

Comparative study of seasonal and intradiurnal variation of airborne herbaceous pollen in urban and rural areas

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Abstract The content of herbaceous pollen in the atmosphere depends on the vegetal cover, climate and the weather and geographical conditions. The aim of the study reported here was to compare aerobiological data obtained from pollen monitoring stations located at sites differing with respect to their flora and microclimate – i.e. a town and a rural area. A volumetric method was used for sampling. In each microscopic preparation 12 vertical strips corresponding with 2-h intervals were analysed. A 90% method was used to determine the pollen season. The results were statistically verified using the *u* test and the Kolmogorov-Smirnov, Spearman and Wilcoxon tests. Higher values of the Seasonal Pollen Index (SPI), higher daily average concentrations and higher peak values were recorded in the rural area. An analysis of intradiurnal variations of airborne pollen showed that apart from the Poaceae the number of pollen grains in the air began to increase earlier in the day in the rural area; in the case of *Rumex* and *Ambrosia*, the maximum values also appeared a few hours earlier. For all the taxa investigated, the analysis of correlation showed a significant association between the daily average concentrations at both sites. The weakest

association occurred for *Plantago lanceolata*; for all other taxa, the determination coefficients (R^2) were high. The results of the Wilcoxon test showed that, despite the strong positive association between daily concentrations of the pollen types investigated, there were differences in mean pollen concentrations in the overlapping pollen season. Mean concentrations of Poaceae and *Rumex* airborne pollen were significantly higher in the rural area in both years, and those of *Urtica* and *P. lanceolata* were significantly higher only in 2002.

Keywords Aerobiology · Herbaceous pollen · Intradiurnal variations · Pollen grains · Seasonal variations · Rural environments · Town environments

1 Introduction

The qualitative and quantitative composition of the spectrum of airborne pollen grains in any given area mainly depends on the vegetal cover in that area. Most of the airborne pollen originates from anemophilous plants (Dyakowska, 1959; Szczepanek, 2003), and its production depends not only on the condition of a plant or on the degree of its ploidy but also on the number of flowers and inflorescences and the size of the anthers (Molina et al., 1996; Subba Reddi &

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Reddi, 1986). The flora of towns differs from that of rural or natural areas. In towns the biodiversity is reduced and plants form characteristic synanthropic communities. Theoretically, the sources of pollen in such urban environments are scarce; additionally, the compact form in which towns develop considerably limit the spread of pollen and its reaching the upper layers of the atmosphere. This is particularly true for herbaceous plants (Emberlin & Norris-Hill, 1991; Hart et al., 1994; Spieksma et al., 2000). On the other hand, thermal wind systems, which are frequently noted in larger urban agglomerations, can transport pollen grains from suburban areas into the town centre, thereby increasing their concentrations in the air (Norris-Hill & Emberlin, 1991). In open areas the movement of air is free, and pollen can be easily transported even farther (Emberlin & Norris-Hill, 1991).

Other important factors influencing the content of pollen in the air and its seasonal dynamics are weather conditions and the climate. The current opinion is that a town is a climate-shaping factor. The so-called heat urban island is frequently formed, causing thermal contrasts between a town and suburban territories or open spaces (Tamulewicz, 1997; Unger, 1999). The higher temperatures in a town can cause a longer vegetative period. The microclimate of towns is characterized by reduced levels of relative air humidity, specific winds, an increased content of aerosols in the air, and a greater frequency of fogs.

The first aeropalynological studies of a natural area in Poland were carried out by Brem and Sobolewska (1939) in the Białowieża Primeval Forest. In their classic and still frequently cited study, these authors found that the pollen rain in this forest was a true reflection of the forest conditions of the region. Hyde (1959a, b) conducted long-term investigations of pollen fall in the UK. He found that the composition of the fall depended on the land use of the area being monitored. Kasprzyk (1999) compared the pollen fall at stations established in a town, in a village and in a natural region and noted that while there were only small differences in the taxonomic composition, the quantitative differences were much larger. Numerous studies have been conducted using biological (e.g. moss, lichen) or

artificial traps to assess the dependence between annual pollen fall and the vegetal cover as well as other habitat conditions, such as the pH of the soil or organic content of the soil (see Gaillard et al., 1994). Based on these studies, the generally accepted conclusion is that the participation of arboreal pollen in the pollen fall reflects regional conditions, while the content of pollen of herbaceous plants reflects local ones (Hicks, 1991). Successive comparative studies on herbaceous plant pollen content in the air were based chiefly on results obtained in towns (Belmonte et al., 1999; Emberlin & Norris-Hill, 1991; Emberlin et al., 1994; Fernández-González et al., 1999; Gutierrez et al., 2000; Trigo et al., 1996). The monitoring stations were sometimes very distant from each other and established in regions which differed considerably in their floristic and climatic conditions (Sanchez-Mesa et al., 2003; Spieksma et al., 2003).

