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EVALUATION OF THE EFFECT OF WEATHER ON CONCENTRATIONS OF AIRBORNE ARTEMISIA POLLEN USING CIRCULAR STATISTIC

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Abstract

The diurnal pollen pattern of *Artemisia* seems to be similar in many regions in Central and Eastern Europe, with its highest concentration before noon. This research is a continuation of a preliminary study that was carried out in Rzeszów 10 years ago. The Spearman nonparametric correlation test and the angular-linear correlation were used to verify assumptions about the influence of meteorological parameters on daily and hourly variations of *Artemisia* pollen concentrations in the atmosphere. The results showed that the patterns of hourly and daily *Artemisia* pollen concentration in the air of Rzeszów did not differ significantly from the results obtained in previous years, except PI value which was significantly lower. The majority of *Artemisia* pollen grains appeared in the air before noon and in the early afternoon. However, on some days the peaks occurred around midnight. The hourly and daily *Artemisia* pollen concentrations were strongly influenced by temperature and relative humidity. Daily concentration was also influenced by radiation and sunshine duration. We do not exclude other factors, such as secondary deposition and long distance transport. We proposed circular statistics as an appropriate method of analysis of the relationship between meteorological parameters and hourly airborne pollen concentration.

Key words: aerobiology; *Artemisia*; diurnal variation; seasonal variations; meteorological relationships; circular statistic

INTRODUCTION

The genus *Artemisia* L. included in the Asteraceae family comprises between 200 to 600 species, depending on the literature data. *Artemisia* is mostly distributed in the Northern hemisphere, from sea level to high mountains and from arid zones to wetlands [1, 2]. Some of the species, e.g. *A. absinthium* L. are useful in traditional and modern medicine [3]. Leaves and oil from *A. dracunculus* L., commonly named tarragon, are used in cuisine and the food industry as an aromatic spice [4]. However, many mugwort species are also prone to causing allergies. The most important *Artemisia* species are those considered as synanthropic and pioneer plants in ruderal places on disturbed soils. They also occupy dry areas, grasslands, agricultural fields, roadsides, fallow ground and wasteland [5]. Endemic and endangered mugwort species are also known, such as those in Sierra Nevada [6].

18 *Artemisia* species are documented as growing wild or commonly cultivated in Poland, including 9 native species [7]. Among them, *Artemisia vulgaris* L., *A. campestris* L. and *A. absinthium* L. are the most widespread weeds in urban and rural areas, and therefore the most significant from an aerobiological point of view. Rarely occurring but also significant species are *A. abrotanum* L., *A. annua* L., *A. austriaca* Jacq., *A. pontica* L. and *A. scoparia* W. et K. [8]. One other species, *A. verlotiorum* Lamotte, occurs in the south-east of Poland [9]. In various parts of Rzeszów (south-east Poland), as well as in Szczecin and Upper Silesia, the presence of the expansive species *A. biennis* Willd. is also noted [10]. It is one of the latest blooming mugworts. Its blooming time falls in August and September [8].

The main *Artemisia* pollen season starts earlier in Northern (Scandinavia), Eastern (Poland) and Southern (Balkan) Europe than in Western Europe (Spain). In Spain the season starts at the end of August, while in the rest of the afore-mentioned parts of Europe it begins at the end of July or the beginning of August. The season finishes at the end of August in Northern and Eastern Europe, while in Southern Europe the end falls during the third 10-day period of September. In Spain, where three mugwort pollen seasons were distinguished, the last ends in the first 10-day period of February [11–13]. In Poland the mean *Artemisia* pollen season usually starts in the second or third 10-day period of July and lasts until the third 10-day period of August or the beginning of September, depending on the area and the year [13]. During the main pollen season concentrations range from 30 to 200 pm^{-3}, although concentrations above 200 and 300 pm^{-3} occasionally occur [14–18]. In the city of Rzeszów the mugwort pollen season spans from the third 10-day period of July to the beginning of September [19].

The diurnal pollen pattern of *Artemisia* seems to be similar in many regions in Central and Eastern Europe, with its highest concentration before noon. Pollen grains release from the anthers most intensively at 9 am, thus the peak of airborne pollen concentrations forms a bit later [14, 20–24]. Peaks occurring at different times of day may be the result of long distance transport or redeposition [12, 23]. The diurnal pattern might change during the pollen season when different species of the same taxa bloom successively (eg. grass) [24–27]. Mullins et al. [28] and Norris-Hill [29] stated that the pattern of hourly concentrations of airborne pollen of some taxa may also depend on the microclimate. Peak concentrations occur earlier in natural habitats, and in suburban areas rather than in cities, and the peaks in the latter are usually lower. Preliminary studies conducted in SE and NW Poland seem to confirm this thesis [19, 30].

