from Russia and Ukraine around the Azov Sea (Fig. 8c). During this period, a series of high-pressure systems (1016–1020 hPa) that came from the south of Ukraine passed over the Black Sea and Turkey and continued to the southeast of Europe (Fig. 8d). Only on two of these days (23 and 24 August), was the synoptic situation characterized by a low-pressure system (1020 hPa) that came from Ukraine and rose to Africa.

Conclusion

The present study indicates that the *Ambrosia* pollen grains identified in August and September in Bursa were not from local sources. The main source area for long distance transported *Ambrosia* pollen was Russia which accounted for 35% of the trajectories calculated on days when pollen exceeded 30 P m^{-3} . This was followed by Ukraine (30%), both Ukraine and Russia around the Azov Sea (15%), the Black Sea region of Turkey (12%), and Bulgaria and Romania (8%). This study supports the hypothesis that the long-distance transport of ragweed pollen to Turkey is mainly related to the passage of air masses from the north and/or northeast direction. Pollen grains can originate from any point along a trajectory, and local sources cannot be ignored as seen in 2014 when diurnal *Ambrosia* pollen concentrations peaked around midday. The results of this study showed that airborne

Ambrosia pollen concentrations exceeded 10 P m^{-3} 49 times, 30 P m^{-3} 28 times, and 50 P m^{-3} 7 times during the years under investigation. The present data and findings in this paper suggest that the season of allergy in the area may prolong until the end of September, which may lead to an increase in the number of susceptible people exposed to *Ambrosia* allergens in the near future. The ongoing invasion of *Ambrosia* has become an important environmental problem, not only threatening health but also acting as a bio-invader plant.

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References

- Albertemst B, Nawrath S (2008) Ambrosia-pollen: does changes in a climate have an influence on pollen calendar? *Allergologie* 31(9): 398–399
- Asero R, Bellotto E, Ghiani A, Aina R, Citterio S (2014) Allergy to *Ambrosia artemisiifolia* and *Artemisia vulgaris* in Northern Italy: are both pollens primary sensitizers? *Allergy* 69:142–142
- Basky ZS (2009) A Magyarországon őshonos levéltetvek hatása a parlagfű fejlődésére. (Effect of native aphids on the development of ragweed in Hungary.). *Növényvédelem* 45 (425–432.)
- Behrendt H (2009) Allergy research in climate change—health risks from pollen of Ambrosia? *Allergologie* 32(10):401–401
- Bianchi DE, Schwemmin DJ, Wagner WH (1959) Pollen release in the common ragweed (*Ambrosia artemisiifolia*). *Bot Gaz* 120:235–243
- Bullock J (2010) Assessing and controlling the spread and the effects of common ragweed in Europe. Final report: ENV.B2/ETU/2010/0037:.
- Cecchi L, Malaspina TT, Albertini R, Zanca M, Ridolo E, Usberti I, Morabito M, Dall' Aglio P, Orlandini S (2007) The contribution of long-distance transport to the presence of Ambrosia pollen in central northern Italy. *Aerobiologia* 23(2):145–151. doi:10.1007/s10453-007-9060-4
- Comtois P Satellite symposium proceedings: ragweed in Europe. Ragweed (*Ambrosia* sp.): the phoenix of allergophytes. In: 6th International Congress on Aerobiology, Perugia, Italy, 1998.
- Dahl A, Strandhede SO, Wihl JA (1999) Ragweed-an allergy risk in Sweden? *Aerobiologia* 15:293–297
- De Weger LA, Bergmann KC, Rantio-Lehtimäki A, Dahl A, Buters J, Déchamp C, Belmonte J, Thibaudon M, Cecchi L, Besancenot JP, Galán C, Waisel Y (2013) Impact of pollen. In: Sofiev M, Bergmann KC (eds). *Allergenic pollen*. Springer, Netherlands, pp 161–215. doi:10.1007/978-94-007-4881-1
- Dimitrov D, Tzonev R (2002) On the distribution of *Ambrosia artemisiifolia* L. (Asteraceae) in Bulgaria. *Phytologia Balcanica* 8(1):31–33
- Essl F, Biró K, Brandes D, Broennimann O, Bullock JM, Chapman DS, Chauvel B, Dullinger S, Fumanal B, Guisan A, Karer G, Kazinczi G, Kueffer C, Laitung B, Lavoie C, Leitner M, Mang T, Moser D, Müller-Schärer H, Petitpierre B, Richter R, Schaffner U, Smith M, Starfinger U, Vautard R, Vogl G, von der Lippe M, Follak S (2015)

