

Diurnal patterns of airborne pollen concentration of the selected tree and herb taxa in Gdańsk (northern Poland)

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The diurnal variation of airborne pollen concentrations of *Alnus*, *Betula*, *Pinus*, Poaceae, *Urtica* and *Artemisia* was examined at the sampling station in Gdańsk, northern Poland. Diurnal patterns of *Alnus* and *Pinus* pollen show distinctly lower values and low frequency of diurnal maxima between midnight and late morning and a clear rise of pollen counts at around noon. The rather high values remain during the afternoon and evening. The *Betula* pollen counts are almost evenly distributed along day and night and diurnal maxima appear in similar frequency at any time of day. Pollen concentrations of Poaceae increase at about 9.00 hours and remain high till late evening. Diurnal patterns of *Urtica* and *Artemisia* show very clear variation with high peaks at around 9.00 hours (*Artemisia*) and 13.00 hours (*Urtica*). The comparison of the data from Gdańsk with the data from other aerobiological stations shows very similar general features in the diurnal patterns irrespective the region or the local situation.

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Pollen production and dispersal ability characteristic for a particular taxa represent a baseline for the potential level of their pollen concentration in the atmosphere (Subba Reddi & Reddi 1985). Airborne pollen concentration is dependent on climatic, environmental and temporal factors. The meteorological variables (e.g. Andersen 1980, Wolf et al. 1998, Galán et al. 2000, Latałowa et al. 2002) and environmental conditions, e.g. distance of a station from the main pollen source area or abundance of a taxon in the local/regional vegetation (e.g. Emberlin & Norris-Hill 1991a, Norris-Hill 1999), strongly modify particular parameters of pollen seasons. The impact of particular factors on the pollen seasons is among the most important problems in aerobiology, justifying the need for further examination of these processes in different conditions.

One of the aerobiological parameters which is a subject of interest is the diurnal pattern of pollen counts of different taxa. Knowledge of variations of pollen concentration in the diurnal scale is not only a theoretical problem, but from the practical point of view, it should help to avoid exposure to pollen allergens that are of importance for people suffering from pollinosis (Norris-Hill 1999, Clot 2001). The diurnal patterns of pollen of some tree and herb taxa in various geographical regions at the sampling sites located at different heights and in different distances from the main pollen source areas is a well researched topic (Käpylä 1981, 1984, Galán et al. 1989, Emberlin & Norris-Hill 1991, Norris-Hill & Emberlin 1991, Rantio-Lehtimäki et al. 1991, Trigo et al. 1997, Norris-Hill 1999, Kasprzyk et al. 2001). The increasing amount of data available enables common

features in the diurnal patterns of particular taxa to be detected.

The aerobiological database at the University of Gdańsk (AEROBIOL-UGDA DATABASE) contains pollen counts collected systematically from 1994 by means of the Burkard sampler. It enables selection of the significant diurnal pollen counts taken for rain free days in the main parts of the pollen seasons. The aim of this paper is to present the diurnal variation of pollen concentration of *Alnus*, *Betula*, *Pinus*, Poaceae, *Urtica* and *Artemisia* at the sampling site in Gdańsk. The results will be compared with data from other regions to look for more general features of the diurnal patterns of particular taxa, irrespective of the sampling site conditions.

MATERIAL AND METHODS

Study area

Gdańsk, the capital of the region, is a part of the large city agglomeration extending over a distance of about 50 km along the southern Baltic coast in northern Poland (Fig. 1). The main body of this agglomeration forms a relatively narrow (3–5 km) strip bordering with the Gdańsk Bay to the east and a range of the moraine hills reaching height of 40–160 m a.s.l. to the west. The characteristic environmental feature of this area is the abundance of green spaces with both well kept parks and mostly abandoned areas covered with ruderal vegetation. Small patches of pine (*Pinus sylvestris* L.), birch (*Betula pendula* Roth. *B. pubescens* Ehrh.) and alder (*Alnus glutinosa* (L.) Gaertn) forests are frequent along a flat part of the sea shore, while moraine hills are in great part overgrown by forests with beech (*Fagus sylvatica* L.) as a dominant