The study reported here is an analysis of air-borne pollen collected at two monitoring stations differing with respect to the surrounding land use. The aim of the investigation was to compare the seasonal and intradiurnal variations in the occurrence of herbaceous pollen in the air of urban and rural environments. Percentage values of the SPI (Seasonal Pollen Index), maximum values, the length and dates of the pollen seasons and mean daily concentrations were also compared.

2 Materials and methods

Rzeszów, a town in southeastern Poland and the capital of the Podkarpackie Region, is situated at a distance of several kilometers from the Carpathian Uplands. The town centre lies in the valley of the River Wisłok, 200–215 m a.s.l.; new housing estates are developed on higher terraces. Typical alluvial soils occur on the alluvia of the river, while on other quaternary mounds brown soils are predominant. Most soils have been anthropogenically altered. Climatic conditions are chiefly formed by polar-marine and polar-continental air masses. In the period 1981–2000 the mean annual total precipitation was 633 mm and the mean annual temperature was 8.1°C. During this same period July was the warmest month

(18.3°C) and also the one with the most abundant rainfall; January had the lowest amount of precipitation with the lowest temperature (−2.1°C) (Fig. 1, GUS 2001).

The processes of decline in the quantity and diversity of native flora and vegetation brought about by the anthropo-pressure are visible in Rzeszow. Synantropic vegetation dominates in the town area, where green areas consist of numerous parks, lawns and home gardens. Rush and riparian vegetation is found over the river where some plant species protected by law. The urbanization index (built-up area/total area) of the town is UI=0.54.

Krasne, a small village located in landscape typical of the Podkarpacie region, lies at a distance of about 10 km to the east of Rzeszow. It is characterized by the absence of large monoculture areas. Fields of a few hectares lie next to farm houses surrounded by small gardens. Most farms are non-specialized, with the main crops being wheat, rape and root plants; small fruit plantations are frequent. Tree-covered areas and groves occur between the fields; there are also hay-growing meadows and cherry and apple orchards. In recent years the number of fields and meadows lying fallow have increased. The urbanization index of the Krasne district is UI=0.09.

Continuous monitoring of airborne pollen grains was carried out at stations in Rzeszow and Krasne in 2001 and 2002. In Krasne the monitoring started on April 26, 2001 as a result of technical difficulties; consequently, the comparisons and statistical analyses for the two stations during the 2 years of the study were made only from the period from April 26 to December 31. The volumetric method using Hirst-type pollen trap (Lanzoni VPPS 2000, Bologna, Italy) was applied. Traps were set at similar heights: 12 m above ground level. They were not set directly on roofs but on stands 1–1.5 m high, as this position permitted a free air flow. Microscopic slides were made for each day of the measurements. Pollen grains were counted on 12 vertical sweeps of the microscopic slide (magnification: 400×). Each sweep corresponded to a 2-h interval (Emberlin et al., 1994). The obtained absolute values were multiplied by a conversion factor whose value depended on the area being surveyed. The results were then expressed as a daily average of pollen grains/m³.

Pollen grains were identified as species (i.e. *Secale cereale*), genus (i.e. *Artemisia*), family (i.e. Ranunculaceae) or type (i.e. Chenopodiaceae/Amaranthaceae, *Plantago major/media*). Pollen grains of all grasses were classed in the family Poaceae with the exception of *Secale* and

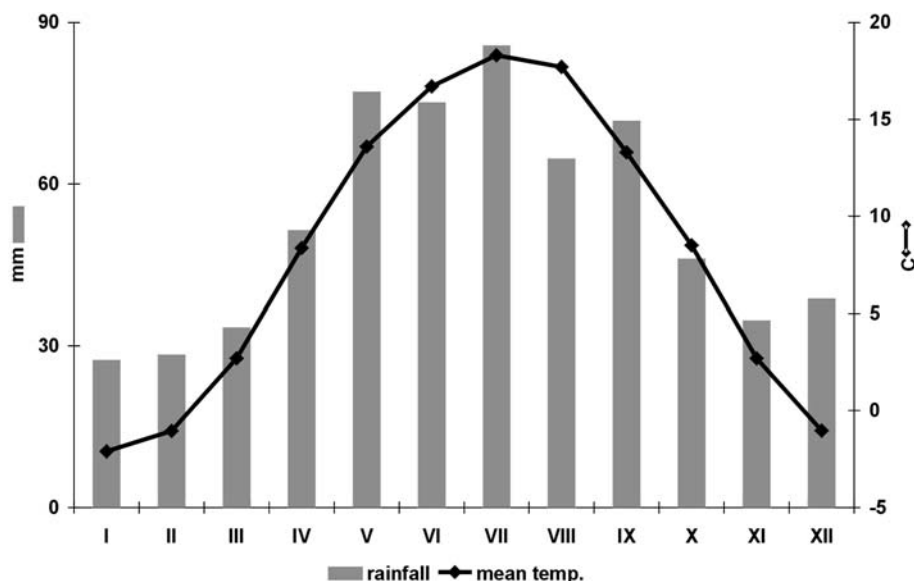


Fig. 1 Monthly temperature and rainfall as an average from 1981 to 2000 (GUS, 2001)