- Biological flora of the British Isles: *Ambrosia artemisiifolia*. J Ecol 104(4):1069–1098
- Follak S, Dullinger S, Kleinbauer S, Moser D, Essl F (2013) Invasion dynamics of three allergenic invasive Asteraceae (*Ambrosia trifida*, *Artemisia annua*, *Iva xanthiifolia*) in central and eastern Europe. Preslia 85:41–61
- Galan C, Carinanos P, Garcia-Mozo H, Alcazar P, Dominguez-Vilches E (2001) Model for forecasting *Olea europaea* L. airborne pollen in South-West Andalusia, Spain. Int J Biometeorol 45(2):59–63. doi:10.1007/s004840100089
- Galan C, Smith M, Thibaudon M, Frenguelli G, Oteros J, Gehrig R, Berger U, Clot B, Brandao R, Grp EQW (2014) Pollen monitoring: minimum requirements and reproducibility of analysis. Aerobiologia 30(4):385–395. doi:10.1007/s10453-014-9335-5
- Hirst JM (1952) An automatic volumetric spore trap. Ann Appl Biol 39:257–265
- Ianovici N, Panaiteescu CB, Brudiu I (2013) Analysis of airborne allergenic pollen spectrum for 2009 in Timișoara, Romania. Aerobiologia 29(1):95–111. doi:10.1007/s10453-012-9266-y
- Ianovici N, Sirbu C (2007) Analysis of airborne ragweed (*Ambrosia artemisiifolia* L.) pollen in Timișoara, 2004. Analele Universității din Oradea Fascicula Biologie 14 (101–108.)
- Jaeger S (2000) Ragweed (*Ambrosia*) sensitisation rates correlate with the amount of inhaled airborne pollen. A 14-year study in Vienna, Austria. Aerobiologia 16:149–153
- Jäger S Global aspects of ragweed in Europe. In: Spieksma FTM (ed) 6th International Congress of Aerobiology, Perugia, Italy, 1998. Satellite Symposium Proceedings pp. 6–10. Alk-Abelló A/S, Horsholm DK
- Juhász M (1995) New results of aeropalynological research in Southern Hungary. Publications of the Regional Committee of the Hungarian Academy of Sciences 5:17–30
- Makra L, Matyasovszky I, Hufnagel L, Tusnady G (2015) The history of ragweed in the world. Appl Ecol Environ Res 13(2):489–512
- Milkovska S, Karadzinska-Bislimovska J, Cvetanov V, Janackov B, Minov J, Risteska-Kuc S, Ezova N, Yankova R, Mijakoski D, Stoleski S (2008) *Ambrosia* and *Artemisia* in r. Macedonia: aeropallinological and allergenic significance Allergy 63:398–398
- Onen H, Gunal H, Ozcan S (2014) The Black Sea highway: the route of common ragweed (*Ambrosia artemisiifolia* L.) invasion in Turkey. Paper presented at the 8th International Conference on Biological Invasions from understanding to action, Antalya, Turkey.
- Ozaslan C, Onen H, Farooq S, Gunal H, Akyol N (2016) Common ragweed: an emerging threat for sunflower production and human health in Turkey. Weed Biology and Management 16(1):42–55. doi:10.1111/wbm.12093
- Peeters A (2000) *Ambrosia* sp. pollen in Switzerland. Aerobiologia 16(2):295–297. doi:10.1023/A:1007656405322
- Peternel R, Culig J, Mitic B, Vukusic I, Sostar Z (2003) Analysis of airborne pollen concentrations in Zagreb, Croatia, 2002. Annals of Agricultural and Environmental Medicine 10(1):107–112
- Puc M (2004) Ragweed pollen in the air of Szczecin. Annals of Agricultural and Environmental Medicine 11(1):53–57
- Reznik SY (2009) Common ragweed (*Ambrosia artemisiifolia* L.) in Russia: spread, distribution, abundance, harmfulness and control measures. Ambrosie. The first international ragweed review 26
- Rich TCG (1994) Ragweeds (*Ambrosia* L.) in Britain. Grana 33:38–43