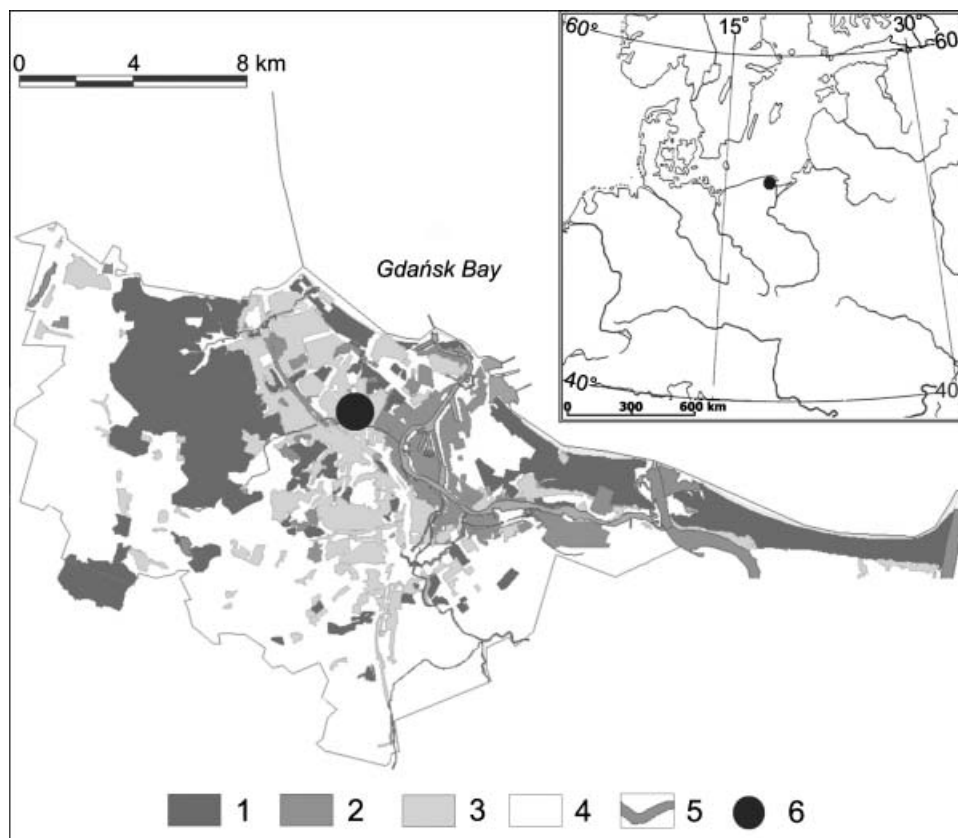


Fig. 1. A map showing the town of Gdańsk and the location of the pollen trap: 1 – forests and large parks, 2 – industrial areas, 3 – built-up area, 4 – open green areas (cultivated land, meadows, others), 5 – rivers, 6 – sampling station.

species and oaks (*Quercus robur* L. and *Q. petraea* (Matt.) Liebl.), pine (*Pinus sylvestris*, birch (*Betula pendula*), hornbeam (*Carpinus betulus* L.) and spruce (*Picea abies* (L.) Karst)) being in admixture. Numerous small valleys along water currents and springs are covered by alder forests or wet meadows. The elements of the above natural and semi-natural vegetation wedge into the city.

The sampling site is located about 3 km from the seashore and about 1.5 km of the forested edge of the moraine upland, in a quarter called Wrzeszcz. The area surrounding the site within about 0.5 km distance is moderately built up. There are mostly three-four storey buildings or small family houses. On one side of the sampling station, there is an open space covered by lawns. Several green areas are present within a distance of 0.5–1 km.

The climate of Gdańsk is typical for the southern Baltic coast region being under the influence of Atlantic air masses. The intensification of the westerly circulation is observed from the mid-70s (Miętus & Wielbińska 1996). Mean annual temperature is about 7.5–8°C, with maximum average 17.5°C in July and minimum average of about –1–0°C in January. Mean annual rainfall is below 570 mm and the relative humidity is about 79% in annual scale. The relatively frequent and strong winds, mostly from the western directions, are typical for this area (Trapp et al. 1987).

The sampling period of 1994–2000 was 0.4°C warmer and the mean annual precipitation was nearly 12 mm less than average. The most contrasting and atypical years were those of 1996 with a long, cold and dry winter and a cold and dry spring and 2000 with a hot and very dry spring (Latałowa et al. 2002).

The open urban landscape and almost permanent airflow from the direction of the sea restricts the phenomenon of the urban heat island, typical for large cities (Oke 1987). It has been observed that

in the area where the sampling station is located, modification of the local climate due to urban warmth is dependent on the atmospheric circulation and on the season of a year, but usually temperature is only about 1–1.5°C higher than in the no-urbanized areas (Korzeniewski 1994).

Sampling and counting pollen, selection and presentation of the data

Sampling was carried out over seven consecutive years (1994–2000) by means of a Burkard spore trap situated on the flat roof of a small tower, about 30 m above ground level. The tower is distinctly higher than the other buildings present within a large area and is hence exposed to airflows from all directions. As a rule, pollen was monitored from February through to the end of October; however, in 1995 and 1999, due to technical problems, sampling started a little later, so the data for the *Alnus* seasons are not complete for these years.

Pollen counts were derived by counting all pollen grains in 4 mm transversal bands, i.e. one every second hour of the day. The average number of pollen grains per m³ air and 2 hours were calculated for each band, according to Kämpylä & Penttinen (1985).

The diurnal variation patterns have been calculated considering only rain free days when the mean daily pollen concentration was above 50 grains m⁻³ with the exception of *Alnus* for which the lower limit was 20 grains m⁻³. Also two abnormally high values of hourly pollen concentration almost 7 600 pollen grains per m³ air (*Betula*) and 6 400 pollen grains per m³ air (*Pinus*) both recorded in night were excluded as a clear deviation from the pattern. The

weather data were obtained from the State Institute of Meteorology and Water Management, Maritime Branch in Gdynia.

The averaged diurnal patterns are presented as percentages of the daily total. The variation in the diurnal patterns is illustrated by the distribution of maximum daily values and the frequencies of daily maxima in particular two-hour periods.

RESULTS

The general features of the pollen seasons

The pollen seasons of the different taxa presented in this paper vary according to the period within a year, number of days and level of the pollen concentration values (Figs 2, 3).

In Gdańsk, the release of *Alnus* pollen begins irregularly from year to year strongly depending of the duration of the low temperature period. In 1994–2000 the starting dates of the pollen seasons counted according to the 5% method (Nilsson & Persson 1981) fall between 7 February (in 2000) and 7 April (in 1996). The number of days was from 12 to 59 and the mean daily pollen concentration for the season was from 20 (in 1994) to 50 grains m^{-3} (in 1998). The

maximum daily values for a season attained between 80 (1997) and 370 grains m^{-3} (in 2000). The averaged data shows that potential period for the *Alnus* pollen season is defined between 7 February and 20 April.