Numerous pieces of research indicate the strong impact of weather variables on pollen concentration during the pollen season. Out of them, the maximum and mean daily temperatures as well as relative humidity and rainfall seem to have the greatest significance [17, 31]. In some regions wind direction also plays an important role [12]. Also the weather several weeks before pollen season influences its duration and intensity [12, 13, 31].

Mugwort pollen is one of the most abundant and most strongly allergenic of herbaceous plants. In Western and Central Europe the incidence of allergic rhinitis and conjunctivitis caused by *A. vulgaris* is estimated between 3 and 15% [32]. Allergens Art v1 and Art v3 appear to play the greatest role in mugwort allergies. An increase in the severity of the allergy reaction may be caused by cross-reactivity between *Artemisia* and *Ambrosia* L. pollen allergens, whose pollination and pollen seasons partly overlap in some regions [33]. The first allergy symptoms in reaction to mugwort pollen appear in the majority of sensitive people at a concentration higher than 50 pollen grains per cubic metre, more serious symptoms are observed at 70 and the most serious-dyspnea at 120 grains per cubic metre [34]. In Poland, mugwort pollen is the second most common reason for pollinoisis during late summer (after grass pollen). Obtułowicz et al. [35] stated that in the Cracow region about 40% of patients suffering from pollen allergy in south-eastern Poland are sensitive to *Artemisia* pollen. Even so, very few detailed pieces of research on the daily and diurnal patterns of airborne *Artemisia* pollen have been carried out so far in Poland. *Artemisia* species are widespread not only in Poland but also in many European regions, and their pollen often occurs in the air in concentrations sufficient to cause allergy [12, 13]. In previous years the maximum daily pollen concentration in Rzeszów ranged from 30 to about 100 pm^{-3}, so it might be said that mugwort is significant for citizens who suffer from inhalant allergies. This research focuses on different aspects of the *Artemisia* pollen season in Rzeszów, and is a continuation of a preliminary study that was carried out from 1997 to 2005 [19, 36].

The main objective of the study was to verify assumptions about the influence of meteorological parameters on daily and hourly variations of *Artemisia* pollen concentrations in the atmosphere. Our goal was to compare results obtained by nonparametric and circular statistics. This study aims to verify the thesis that diurnal behavior has not changed over the last 10 years.

MATERIAL AND METHODS

Aerobiological monitoring was carried out in Rzeszów (SE Poland; 50°01'45''N; 22°00'57''E) from 2010 to 2013. The meteorological station was situated at Zalesie – an area of the city about 3 km from the aerobiological station.

Rzeszów is situated at a distance of several kilometers from the Carpathian Uplands at about 210–215 m a.s.l. in Rzeszów Pogórze. The city centre lies in the wide river Wisłok valley. Typical alluvial soils occur on the alluvia of the river, while on other quaternary mounds, brown soils are predominant. Climatic conditions are chiefly affected by polar maritime and polar continental air masses. In the years 1981–2000 the mean annual air temperature was 8.1ºC [37]. During the same period the average annual total precipitation was 633 mm. July is the warmest month (18.3ºC) [37] and usually has the greatest rainfall [38]. In January, the lowest total of precipitation [38] and the lowest temperature (-2.1ºC) [37] are recorded. In the Carpathian Pogórze the wind blows mainly from the west (SW, W and NW). [37–38]. Rzeszów is considered a medium sized city with a typically urban structure. The urbanization index is 0.54. Native flora and vegetation are strongly influenced by human activity. Synantropic vegetation dominates in the town area, where there are numerous green areas in the form of parks, lawn and home gardens. Riparian vegetation grows over the river Wisłok and at the oxbow lakes . The city boundaries are made up of a mosaic of forests and cultivated fields.

Aerobiological monitoring was carried out using a volumetric Hirst type pollen trap [39]. The pollen trap was located on the roof of the University of Rzeszów building (in the city center) at about 12 m above ground level. Mugwort pollen grains were counted and identified under 400x magnification from 12 latitudinal transects on each microscope slide. The results were expressed as daily average pollen grains/m^3 (pm^{-3}) [40].

The main pollen season of *Artemisia* was distinguished using 95% and 90% methods. This means that the day on which 2.5% or 5.0% respectively of PI (pollen index – yearly total sum of pollen grains) had been reached was the first day of the pollen season and the day on which 97.5% or 95.0% of PI was recorded was the last day [41].

In order to study pollen frequency distribution during the day, an arbitrary selection of days was made. Only days without rain were chosen for further analysis. At low concentrations of airborne pollen grains, diurnal patterns would have a random character, and therefore days with more than 20 grains (absolute value) were selected for further analysis. Additionally, days were chosen from a compact period of no less than 5 days with a daily concentration exceeding 10. The pollen counts for each day were calculated as percentages. The highest percentage value was a main diurnal peak. The values which exceeded 2/3 of the main peak's value of the day were classified as the secondary or next peaks. When two peaks occurred one by one they were considered a single peak (e.g. for two periods, 8–10 h and 10–12 h, the peak was at 10 h).