- Rodinkova V, Palamarchuk O, Kremenska L, Bilous O, Motruk I, Mazjur O, Slobodyanuk L, DuBuske LM (2012) Prevalence of *Ambrosia* (ragweed) pollen in Ukraine. Annals of Allergy Asthma & Immunology 109(5):A50–A50
- Sikoparija B, Skjøth CA, Celenk S, Testoni C, Abramidze T, Alm Kübler K, Belmonte J, Berger U, Bonini M, Charalampopoulos A, Damialis A, Clot B, Dahl A, de Weger LA, Gehrig R, Hendrickx M, Hoebeke L, Ianovici N, Kofol Seliger A, Magyar D, Mányoki G, Milkovska S, Myszkowska D, Páldy A, Pashley CH, Rasmussen K, Ritenberga O, Rodinkova V, Rybniček O, Shalaboda V, Šaulienė I, Ščevková J, Stjepanović B, Thibaudon M, Verstraeten C, Vokou D, Yankova R, Smith M (2016) Spatial and temporal variations in airborne *Ambrosia* pollen in Europe. Aerobiologia:1–9. doi:10.1007/s10453-016-9463-1
- Šikoparija B, Skjøth CA, Kubler KA, Dahl A, Sommer J, Grewling L, Radišić P, Smith M (2013) A mechanism for long distance transport of *Ambrosia* pollen from the Pannonian Plain. Agric For Meteorol 180:112–117. doi:10.1016/j.agrformet.2013.05.014
- Šikoparija B, Smith M, Skjøth CA, Radišić P, Milkovska S, Šimić S, Brandt J (2009) The Pannonian plain as a source of *Ambrosia* pollen in the Balkans. Int J Biometeorol 53(3):263–272. doi:10.1007/s00484-009-0212-9
- Skjøth CA, Smith M, Šikoparija B, Stach A, Myszkowska D, Kasprzyk I, Radišić P, Stjepanović B, Hrga I, Apatini D, Magyar D, Páldy A, Ianovici N (2010) A method for producing airborne pollen source inventories: an example of *Ambrosia* (ragweed) on the Pannonian Plain. Agric For Meteorol 150(9):1203–1210. doi:10.1016/j.agrformet.2010.05.002
- Smith M, Cecchi L, Skjøth CA, Karrer G, Sikoparija B (2013) Common ragweed: a threat to environmental health in Europe. Environ Int 61:115–126. doi:10.1016/j.envint.2013.08.005
- Smith M, Jäger S, Berger U, Šikoparija B, Hallsdóttir M, Sauliė I, Bergmann KC, Pashley CH, de Weger L, Majkowska-Wojciechowska B, Rybniček O, Thibaudon M, Gehrig R, Bonini M, Yankova R, Damialis A, Vokou D, Bustillo AMG, Hoffmann-Sommergruber K, van Ree R (2014) Geographic and temporal variations in pollen exposure across Europe. Allergy 69(7):913–923. doi:10.1111/All.12419
- Stach A, Smith M, Skjøth CA, Brandt J (2007) Examining *Ambrosia* pollen episodes at Poznań (Poland) using back-trajectory analysis. Int J Biometeorol 51(4):275–286. doi:10.1007/s00484-006-0068-1
- Stein AF, Draxler RR, Rolph GD, Stunder BJB, Cohen MD, Ngan F (2015) NOAA's HYSPLIT atmospheric transport and dispersion modeling system. Bull Amer Meteor Soc 96:2059–2077
- Taramacaz P, Lambelet C, Clot B, Keimer C, Hauser C (2005) Ragweed (*Ambrosia*) progression and its health risks: will Switzerland resist this invasion? Swiss Med Wkly 135:538–548
- Visiani R (1842) Flora Dalmatica, vol II. F. Hofmeister, Leipzig
- Wayne P, Foster S, Connolly J, Bazzaz F, Epstein P (2002) Production of allergenic pollen by ragweed (*Ambrosia artemisiifolia* L.) is increased in CO₂-enriched atmospheres. Annals of Allergy Asthma & Immunology 88(3):279–282
- Yankova R, Baltadjieva D, Peneva R, Zlatev V (1996) Pollen grains of *Ambrosia* in the air of Sofia, Bulgaria. Aerobiologia 12(1):273–277
- Zauli D, Tiberio D, Grassi A (2006) Ragweed pollen travels long distance. Annals of Allergy Asthma & Immunology 97(1):122–123