The *Betula* pollen season is much more regular. In the period 1994–2000 it used to start between 11 and 28 April, lasting for about 9–24 days with the exception of 1997 when very cold weather conditions extended to the middle of May. The mean daily pollen concentration in seasonal scale was between 16 (in 1997) and 600 grains m^{-3} (1998). The maximum daily values in particular seasons were from 125 (in 1997 – an atypical year) to 2 200 grains m^{-3} (in 2000). In Gdańsk the annual *Betula* pollen counts show very clear biennial rhythm (Latalowa et al. 2002). The averaged data indicates the potential period for birch pollen season is between 11 April and 16 May.

Five percent of *Pinus* pollen appeared in the atmosphere of Gdańsk between 7 May (2000) and 27 May (1995 and 1996) and seasons lasted relatively long, for 21 days on average. Mean seasonal pollen concentration per day in the reported period was between 20 (1994) and 560 grains m^{-3} (1999) and the maximum daily values in the seasonal scale were from 306 in 1994 to 2920 grains m^{-3} in 1998. According to the data obtained so far, the potential pollen season for *Pinus* is between 7 May and 27 June.

The Poaceae pollen season started between 17 May (2000) and 14 June (1997) and lasted from 58 days in 1995 to 99 days in 1999 and 2000. Mean daily pollen concentration for particular seasons was between 12 in 1998 and 30 grains m^{-3} in 1999; the maximum daily value in 1996 was 161 grains m^{-3} only, but in 2000 it attained 455 grains m^{-3} . The averaged data shows that the potential period for the Poaceae pollen season is between 17 May and 3 September.

In Gdańsk pollen of *Urtica* occurs regularly. In the sampling period the season started between 28 June in 1997 and 7 July in 1995. The shortest season occurred in 1995 (43 days) while the longest one was in 2000 (109 days). *Urtica* pollen occurs in great abundance and it attains high daily values during most of the season. Mean daily pollen counts for particular seasons were between 36 in 1994 and 93 grains m^{-3} in 1999. The maximum daily values recorded in the seasonal scale were from 495 in 1994 to 1465 grains m^{-3} in 1998. According to the averaged data the potential period for the *Urtica* pollen season is between 28 June and 30 August.

The pollen season of *Artemisia* is the most regular. In 1994–2000 the earliest date was 18 July (in 1999) while the latest one was on 28 July (1996). The season lasted from 28 days in 1996 to 52 days in 2000. The lowest seasonal mean pollen concentration per day was 14 grains m^{-3} in 1994 and the highest value of 29 grains m^{-3} was recorded for 1996. The seasonal daily maxima were between 223 (1995) and 630 grains m^{-3} (2000). The averaged data indicates the potential period for the *Artemisia* pollen season is from 18 July to 12 September.

Diurnal variation of tree pollen concentrations

Alnus

The diurnal variation of the alder pollen counts (Fig. 4 A) is marked by relatively low concentrations between 01.00

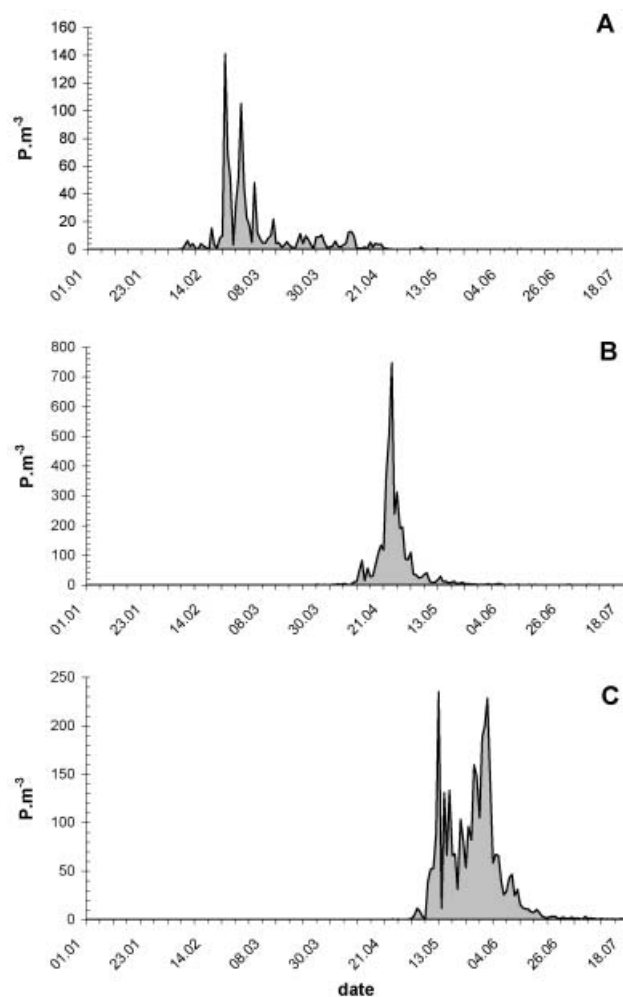


Fig. 2. The averaged seasonal pollen concentrations for *Alnus* (A), *Betula* (B) and *Pinus* (C) based on the daily pollen counts obtained at the sampling station in Gdańsk (1994–2000).