Triticum, which were separately distinguished. For plants with the highest SPI values (above 200–300 in each year), i.e. *Ambrosia*, *Artemisia*, *Plantago lanceolata*, Poaceae, *Rumex* and *Urtica*, the pollen season (90% method; Nilsson & Persson, 1981), the maximum daily pollen concentration (MPA) and percentage participation in the seasonal totals were determined. The results were analysed according to standard statistical methods. The *u* test was used in verifying if the percentage participation of different taxa in the seasonal totals significantly differed between the stations. Further stages of statistical analysis were carried out according to procedures proposed by Trigo et al. (2000). After the distribution of a sample was established (Kologomorov-Smirnov normality test for one sample), the Spearman test was used to determine the strength of the association between the pairs of data obtained from the monitoring stations. The Wilcoxon test was used to compare the mean daily concentrations for the two stations during the period of the overlapping pollen seasons. The tests were carried out for each year separately. For all of these tests statistical significance was accepted at the level of $\alpha \leq 0.05$. In the case of five taxa (*Ambrosia*, *Artemisia*, Poaceae, *Rumex* and *Urtica*) the intradiurnal dynamics of pollen incidence in the air were compared. Days without rain and with daily pollen concentrations above thresholds were selected for analyses. With respect to daily averages of pollen grains the following threshold values of daily pollen grain counts were considered: for *Ambrosia* and *Rumex*, 20; for *Artemisia* and Poaceae, 50; for *Urtica*, 100. Circadian rhythms were approached as a circular scale. When a day corresponds to 360° then each of twelve 2-h intervals correspond to 30° , with the appropriate angles (a_i) being adjusted to the hourly intervals. For every angle adequate numbers of pollen grains were set in order; then, using respective circular statistics, the average time of maximum concentration appearance and the values of angle deviations were calculated. The following formula was used:

$$Y = \sum f_i \sin a_i / n; \quad X = \sum f_i \cos a_i / n;$$

where n is the number of angles (in this case 12),

f_i is the number of pollen grains within the interval

$$r = (X^2 + Y^2)^{\frac{1}{2}}$$

$$\cos a_i = X/r; \quad \sin a_i = Y/r$$

Then, the obtained values should be changed into mean angles. All procedures were carried out following by Zar (1999).

3 Results

The seasonal totals of pollen grains (expressed as SPI values) were usually greater in the rural area, with the exception of *Ambrosia*, *Plantago major/media* and *Urtica* whose indexes were higher in the town in 2001 (Table 1). Asteroideae, *Filipendula* and Lamiaceae showed the greatest differences in SPI values. In both years the counts of total pollen grains originating from entomophilous taxa were twofold higher in the village (rural area) than in the town (urban).

Among herbaceous plants the highest percentages were noted for *Urtica* followed by Poaceae at both stations. The percentage participation values of *Ambrosia*, *Artemisia*, *P. lanceolata* and *Rumex* were very similar and within 1–3% of each other. In 2001, the percentage participations of *Ambrosia*, *Artemisia* and Poaceae pollen in the seasonal totals were higher in the rural area; in 2002, higher percentages of *P. lanceolata*, Poaceae and *Rumex* were noted in the rural area. In both years *Urtica* attained a higher percentage participation in the urban area. The differences were statistically significant (Tables 2, 3; the *u* test).

In the rural area the daily average concentrations and maximum counts were higher. The pattern of pollen seasons was very similar at both sites, with the concentrations of pollen increasing or decreasing at almost the same time. The maximum counts of most taxa occurred on the same days or with a delay of several days. In the case of *Ambrosia*, *Artemisia*, *Rumex* and *Urtica*, the curves obtained from the monitoring station at Krasne ran almost perfectly above those from the station at Rzeszow. No large

Table 1 Seasonal Pollen Index (SPI) values of herbaceous pollen taxa in urban (Rzeszów) and rural area (Krasne) in 2001–2002