The average time of maximum concentration was calculated using circular statistics. Taking a day to be 360°, each two-hour interval was expressed at an appropriate angle. For each angle, an adequate number of grains was given and then using the respective circular statistic the average time of maximum concentrations was calculated [42]. This operation was performed for each year separately. The following formula was used:

$$Y = \sum f_i \sin\frac{a_i}{n} \quad X = \sum f_i \cos\frac{a_i}{n}$$

where:

n – the number of angles (in this case 12)

f_i – the number of pollen grains within the interval

Then sine and cosine were calculated:

$$r = \sqrt{X^2 + Y^2}$$

$$cosa_i = \frac{X}{r}; \quad sina_i = \frac{Y}{r}$$

The mean angle was obtained as a function of the cosine and sine and then recalculated in hours.

We did not have a full weather database for all years, therefore statistical analysis concerned the relationship between daily and diurnal pollen counts, and meteorological parameters were taken only for 2012–2013. Temperature (Tmean, Tmax Tmin), air relative humidity (Hmean, Hmax, Hmin), rainfall, evaporation, pressure (P), total radiation (R), sunshine duration (SD), wind speed (WS) and wind direction (WD) were recorded at 1 hour intervals, then average values for each two-hour period were recalculated. Firstly the Shapiro-Wilk test was used to check normality. The S-W test showed that the data did not have normal distribution. The Spearman nonparametric correlation test was used to verify the null hypothesis about the lack of correlation between weather parameters and the daily concentration of *Artemisia* pollen grains during pollen seasons (95% and 90% methods). The statistical significance of the tests was accepted at the level of $\alpha \leq 0.05$. In order to assess the relationship between diurnal pollen concentration and some meteorological factors, the angular-linear correlation was calculated using equation:

$$r_{al} = \sqrt{\frac{r_{xc}^2 + r_{xs}^2 - 2r_{xc}r_{xs}r_{cs}}{1 - r_{cs}^2}}$$

where:

r_{al} is the angular-linear correlation coefficient,

r_{xc} is the correlation coefficient between the linear parameter's value and the cosine of angle

r_{xs} is the correlation coefficient between the linear parameter's value and the sine of the angle

r_{cs} is the correlation coefficient between the cosine and the sine of the angle

The value of the angular-linear correlation coefficient r_{cs} fluctuates between 0 and 1 and it is never negative [42].

The time of maximum concentrations in a particular day was the dependent variable (angular parameter), whereas the change in the value of the meteorological parameter (with respect to the previous day) was the independent one. For correlation between wind direction and pollen concentrations the latter was an angular parameter.

RESULTS

With the exception of 2010, the pollen season of *Artemisia* passed in a similar way each year. According to the 95% method, *Artemisia* pollen grains were recorded in the air of Rzeszów from the third 10-day period of July to the first or second 10-day period of

September (Fig 1a–d) and lasted 42–46 days. In 2010, the pollen season started earlier – in the second 10-day period of July and was the longest – 60 days. The highest pollen concentration was noted with its peak in the first 10-day period of August, except for 2010, when it appeared in the second 10-day period of August – one month from the start of the pollen season. The PI was the seasonal parameter with the greatest variability: it fluctuated from 198 to 785 grains (Table 1).

On a diurnal cycle, the *Artemisia* pollen concentrations achieved their highest value before noon and in the early afternoon. However, relatively high concentrations were recorded on some days in the evening and at midnight. The minima were noted in early morning (2.00–6.00) and late afternoon (16.00–18.00) for all studied years (Fig. 2). Due to the lack of days conforming to the above-mentioned criteria for diurnal analysis (see Material and Methods), the year 2010 was not taken into consideration for further analysis. There were notable differences in the time of day that the peaks appeared between years (Fig. 3). On some days, 2 or even 3 peaks were registered. We can state that maximum pollen concentration occurred generally from 8.00 to 10.00 in 2012, and from 20.00 to 22.00, as well as from 24.00 to 2.00, in 2013. In 2013, the peaks were also frequently recorded from 8.00 to 12.00. Thus in 2013 we observed nightly and daily peaks. More detailed analysis revealed that these nightly and evening peaks occurred in the days preceding daily maximum concentration (06.08.2013; Table 1). Results of circular statistics confirm that the diurnal pattern in 2013 differed a great deal from that obtained for 2011 and 2012. The average maximum pollen count was between 10.00–12.00 in 2011–2012, whereas in 2013 it shifted towards 14.00–16.00 (Tab. 2). Circular statistics showed that in 2012–2013 the highest values of the majority of the meteorological parameters occurred at a similar time. Temperature reached its highest values between 12.00 and 14.00, relative humidity between 24.00 and 2.00, radiation and sunshine duration between 10.00 and 12.00 (Table 2).