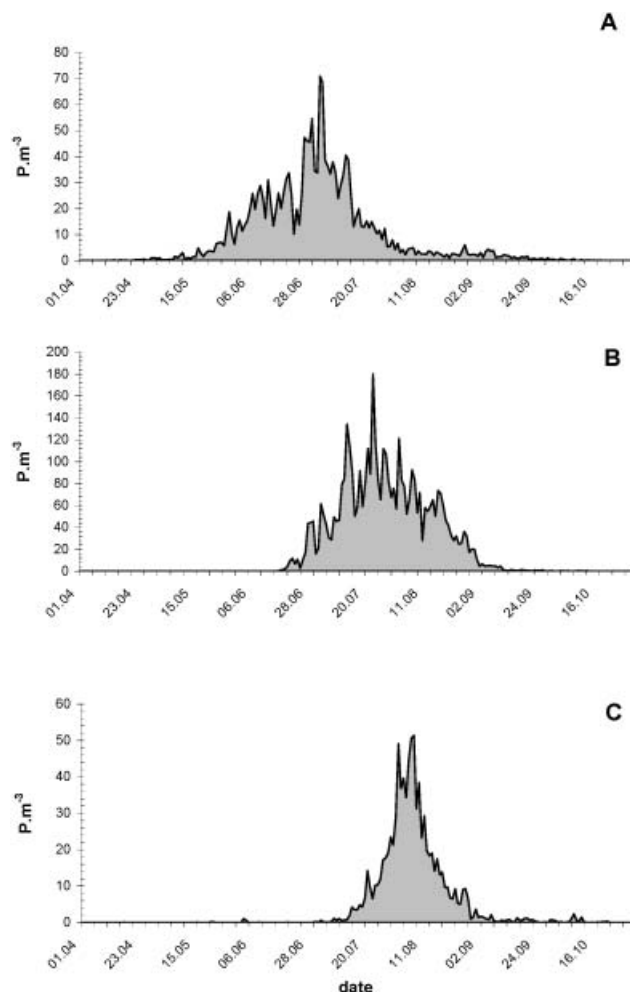


Fig. 3. The averaged seasonal pollen concentrations for Poaceae (A), *Urtica* (B) and *Artemisia* (C) based on the daily pollen counts obtained at the sampling station in Gdańsk (1994–2000).

a.m.–09.00 a.m. and a clear increase after 9.00 a.m. The higher counts tend to occur from 11.00 a.m. through the afternoon and evening up to 21.00 h. However, the averaged pattern expressed as percentages of the total daily pollen count at each 2-hours of the day is rather irregular. A similar pattern is shown by the distribution of diurnal maxima. Diurnal maximum values appear more frequently at about noon and then in the afternoon and evening than in the early hours of a day. Nevertheless, the very high concentrations may appear at any time during the day and night. The hourly counts above 200 pollen grains in m^3 are frequent; the highest values were recorded at 03.00 a.m. (320 grains m^{-3}) and at 21.00 h (370 grains m^{-3}).

Betula

The diurnal pattern of the birch pollen counts (Fig. 4 B) has very low variation. The proportions of pollen in 2-hourly periods are almost the same during the day and night. Diurnal maxima occur in similar frequency during the night

and in the middle of the day. For the total number of 50 records, the lowest number of diurnal maxima occurred at 05.00 a.m. (1) and 15.00–17.00 h (2). The very high hourly pollen concentration between 2 000 and 4 000 grains m^{-3} was recorded both in the day and night. The highest, abnormal value of 7 600 grains m^{-3} appeared at 01.00 hours when the mean daily temperature was above 10°C, maximum temperature of 16.6°C, relative humidity (84%) and low wind speed. It was recorded at the beginning of the *Betula* pollen season on 22 April 2000.

Pinus

Pine pollen has clear variation in the diurnal pattern (Fig. 4 C), however, the differences in the relative values in particular sections of the 24 hours period are between 6 and 12% only. Usually, the lowest values occur at 01.00–05.00 a.m. The pollen concentration rises at around 07.00 a.m. up to maximum value at 15.00 h and then gradually declines reaching the lowest counts during the night. The distribution of diurnal maximum values indicates that the deviations from the above general trend occur rather frequently. Diurnal peaks may appear practically at any time of day or night with the lowest frequency between 05.00 and 11.00 a.m. The maximum diurnal pollen counts above 1 000 grains m^{-3} are rather frequent. The unusual, high value of 6 400 grains m^{-3} was recorded at 03.00 a.m. on 11 May 2000 (the day excluded from the analysis). The meteorological conditions were characterized by the high average daily temperature of 15°C, low relative humidity and low wind speed.

Diurnal variation of grass and herb pollen concentrations

Poaceae

Pollen of grasses has a clear diurnal trend (Fig. 5 A), however, the maximum value of diurnal count may happen at any time of day or night. In general, the lowest values occur between 01.00–07.00 a.m., after 07.00 a.m. pollen concentration rises up to a peak, which most frequently appears between 09.00 and 13.00. In the afternoon pollen concentration gradually decreases, but in many cases the second peak appears in the late evening. The maximum hourly value rarely exceeds 300 grains m^{-3} . The highest count of 800 grains m^{-3} appeared at 21.00. It is typical that night maxima, although less frequent, attain higher values than those occurring during the day.