Taxon	2001		2002	
	Rzeszów	Krasne	Rzeszów	Krasne
<i>Ambrosia</i>	335	274	446	553
<i>Artemisia</i>	789	851	632	886
Asterioideae	36	82	61	134
Cichorioideae	11	18	13	21
Chenopodiaceae/Amaranthaceae	97	136	290	323
Cyperaceae	42	79	48	63
<i>Filipendula</i>	8	16	5	44
Lamiaceae	3	22	10	20
<i>Luzula</i>	23	38	19	32
<i>Plantago lanceolata</i>	386	579	433	787
<i>Plantago major/media</i>	105	67	116	128
Poaceae	4,337	8,050	4,384	7,878
<i>Rumex</i>	738	922	722	1,208
Ranunculaceae	9	12	12	29
<i>Secale</i>	121	261	25	39
<i>Urtica</i>	10,851	10,820	12,368	15,480

Table 2 Descriptive statistics for chosen herbaceous pollen taxa for 2001

2001 Sites	Percentage of seasonal totals		MPA/day ^b		Dates of pollen season		Duration of pollen season (days)	
	RZ ^a	KR ^a	RZ	KR	RZ	KR	RZ	KR
<i>Ambrosia</i>	1.2	0.7	98/4.09	102/4.09	9.08–21.09	9.08–21.09	44	44
<i>Artemisia</i>	2.9	2.2	73/7.08	90/7.08	28.07–21.08	30.07–20.08	25	22
<i>P. lanceolata</i>	1.4	1.5	31/15.07	31/16.07	6.06–8.09	13.06–20.08	95	69
Poaceae	18	21	314/6.07	440/7.07	25.05–1.08	25.05–24.07	69	61
<i>Rumex</i>	2.7	2.8	34/21.06	38/21.05	18.05–1.08	17.05–1.08	76	77
<i>Urtica</i>	39.6	27.7	677/18.08	373/18.08	22.06–25.08	21.06–25.08	65	66

^aRZ, Rzeszów; KR, Krasne^bMPA, Maximum daily pollen appearance**Table 3** Descriptive statistics for chosen herbaceous pollen taxa for 2002

2002 Sites	Percentage of seasonal totals		MPA/day ^b		Dates of pollen season		Duration of pollen season (days)	
	RZ ^a	KR ^a	RZ	KR	RZ	KR	RZ	KR
<i>Ambrosia</i>	1.8	1.7	98/5.09	148/4.09	27.08–9.09	26.08–8.09	14	14
<i>Artemisia</i>	2.6	2.8	86/8.08	72/8.08	2.08–6.09	27.07–7.09	36	43
<i>P. lanceolata</i>	1.8	2.4	17/15.07	39/10.07	20.05–31.08	20.05–19.08	105	92
Poaceae	17.8	20.8	272/6.06	384/6.06	19.05–19.07	10.05–22.07	62	74
<i>Rumex</i>	2.9	3.6	29/10.05	61/14.05	8.05–18.08	7.05–29.07	103	84
<i>Urtica</i>	50.2	46.7	473/9.08	675/10.07	15.06–25.08	17.06–24.08	72	69

^aRZ, Rzeszów; KR, Krasne^bMPA, Maximum daily pollen appearance

differences were found between the stations with respect to the time when the pollen seasons started: the data were frequently very similar, as in the case of *Rumex* and *Urtica*. There were larger differences with respect to the time when they ended (Tables 2, 3; Figs. 2–4).

Analysis of correlation for all of the investigated taxa showed significant positive correlations between the daily average concentrations registered at the two stations. The lowest – that is the most moderate – association was found for *P. lanceolata*; for all other taxa the values of determination coefficients (R^2) were high (Table 4). Results of Wilcoxon test show that, despite the strong positive association between daily concentrations of the pollen types investigated, there were differences in the means of the pollen concentrations in the overlapping pollen season (Table 5). A positive “z” value indicates that the mean daily count of pollen grains was higher in the rural area. No differences were determined between the mean daily concentrations of *Ambrosia* and *Artemisia* at the two monitoring sites. The values of *Urtica* and *P. lanceolata* airborne pollen were higher in the rural area only in

2002, and those of *Poaceae* and *Rumex* were higher in the rural area in both years.

An analysis of the intradiurnal variations showed that in the rural area the number of airborne *Artemisia* and *Urtica* pollen grains began to increase earlier in the day than in the urban area; in the case of *Rumex* and *Ambrosia*, the peaks also occurred a few hours earlier. The maximum counts of *Artemisia*, *Rumex* and *Urtica* were recorded in the forenoon or just after the midday hours, while the minimum counts were recorded in the early morning. The intradiurnal periodicity of these taxa was characterized by an initial rapid increase in pollen counts, followed by a slow decrease after the maximum concentration had been reached. In the urban area, the maximum concentrations of grass pollen occurred during the morning (0800–1000 hours), but in the rural area there was not one clear peak, and the highest concentrations occurred there from 0600 to 1800. *Ambrosia* intradiurnal periodicity was characterized by peaks that occurred during the night. The results of the circular statistics showed that there were small difference in mean time of pollen concentrations;