Spearman nonparametric correlation coefficients showed some relationships between daily pollen concentration and weather parameters (Tab. 3). The temperature, relative humidity, radiation and sunshine duration were correlated with *Artemisia* pollen grain count in both years in the season, calculated by the 95% method. Humidity was negatively correlated, while temperature, radiation and sunshine duration were correlated positively. The strongest relationship with maximum temperature was obtained in 2013. For 90%, seasonal correlations were rarer. In 2013, no correlations were stated. For 2012 rainfall, mean humidity negatively affected pollen count but radiation and sunshine duration affected it positively. No significant correlations were obtained for air pressure (Table 3). There were some connections with wind direction. The highest pollen counts were noted when the wind blew from the South-East (Fig 4a–b).

Spearman correlation coefficients were also calculated between daily pollen concentration and meteorological factors from one and two day earlier (Table 3). In this case, in 2013, using the 95% method, the same parameters as the above-mentioned had significance. In 2012, only mean temperature and radiation from the previous day and the mean temperature from two days earlier affected airborne pollen concentrations. Mean temperature seems to had the greatest positive influence on pollen concentration one and two days earlier, as this relationship is significant in both years for the 95% method and in 2012 for the 90%. Additionally, a strong positive autocorrelation existed with a 2 day lag in both years.

According to angular-linear statistics, significant correlations for the time of the diurnal peak and the change of mean temperature, mean relative humidity, radiation and sunshine duration were stated only for 2013 (Table 4). Although the angular correlation coefficient never assumes negative value, the mean time of maxima for weather parameters allows us to draw conclusions about correlation direction. Comparing the results of angular-linear correlation with the results from circular statistics (Table 2), we can state that temperature, radiation and sunshine duration were positively correlated with pollen concentration, whereas relative humidity was correlated negatively.

DISCUSSION

The start and course of *Artemisia* pollen seasons in Rzeszów in 2010–2013 did not differ clearly from those of previous years [36]. The highest pollen concentrations usually appeared in the air at the beginning of August, as in other Polish cities [15–18, 31, 43]. Weryszko-Chmielewska et al. [44] stated that similar dates of maximum pollen concentration were connected with a constant biological rhythm. Mugwort blooming is probably induced by the shortening days.

The compact and relatively regular *Artemisia* pollen season suggests that a single dominating species was the main pollen source. A similar type of season was recorded in Lublin and Poznań (Poland). In the latter city, the pollen season overlapped with the flowering period of *A. vulgaris,* suggesting that this species was the main pollen source [44, 45]. Święs [46] pointed out that in Rzeszów, *A. vulgaris* was the most frequent.

In some years, there were already small increases in pollen concentration after the end of the period of continuous occurrence. It is difficult to assess the reasons for such increases. Redeposition of pollen grains or long-distance transport cannot be excluded [6, 12, 44, 47]. The increases may also be the result of the blooming of other *Artemisia* species. Grewling et al. [13] stated that in south-eastern Poland *A. annua* and *A. scoparia* might be responsible for the peak of pollen concentration in September. *A. biennis* also occurs in Rzeszów [10]. Although it is a rare species in the flora of Rzeszów, it flowers exactly at the time of autumn's outliers [46].

Only the pollen index (PI) differs significantly from the value recorded in previous years in Rzeszów. During the period 1997–2005, mean yearly pollen count equaled 866 grains. In several years, especially in the nineties, PI was above 1000 [36]. A great decrease has been visible in recent years. In 2010–2013, the average PI was four times lower than the average from 1997–2005. One possible reason is the change in land use. Just a few years ago ruderal vegetation dominated in the vicinity of the monitoring station, and mugwort occurred frequently. Then the area was built upon and the frequency of mugwort decreased. Some investigations confirm that nearby *Artemisia* stands might influence pollen concentrations [31, 48].

The study on diurnal periodicity conducted in different regions showed that two general patterns might be distinguished. The first is irregular – when maximum concentration may appear at any time of day – this is usually the case for trees and grass [14, 19, 22, 25–27, 49, 50]. The second pattern is regular – when diurnal maxima occur at similar frequency during each day of the pollen season. This concerns many herbaceous plants [14, 19, 22, 24].

Against the background of the examined taxa, *Artemisia* is characterized by one of the greatest regularities in diurnal periodicity. Several investigations have indicated a midday or early afternoon peak of *Artemisia* pollen concentration. This is also characteristic of the nettle diurnal cycle [14, 20, 22, 24].

A study carried out 10 years ago proved that the majority of *Artemisia* pollen grains appeared in the air before noon and in the early afternoon [19]. Our results are largely similar. However, on some days the peaks occurred around midnight, especially in the year 2013. The phenomena of evening peaks for *Artemisia* was observed in Murcia, Spain [12]. Vertical air movements can be the cause of nightly peaks. In warm days, which occur frequently in summer, thermal convection lifts pollen into the higher layers of the atmosphere. Then, in the late evening and/or at night, when thermal convection disappears, airborne pollen falls down, even in large amounts [19, 51]. Nightly and evening peaks occurring in Rzeszów might be also caused by transport or secondary fall, as rejected in Spain [12]. It was also observed that pollen might be transported at a very low velocity by slow blowing wind and this could be the reason for particularly high pollen counts [52]. Additionally, Käpylä [20] stated that two daily peaks were anomalies caused by rain during mugwort flowering. As we did not examine days with rainfall, these two or three daily peaks must have a different cause.