Urtica

The diurnal variation of the nettle pollen has a very regular pattern confirmed by all of the evidence (Fig. 5 B). The lowest pollen counts and the lowest frequency of the diurnal maxima occur between 23.00 and 09.00 h. Pollen concentration rapidly increases after 9.00 a.m. attaining maximum value in the late morning or in the second part of a day. The most frequently diurnal maximum happens at around 13.00. In Gdańsk, *Urtica* pollen reaches high counts. The hourly values above 400 grains m^{-3} are rather frequent. The

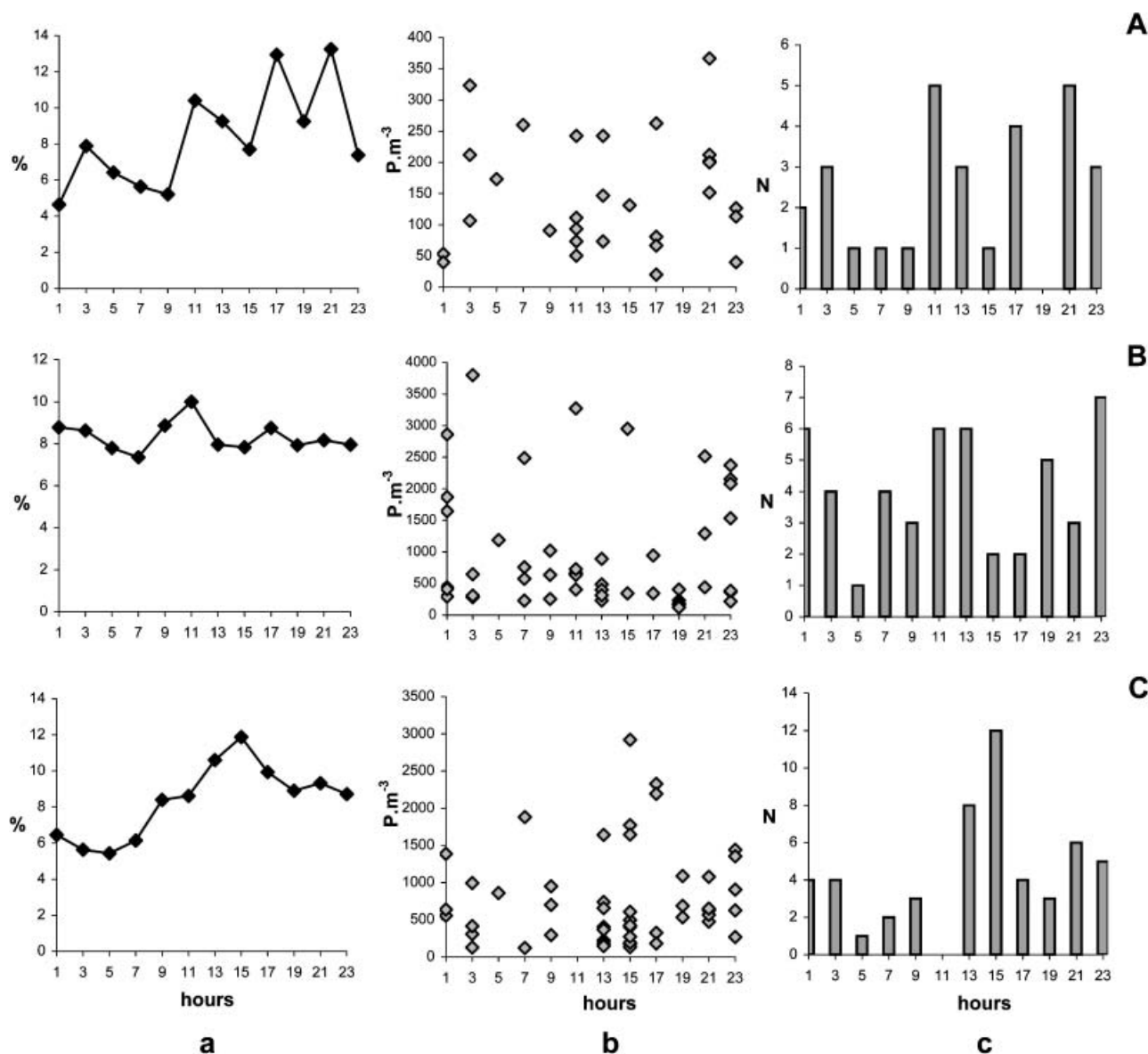


Fig. 4. Diurnal variation of pollen concentration for *Alnus* (A), *Betula* (B) and *Pinus* (C): **a** – the averaged diurnal proportions of pollen counts, **b** – distribution of diurnal maxima and their values, **c** – distribution of the number of diurnal maxima according to the particular 2-hour periods; number of days included to the analysis. *Ainus*–29, *Betula*–50, *Pinus*–53.

highest diurnal maximum of 1 470 grains m⁻³ was noted at 11.00h, which was characterized by high daily temperature (maximum of 33°C), low relative humidity (68%) and the low wind speed.

Artemisia

The mugwort pollen has the most clear diurnal pattern (Fig. 5 C) in respect to the other taxa presented in this paper. It is characterized by a strong peak most frequently appearing at 09.00 a.m. High values of pollen concentration are usually restricted to the period of 09.00–13.00 h. The diurnal maxima are very rare between 17.00–05.00 h. In Gdańsk *Artemisia* pollen attains rather high counts. Hourly

values above 200 grains m⁻³ commonly occur. The highest values of about 500–700 grains m⁻³ were found in the relatively hot temperatures (maximum above 24°C) and dry (below 80% of the relative humidity) days.