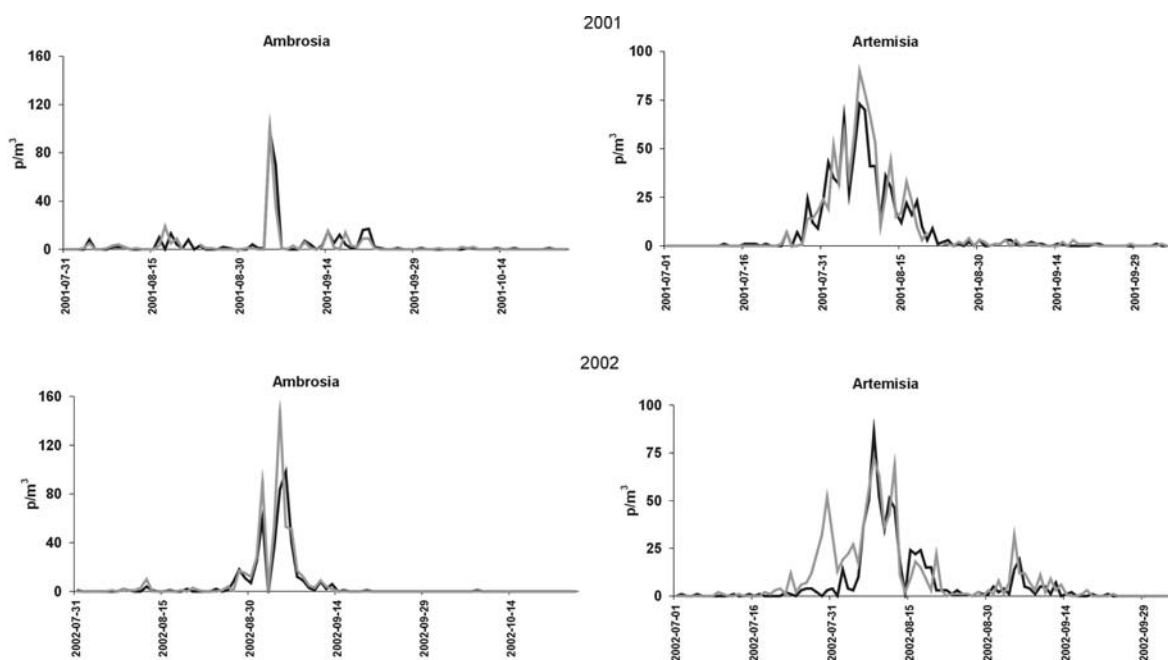


Fig. 2 Daily airborne pollen concentrations of *Ambrosia* and *Artemisia* pollen in urban (Rzeszow; black line) and rural areas (Krasne, grey line), respectively, in 2001–2002