The height at which the pollen trap is located has great significance for the investigation of diurnal periodicity, especially for herbaceous plants. This was confirmed to a considerable extent for *Artemisia* by Spieksma et al. [48] and by Alcazar et al. [53]. Mugwort releases pollen near ground level in the early morning before air turbulence appears [21], and a great amount of mugwort pollen can remain at lower heights until convection raises them into the upper layer of the atmosphere. That is why a maximum pollen concentration registered before or around noon does not necessarily reflect the true time of pollen emission. This should be remembered by people suffering from allergies. Von Wahl and Puls [21] observed that at the height of 1.8 m, the peak was most often formed about 9.00, while at 12 m it was around 11.00.

The aim of the present work has been to determine the influence of different meteorological parameters on daily and diurnal airborne pollen concentrations. Many studies have focused on the relationship between some characteristics of the pollen season and weather conditions from a few weeks preceding the pollen season. For *Artemisia,* temperature and rainfall in the few weeks before the pollen season seem to have a great influence on the start of the pollen season and SPI value. In general, higher temperatures before the season resulted in a delay of the pollen season start day and seasonal peak day [6]. According to Stach et al. [31], higher than average temperatures during the period May-August were usually connected with lower SPI. The same relationship for temperature during June-July was stated by Grewling et al. [13], and also for 6–8 weeks before flowering by Giner et al. [12]. These authors noted that higher rainfall over 4 months or a few weeks before the pollen season influenced a higher SPI value. Cariñanos et al. [6] emphasized that severe droughts 8 weeks prior to flowering were the reason for an extremely low SPI value. Giner et al. [12] also showed that onsets of mugwort species blooming had appeared to be related to the cumulative percentage of insolation from the beginning of March.

However, less is known about how weather parameters influence daily and diurnal concentrations. In Spain it was observed that during the *Artemisia* pollen season no correlation between meteorological factors and daily pollen concentrations existed except for relative humidity in summer and autumn, and temperature in winter [12]. Malkiewicz et al. [43] stated that

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the behaviour of pollen seasons depended on the weather types defined by the type of atmospheric circulation. According to the prevailing atmospheric circulation, different meteorological parameters can affect *Artemisia* pollen concentrations. The most significant were air humidity (expressed as vapour pressure), temperature and wind speed. For one of the weather types, sunshine duration also had significance. We found that temperature, relative humidity, radiation and sunshine duration correlated with daily pollen concentration. Spearman correlation coefficients indicated that higher temperatures, radiation and sunshine duration were connected with a higher pollen grain count, while higher relative humidity coincides with lower concentrations. In contrast to M a l k i e w i e c z et al. [43] and K r u c z e k and P u c [30], we did not find a correlation for wind speed. Additionally, M a l k i e w i c z et al. [43] also noted that higher correlation coefficients were obtained for weather parameters over periods from several days to a month, rather than for weather parameters on a given day. In our studies, weather parameters from previous days also influenced daily pollen concentrations. Temperature was the strongest among them. In some cases mean humidity, radiation and sunshine duration had significance but it was not as clear as temperature. The influence of humidity, radiation and sunshine duration were higher from the previous day than on any given day, but only in 2013.

The choice of method for distinguishing the pollen season seemed to have great significance. In 2013, significant correlations were obtained for the 95% method, and they were quite considerable (coefficients from 0.4 to 0.6), while for 90% there were none. A study on criteria used to define and limit the pollen season showed that there were many differences between the pollen periods distinguished by various methods. The different number of days in the season can modify Spearman correlation coefficients in some cases [54].

Statistical analysis revealed a significant autocorrelation relationship of pollen concentration from previous days. Similarly, M a l k i e w i c z et al. [43] demonstrated that strong autocorrelation for *Artemisia* pollen concentration existed with one, five and even ten day lags.

Only a few studies have been conducted on the relationship between hourly pollen concentrations and meteorological parameters [47]. P u c [50] noted a correlation between meteorological parameters and intradiurnal *Betula* and *Fraxinus* pollen concentration in the first 12 hours of the day. M u ñ o z et al. [26] pointed out that rainfall and temperature had a great impact on grass nightly pollen concentration, while wind direction was the most important factor affecting grass pollen concentration during daylight. The strength and direction of correlation between temperature and hourly pollen concentrations differs in different stages of the pollen season. A positive effect was observed during spring (April, May). In summer (June, July), the relationship was negative because high temperatures limited pollination.