DISCUSSION

In different regions pollen counts of particular taxa are dependent on specific ranges and specific combination of climatic factors (mainly temperature and precipitation) deciding on the features of a pollen season. It is also important to emphasize that in distant geographical regions the same pollen type may represent different species or even members of different genera. In this case the climatic

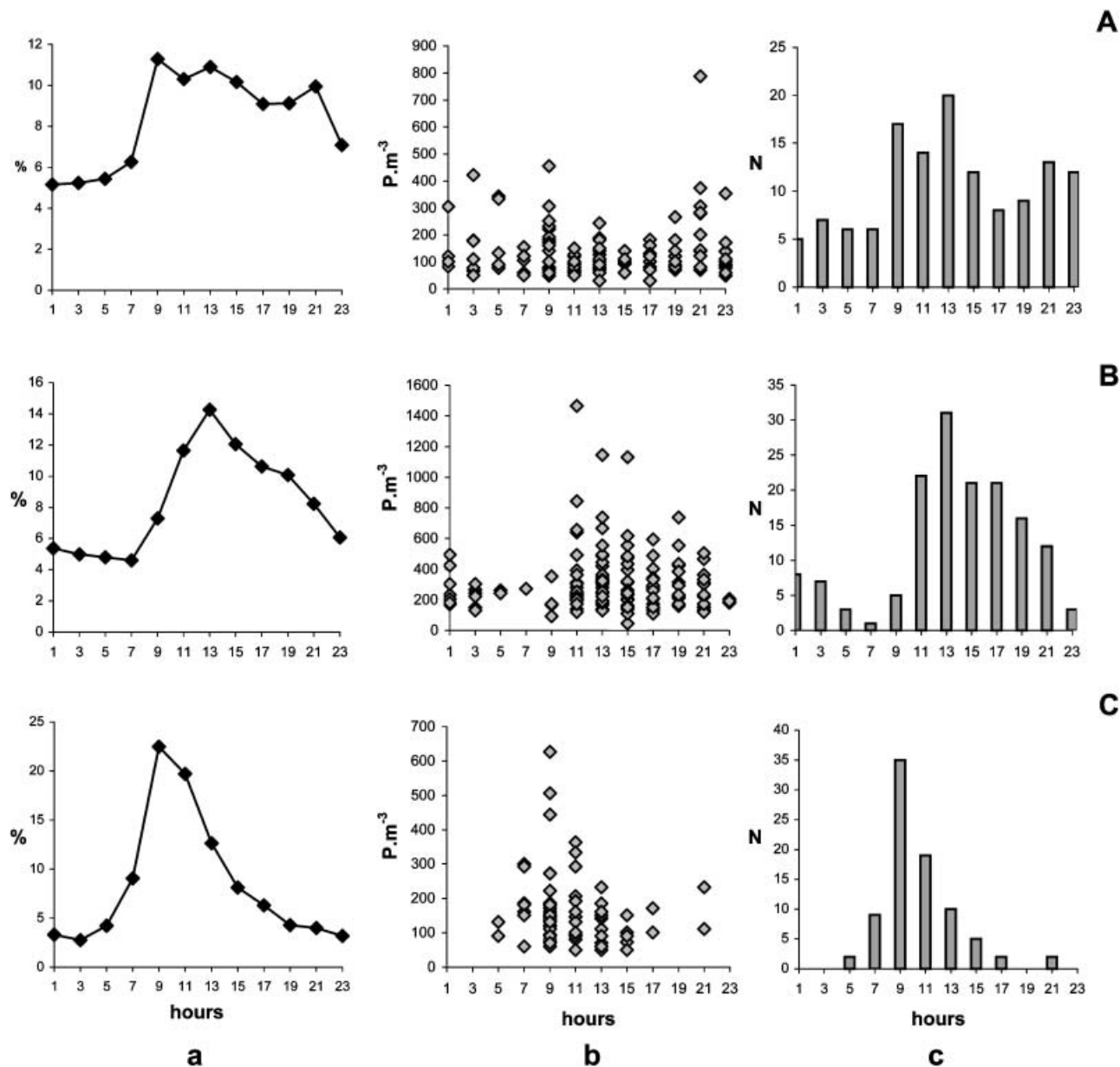


Fig. 5. Diurnal variation of pollen concentration for Poaceae (A), *Urtica* (B) and *Artemisia* (C): **a** – the averaged diurnal proportions of pollen counts, **b** – distribution of diurnal maxima and their values, **c** – distribution of the number of diurnal maxima according to the particular 2-hour periods; numbers of days included to the analysis: Poaceae–129, *Urtica*–150, *Artemisia*–84.

requirements of a particular species and their specific rhythm of pollen release should differentiate the diurnal pollen patterns observed in different areas. In regards to the aerobiological measurement results, it is also dependent on the location of the sampling station, i.e. its height above the ground level (Käpylä 1981, Rantio-Lehtimäki et al. 1991, Spiekma & Wahl 1991, Hart et al. 1994, Galán Soldevilla et al. 1995) and distance from a pollen source (Norris-Hill 1999). Theoretically, all these factors should individualize diurnal patterns of pollen concentration recorded in particular sampling stations to such extent that the direct comparison of the results between stations and regions would be of a limited importance. Meanwhile, the review of

the increasing number of papers dealing with the diurnal patterns of the most important pollen types from different regions indicates very similar, common features of the diurnal pollen incidence of particular taxa. The main factors that should be controlled when comparing the data are rain and the high wind speeds. Both factors strongly modify the diurnal pollen patterns as shown by some authors (Fornaciari et al. 1992, Norris-Hill & Emberlin 1993, Norris-Hill 1995, Berggren et al. 1995). In this discussion we would like to compare the pollen data from exclusively rain free days, searching for more general patterns that eventually could be expected in different sampling situations.

The comparison is based on the data extracted from the

Table I. The basic information on data used for comparison of diurnal patterns (cf. Figs 6).