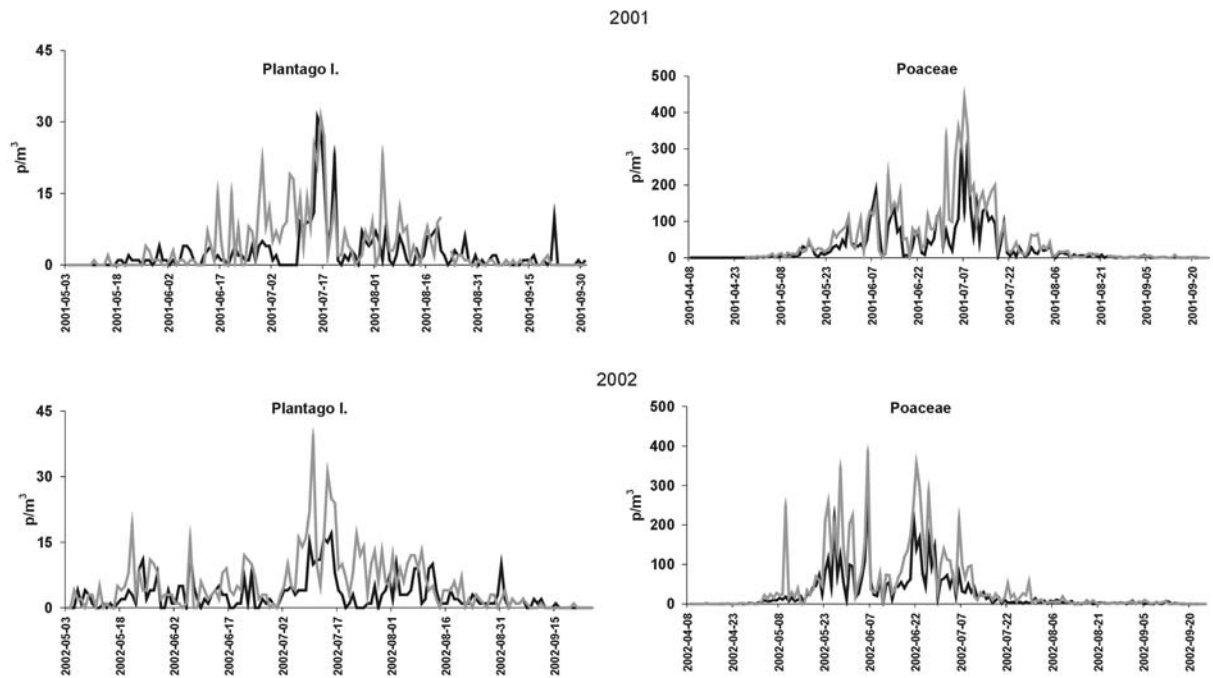


Fig. 3 Daily airborne pollen concentrations of *Plantago lanceolata* and Poaceae pollen in urban (Rzeszow; black line) and rural areas (Krasne; grey line), respectively, in 2001–2002

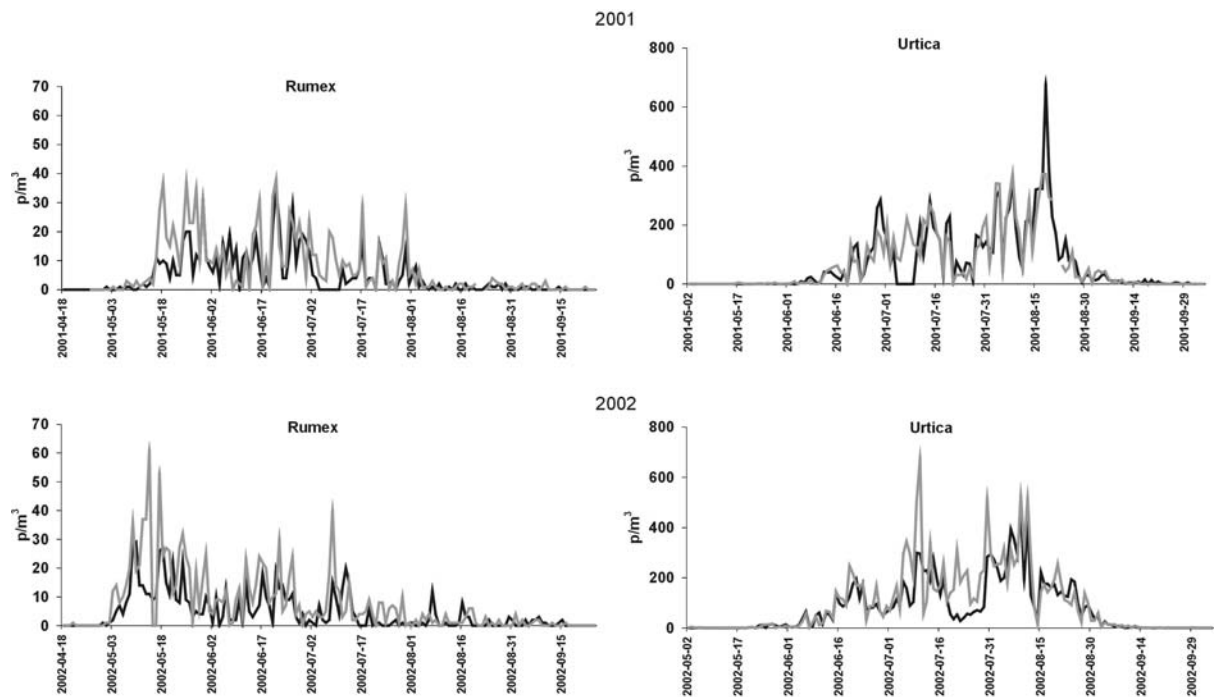


Fig. 4 Daily airborne pollen concentrations of *Rumex* and *Urtica* pollen in urban (Rzeszow; black line) and rural areas (Krasne; grey line), respectively, in 2001–2002

for all pollen taxa the values of angular deviations were very high, i.e. from 2.5 to more than 5 h (Table 6; Fig. 5).

4 Discussion

On the basis of source documents (Brem & Sobolewska, 1939; Emberlin & Norris-Hill, 1991; Faegri & van der Pijl, 1979; Hyde, 1959a, b; Kämpylä, 1981; Norris-Hill, 1999; Spieksma et al., 2000), it was preliminary assumed that differences would appear in the measurements obtained at two the monitoring stations. A direct comparison of the data clearly showed that the concentration of pollen grains of herbaceous plants were higher outside of the town. For all the taxa investigated in this study the curves showing the seasonal rhythm of the pollen counts in the air of Krasne ran above the curves from Rzeszow. With only a few exceptions (*Ambrosia*, *Plantago major/media* and *Urtica* in 2001), the SPI values were also