To our knowledge this is the second study focused on the influence of the weather on *Artemisia* hourly pollen concentration. The first was carried out in Spain by G i n e r et al. [12]. They stated that temperature and relative humidity seem to be the most significant factors. The results we obtained indicate that, as in Spain, temperature and humidity were the most important factors. In 2013, the influence of weather parameters on hourly concentration was stronger than in 2012. This might be caused by a smaller number of days chosen for analysis in 2012. We do not exclude other factors, such as secondary deposition and/or long distance transport.

In our analysis we applied the very rarely used statistical method of circular statistics. We believe that it is an appropriate method for the investigation of intradiurnal pollen concentration.

Table 1
Characteristics of the *Artemisia* pollen season determined by two methods

year	pollen season			pollen season			peak		PI
	start	end	duration	start	end	duration	pm^{-3}	date	
	95% method			90% method					
2010	15.07	13.09	60	23.07	10.09	49	27	14.08	198
2011	27.07	11.09	46	31.07	29.08	29	24	03.08	325
2012	24.07	05.09	43	27.07	24.08	28	61	08.08	517
2013	21.07	01.09	42	23.07	20.08	28	172	06.08	785
mean	21.07	07.09	47.75	26.07	28.08	33.5	71.0	07.08	456.25
V%	2.5%	2.19%	17.4%	1.8%	3.8%	30.4%	97.7%	2.1%	56.0%

Table 2
Results of circular statistic for diurnal pollen concentrations and meteorological parameters
(mean time was expressed in two-hour period; angular deviation in hours)

		pollen count	T_{mean}	H_{mean}	R	SD	WS
2011	mean time	10:00	-	-	-	-	-
	angular deviation	4h 6min	-	-	-	-	-
2012	mean time	12:00	14:00	2:00	11:00	11:00	13:00
	angular deviation	3h 41min	3h 44min	3h 48min	3h 49min	3h 49min	3h 41min
2013	mean time	14:00	13:00	2:00	11:00	11:00	12:00
	angular deviation	3h 12min	3h 47min	3h 49min	3h 49min	3h 49min	3h 45min

T_{mean} – mean temperature, H_{mean} – mean relative humidity, R – radiation, SD – sunshine duration, WS – wind speed

Table 3
Results of Spearman's correlation between daily pollen count and the meteorological parameters

Meteorological parameters	from actual day				from previous day				from two days earlier			
	95%		90%		95%		90%		95%		90%	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
T_{min} (°C)	-	0.4011	-	ns	-	0.3789	-	ns	-	0.3701	-	ns
T_{max} (°C)	-	0.6057	-	ns	-	0.6068	-	ns	-	0.5246	-	ns
T_{mean} (°C)	0.3964	0.5966	ns	ns	0.4357	0.5959	0.4084	ns	0.5298	0.5394	0.550797	ns
Rainfall (mm)	ns	ns	-0.4331	ns	ns	ns	-0.3894	ns	ns	ns	ns	ns
H_{min} (%)	-	-0.4836	-	ns	-	-0.5350	-	ns	-	-0.4020	-	ns
H_{max} (%)	-	-0.3309	-	ns	-	-0.3461	-	ns	-	ns	-	ns
H_{mean} (%)	-0.4232	-0.5347	-0.5821	ns	ns	-0.5744	-0.4245	ns	ns	-0.3120	ns	ns
Evaporation ($mm/m^2 \times h$)	-	ns	-	ns	-	ns	-	ns	-	-0.3622	-	-0.4164
Radiation (W/m^2)	0.4676	0.4989	0.4806	ns	0.3167	0.5809	ns	ns	ns	0.4578	ns	ns
Sunshine duration (s)	0.3791	0.4790	0.4766	ns	ns	0.5469	ns	ns	ns	0.3815	ns	ns
P (hPa)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
WS_{max} (m/s)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
WS_{mean} (m/s)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
pollen count	-	-	-	-	0.7464	0.7616	0.7113	0.6013	0.5556	0.6290	0.4928	0.4014

T – temperature, H – relative humidity, R – radiation, SD – sunshine duration, P – air pressure, WS – wind speed

Table 4
Results of angular-linear correlation (the correlation coefficients) between the time of peaks of pollen count
and the meteorological factors

	ΔT_{mean}	ΔT_{max}	ΔH	ΔR	ΔSD	WD
2012	ns	-	ns	ns	ns	ns
2013	0.8558	0.8227	0.7933	ns	ns	ns
2012-2013	0.8219	-	0.7847	0.7145	0.5431	ns

r – angular-linear correlation coefficient; Δ – the hourly difference of meteorological parameter