Site name	Position of the trap above ground level [m]	Taxa	Author
East Perugia	30	Urticaceae	Fornaciari et al. 1992
Malága	15	Urticaceae	Trigo et al. 1996
London	>20	Urticaceae, Poaceae	Emberlin & Norris-Hill 1991b, Norris-Hill 1997
Neuchâtel	18	<i>Betula</i>	Clot 2001
Turku	15	<i>Alnus</i> , <i>Betula</i> , <i>Pinus</i> , Poaceae, <i>Urtica</i> , <i>Artemisia</i>	Käpylä 1981 1984
Germany	18	<i>Artemisia</i>	Spieksma & Wahl 1991
Poznań	34	<i>Alnus</i> , <i>Betula</i> , Poaceae, <i>Urtica</i> , <i>Artemisia</i>	Kasprzyk et al. 2001
Warszawa	16	<i>Alnus</i> , <i>Betula</i> , Poaceae, <i>Urtica</i> , <i>Artemisia</i>	Kasprzyk et al. 2001
Ostrowiec Świętokrzyski	36	Poaceae, <i>Urtica</i> , <i>Artemisia</i>	Kasprzyk et al. 2001
Kraków	20	Poaceae, <i>Urtica</i> , <i>Artemisia</i>	Kasprzyk et al. 2001
Zakopane	10	Poaceae, <i>Urtica</i>	Kasprzyk et al. 2001
Gdańsk	30	<i>Alnus</i> , <i>Betula</i> , <i>Pinus</i> , Poaceae, <i>Urtica</i> , <i>Artemisia</i>	Latalowa et al. (this paper)

literature (Table I). The data from research where the height of the sampling station was unknown, the stations were located close to the ground or the number of days were too low were excluded. In some cases the data were recalculated: the records from the same station were averaged and all pollen counts were expressed as percentages in 2-hour periods. The data were not corrected according to different time zones.

In most sites the diurnal pattern of *Alnus* pollen concentration is rather irregular (Fig. 6 A), but on average the highest proportions of daily totals tend to occur in the afternoon (Janzon et al. 1977, Galán et al. 1991, Kasprzyk et al. 2001). Käpylä (1984) indicated night peaks as typical for *Alnus* pollen and this observation is confirmed by data from Gdańsk and some other sites (Galán et al. 1991, Kasprzyk et al. 2001). According to this author the diurnal maxima may occur at any time, but those with the highest values are recorded during the night, which is also in accordance with the data from Gdańsk (Fig. 4 A). In most sites, including Gdańsk, the lowest concentrations were observed in the morning up to about 8.00–10.00 a.m. The pollen curve from Turku is clearly different from those of other sites. The strong variation of the *Alnus* diurnal concentration patterns on particular days and the differentiation between particular sites is probably due to the early season which is usually characterized by strong fluctuations of temperature and other weather variables within the scale of a day. The relatively low *Alnus* pollen counts are another limiting factor in respect to the consistency of the results.

According to the data from Gdańsk and other available data (Fig. 6 B), the *Betula* peak pollen concentrations may occur at any time of the day and in most sites the distribution of diurnal pollen counts does not show any particular trend (Käpylä 1984, Clot 2001, Kasprzyk et al. 2001). Usually birch pollen concentrations are lower in the morning than in the afternoon or at night (Käpylä 1984, Berggren et al. 1995, Clot 2001, Kasprzyk et al. 2001). In comparison to other taxa presented in this paper, *Betula* shows the most evenly distributed patterns in both the pollen counts and frequency of diurnal maxima.

There is not much data on the *Pinus* pollen diurnal

pattern. However, the trend of the curves illustrating the diurnal distribution of the averaged concentrations for Gdańsk and for Turku (Käpylä 1984) seems to be very similar (Fig. 6 C), although the sites are located in different geographical regions. The curves show a minimum early in the morning and a period of high pollen counts from about noon to midnight. In Gdańsk the highest values and the best frequency of diurnal maxima are in the afternoon (Fig. 4 C), while in Turku the peaks are almost evenly distributed from about 10.00 to midnight (Käpylä 1984). The rise in the hourly *Pinus* pollen counts late in the morning or at about noon is probably correlated with the increase of temperature and decrease of the relative humidity. Such suggestion was earlier presented by Käpylä (1984) as well as by Sarvas (1955) and Boydak (1977) - quoted after Chałupka (1993).

As investigated by Norris-Hill (1999), Poaceae pollen concentration in a rural area shows distinctive circadian periodicity. Maximum pollen concentrations were typically recorded by this author between 14.00 and 16.00 h on days both above and below an average daily Poaceae pollen count of 50 grains m⁻³. The time of peak pollen concentration at this rural site was generally earlier than in other sites as the sampling was conducted closer to Poaceae pollen source areas than in urban-based studies. In urban sites the irregular behaviour of the Poaceae pollen counts with little differences between the timing of the maximum and minimum concentrations is rather common (Trigo et al. 1997, Kasprzyk et al. 2001). In other sites there are clear peaks in the morning and in the afternoon (Kasprzyk et al. 2001) or only the morning peak appears (Käpylä 1981, Kasprzyk et al. 2001). In Derby (Corden & Millington 1991) and in London (Norris-Hill & Emberlin 1991) the highest pollen counts are typically in the afternoon or early evening. In London this is due to the late arrival of the pollen cloud from the surrounding areas. As underlined by many authors, the irregular diurnal pattern of Poaceae pollen is mainly due to the complex taxonomical composition of this family comprising species that show the individual variation in the time of pollen shedding (Jones & Stillwater 1952). This factor should additionally differentiate diurnal patterns between various geographical regions characterized by