higher in Krasne. According to Świąś (1993) *P. major* and *Urtica dioica* are common in all synanthropic communities of Rzeszow, which surely contributed to the higher SPI values recorded in the town. Belmonte et al. (1999) also stressed a significant effect of environmental conditions on the increasing numbers of *Urtica* pollen grains in the air, with the nitrophilous species of nettle being closely associated with urbanized environments. In Poland the genus *Artemisia* is represented by seven species and in Rzeszow the ruderal species *Artemisia vulgaris* is very common (Świąś, 1993). However, in the 2 years of this investigation the SPI values for this species were higher in the rural area. This result was probably due to an increasing surface area of fields and meadow lying fallow in this region and also to a portion of land turned over to ruderal vegetation that had been cleared in the vicinity of the monitoring site in the town in 2001. A decrease in the counts of mugwort pollen grains was also observed by Spieksma et al. (2000) after

Table 4 Spearman correlation coefficients between daily pollen concentrations in two sites in overlapping pollen seasons and values of coefficients of determination

	2001			2002		
	<i>n</i>	<i>R</i>	<i>R</i> ² %	<i>n</i>	<i>R</i>	<i>R</i> ² %
<i>Ambrosia</i>	42	0.651***	42.3	13	0.946***	89.4
<i>Artemisia</i>	22	0.854***	72.8	36	0.785***	61.6
<i>P. lanceolata</i>	69	0.360***	12.9	92	0.377***	14.2
Poaceae	61	0.790***	62.4	61	0.857***	73.4
<i>Rumex</i>	76	0.604***	36.5	83	0.627***	39.3
<i>Urtica</i>	63	0.762**	52.1	69	0.549***	30.1

*** $\alpha \leq 0.001$; ** $\alpha \leq 0.01$

Table 5 Results of Wilcoxon test (*z*) used to compare the mean of daily concentrations in overlapping pollen seasons in urban and rural areas

	2001		2002	
	<i>n</i>	<i>z</i>	<i>n</i>	<i>z</i>
<i>Ambrosia</i>	42	0.8994 ns	13	1.7120 ns
<i>Artemisia</i>	22	1.6791 ns	36	0.5838 ns
<i>P. lanceolata</i>	69	1.0827 ns	92	5.5012***
Poaceae	61	5.2598***	61	5.7390***
<i>Rumex</i>	76	4.1946***	83	4.8332***
<i>Urtica</i>	63	0.2398 ns	69	3.4349**

** $\alpha \leq 0.01$; *** $\alpha \leq 0.001$; ns, not significant

Table 6 Results of circular statistics

Taxon	T ^a		AD ^b	
	RZ ^c	KR ^c	RZ	KR
<i>Ambrosia</i>	7.5	8.0	4.6	5.3
<i>Artemisia</i>	11.5	9.3	3.4	2.4
Poaceae	11.8	11.5	4.3	4.4
<i>Rumex</i>	11.6	9.8	4.0	3.9
<i>Urtica</i>	10.9	10.6	2.5	2.6

^aT, Mean time of maximum pollen concentrations

^bAD, Angular deviation in hours

^cRZ, Rzeszów (urban area); KR, Krasne (rural area)

these plants had been cleared from land nearby a monitoring station.

Pollen seasons of the analysed taxa showed a very similar pattern at the two stations. The percentages of the explained variation (the determination coefficient) were very high, showing very a close associations between the seasonal changes in pollen counts in the air of the urban and the rural areas. Despite these strong associations, the mean daily concentrations of the most of the investigated taxa were significantly higher in the rural area. Some authors claim that spatial differences occur in the dynamics of pollen seasons or in the daily values of the pollen concentrations even in a very small area – even in different quarters of the same town (Arobba et al., 2000; Emberlin & Norris-Hill, 1991; Gutierrez et al., 2000).

Investigations into circadian variations in airborne pollen concentrations have revealed that peaks occur slightly earlier in suburban areas/country than in towns and that the peaks in the latter are usually lower (Käpylä, 1981; Mullins et al., 1986; Norris-Hill, 1999) owing to the increasing distance from the sources of pollen and to convectional air currents over the towns (Norris-Hill & Emberlin, 1991). The results of present study confirmed these tendencies only to a certain degree. This is probably due to the relatively short distance between the monitoring stations or/and to neither distinct nor frequent convectional currents over Rzeszow, which is not a large urban agglomeration. In addition, the

mean time of appearance of the maxima was similar at the two stations. However, a high value of the angular deviation suggests considerable dispersion of peaks during a 24-h cycle. Interesting changes in the counts of *Ambrosia* pollen were found in the intradiurnal cycle: the appearance of high concentrations only at night suggests that the pollen of the genus may arrive from long-distance transport. This is confirmed by floristic studies showing that the nearest single sites of *A. artemisifolia* lie at a distance of over 100 km from the town and also by the results of the circular statistic, i.e. the highest values of the angular deviation.