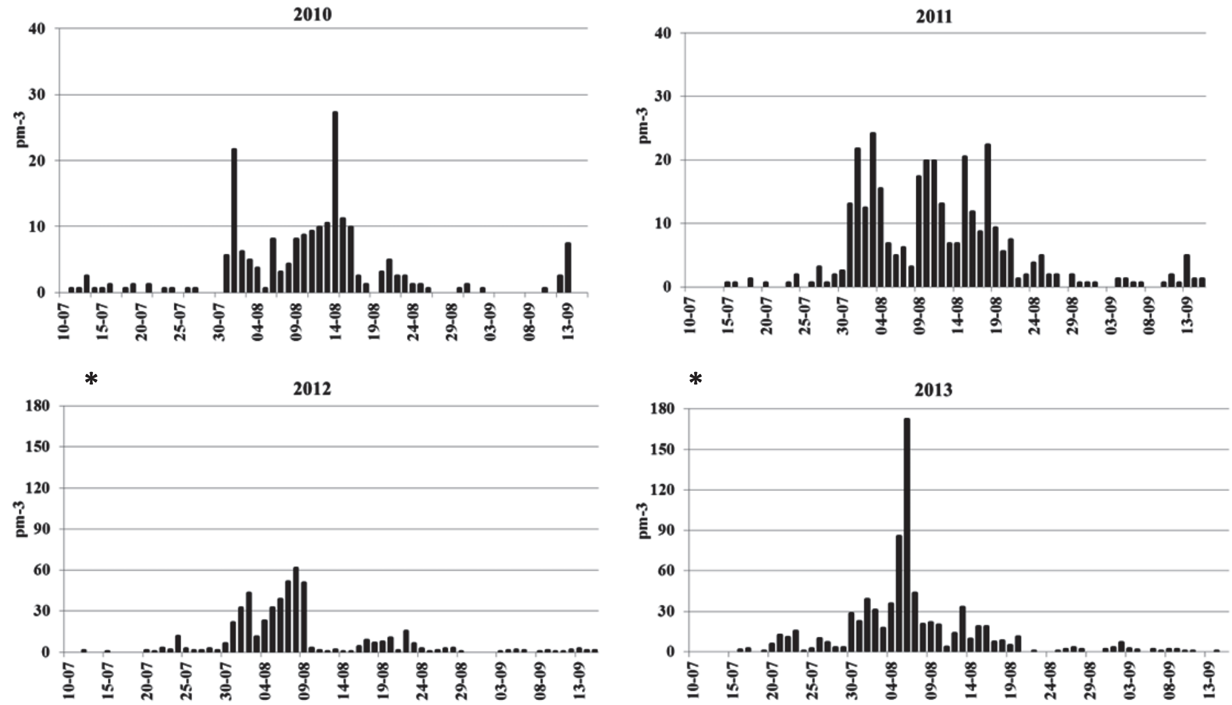

Fig. 1. Daily airborne *Artemisia* pollen concentration in the years 2010–2013; * – changed scale

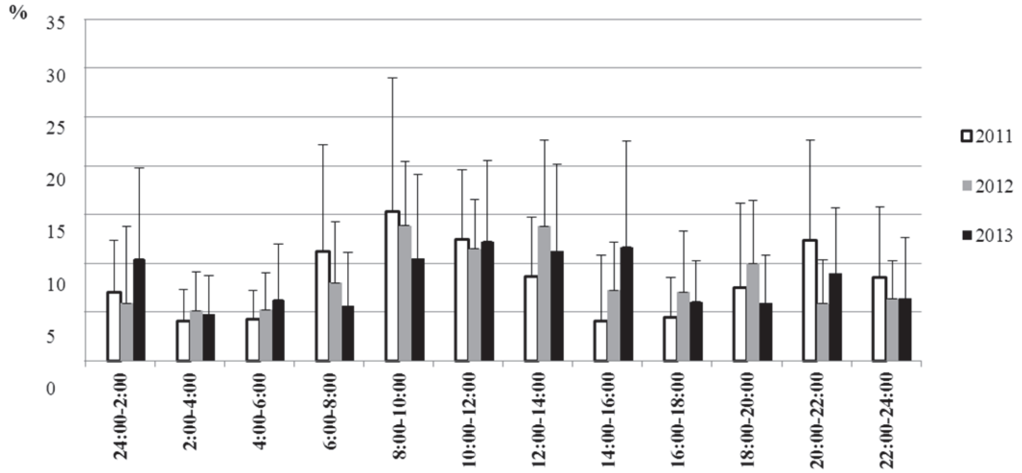

Fig. 2. Mean *Artemisia* pollen counts over day in 2011–2013 (mean+SD)

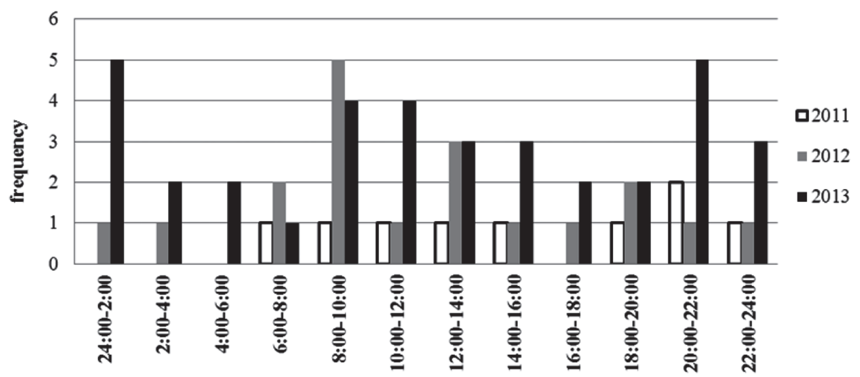

Fig. 3. Frequency of diurnal peaks in the following intervals in 2011–2013.