The results reported here show that the pollen spectrum and the seasonal periodicity of airborne pollen were similar at the two monitoring stations owing to similar geoclimatic conditions at Rzeszow and Krasne. It is likely that the generative development of plants occurred at a similar time (Arobba et al., 2000) as there were no differences in the flowering phenology and the conditions of pollen distribution were similar. The effect of differences in the flora and vegetation between the stations was visible in the daily counts, the maxima, the intradiurnal variations and, in some cases, in the mean of pollen concentrations. In the case of our sites, the effect of the microclimate of the habitat on the investigated phenomena was not as strong as has been previously assumed. The results further suggest that it may be possible to forecast the concentrations of pollen at one site using the data taken from another (Trigo et al., 2000).

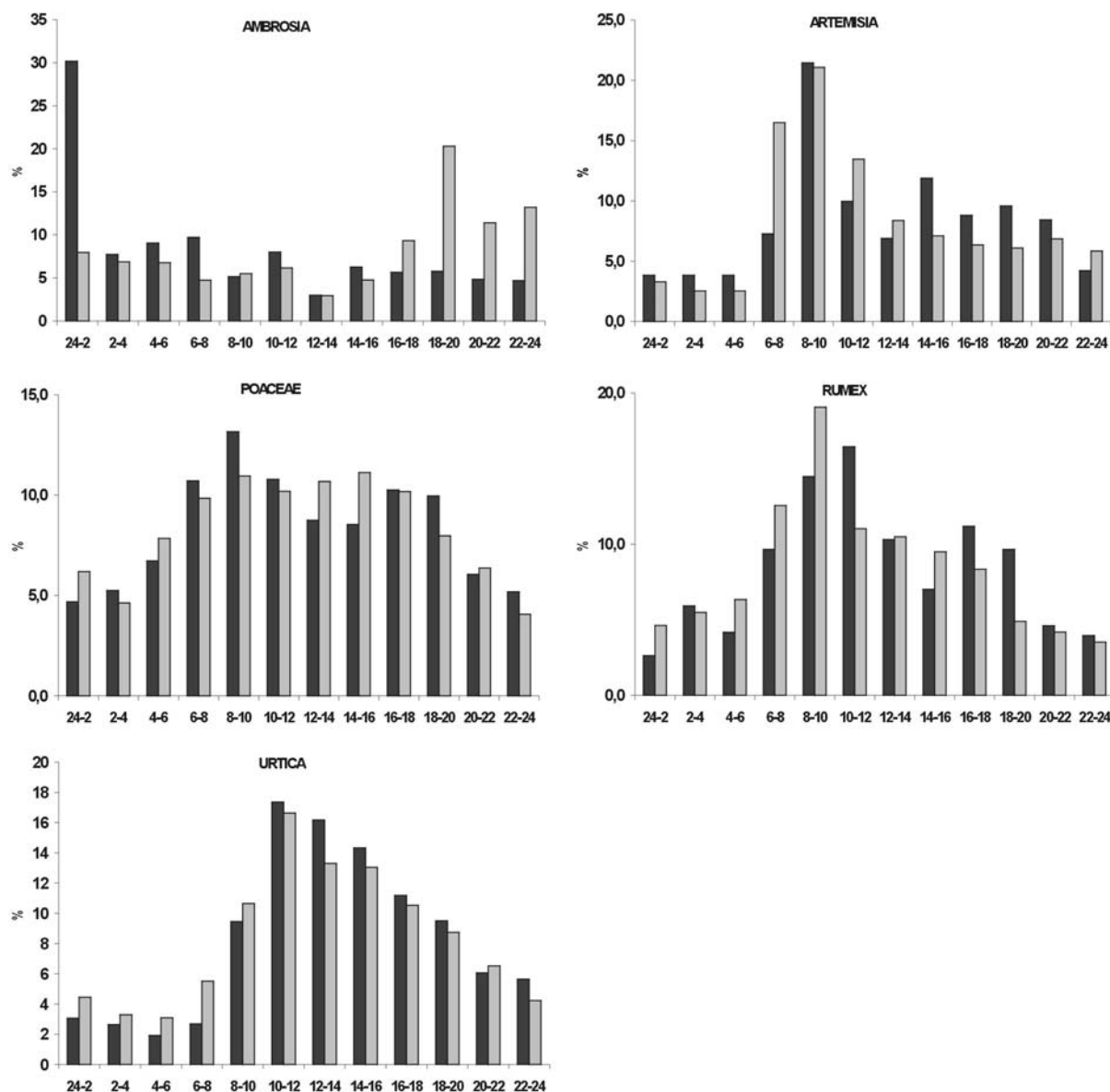


Fig. 5 Intradaily variations of airborne pollen of chosen taxa in urban (Rzeszow; black columns) and rural areas (Krasne; grey columns), respectively

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