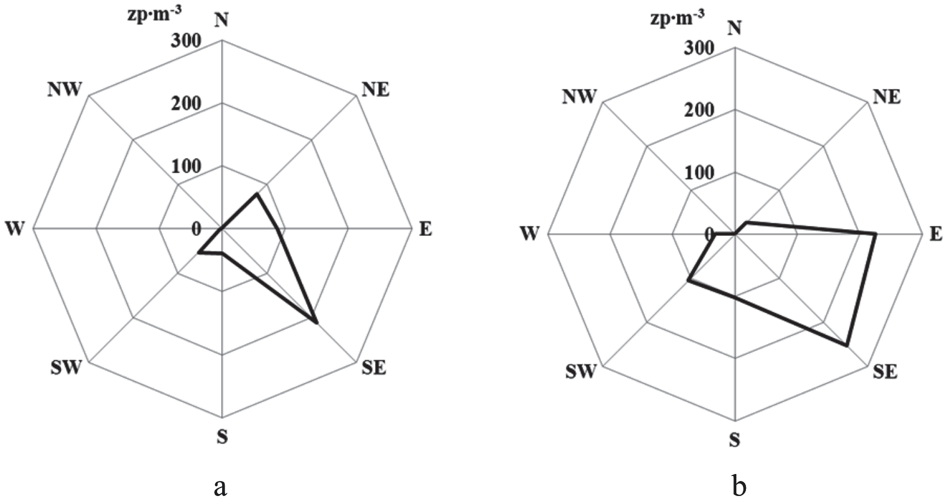

Fig. 4. *Artemisia* pollen concentrations in the air in relation to wind directions in 2012 (a) and 2013 (b)

CONCLUSIONS

1. The patterns of hourly and daily *Artemisia* pollen concentration in the air of Rzeszów did not differ significantly from the results obtained in previous years, which may indicate that the species spectrum did not change. One of the most important differences was a PI value, which was twice as low as that registered in 1997–2005. This may be a result of modifications in land use.
2. The hourly and daily *Artemisia* pollen concentrations were strongly influenced by temperature and relative humidity. Daily concentration was also influenced by radiation and sunshine duration. We can assume that the main pollen sources are to be found the south-east of the pollen trap.
3. Circular statistics were proposed as an appropriate method of analysis of the relationship between meteorological parameters and hourly airborne pollen concentration.

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Authors' contributions

Concept of study: IK; microscope analysis: KB; statistical analysis: KB; IK; writing the manuscript: KB;

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Ocena wpływu warunków meteorologicznych na stężenia ziaren pyłku *Artemisia* w powietrzu z zastosowaniem statystyki kołowej

Streszczenie

Dzienny przebieg występowania ziaren pyłku *Artemisia* w powietrzu jest podobny w różnych rejonach Europy Zachodniej i Centralnej. Najwyższe stężenia notuje się zwykle przed południem. Badania aerobiologiczne prowadzono w Rzeszowie w latach 2010–2013. Stanowiły kontynuację badań przeprowadzonych w Rzeszowie w latach 1997–2005. Ich celem było zweryfikowanie założenia, że cykl występowania pyłku bylicy w powietrzu w ciągu doby nie zmienił się. Korelacje pomiędzy dobowymi i dziennymi stężeniami a czynnikami meteorologicznych badano za pomocą nieparametrycznego testu Spearmana oraz za pomocą korelacji kątowo-liniowej. Stwierdzono, że godzinowy przebieg koncentracji pyłku *Artemisia* w Rzeszowie nie różnił się istotnie od wyników jakie uzyskano w latach wcześniejszych. Największe dobowe stężenia ziaren pyłku rejestrowano przed południem i wczesnym popołudniem. Jednakże, w niektórych dniach ich występowanie notowano około północy. Największy wpływ na godzinowe i dobowe stężenia pyłku *Artemisia* miała temperatura i wilgotność względna powietrza, a na stężenia dobowe również promieniowanie i usłonecznienie rzeczywiste. Zaproponowana metoda statystyki kołowej jest odpowiednia do oceny zależności między czynnikami meteorologicznymi a stężeniami ziaren pyłku w cyklu dobowym.

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