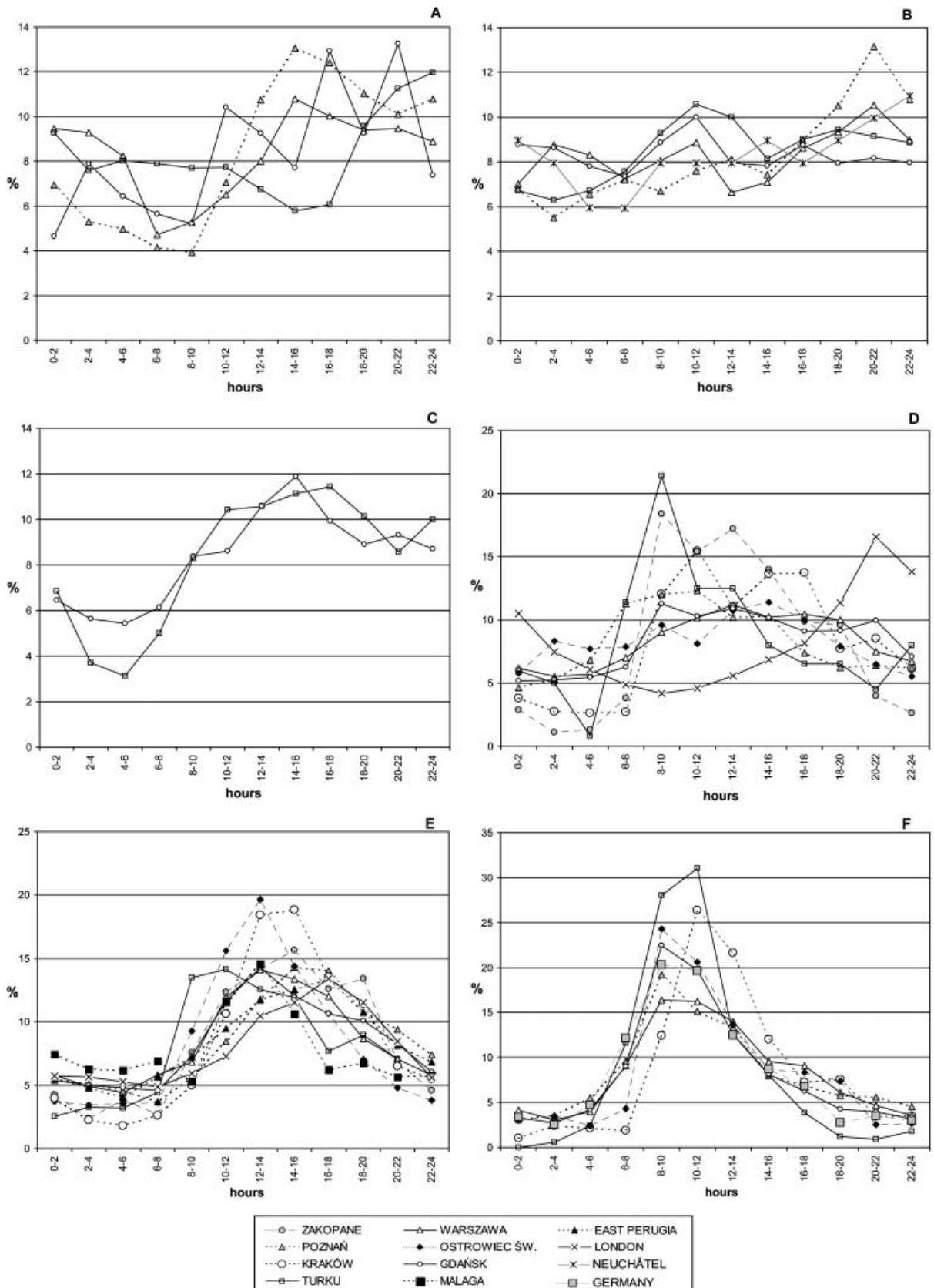


Fig. 6. Comparison of the averaged diurnal proportions of the pollen counts recorded in different sampling sites (cf. Table I): A – *Alnus*, B – *Betula*, C – *Pinus*, D – *Poaceae*, E – *Urtica/Urticaceae*, F – *Artemisia*.

different dominating species of grasses. Meanwhile, the comparison (Fig. 6 D) shows some common features of the patterns from all Polish sites and a site of Turku (Finland), i.e. distinctly lower pollen counts in the late evening, through the night and early morning than in other periods of a day.

The diurnal curves of *Urtica* pollen (in all Polish sites and in Turku (Finland) it is mainly *U. dioica* L.) have well defined shapes, in most cases with no definite peak hour, but with a very clear trend (Fig. 6 E). The most characteristic trend is low concentration during the night and early morning, sharp increase before noon and persistence of high values in the afternoon and then fall in the evening. This has also been observed with the pollen of Urticaceae representing both *Urtica* and *Parietaria* even in the very distant regions (sites of Málaga, East Perugia and London). In this comparison, the shape of the curves does not show any relation to the altitudinal location of the trap within the range of the compared stations (cf. Table I), even when comparing the data from the close geographical regions (e.g. Warszawa, Poznań and Ostrowiec Świętokrzyski from central Poland). However a relationship is clear when comparing a set of stations located at different heights at the same site as shown by Hart et al. (1994).

Artemisia pollen shows a distinct, very similar pattern irrespective of the region and altitudinal location of the sampling station within the range accepted for the comparison (Fig. 6 F). In the same site, the shape of the curve and the peak hours are recurrent in following years (Kasprzyk et al. 2001). It is characterized by the sharp increase and clear peak occurrence in the morning or eventually just before noon, rather rapid fall already in the early afternoon and very low frequencies in the evening, night and early morning hours. In most of the sites a sharp increase of pollen concentration starts between 6.00 and 8.00 hours and then attains the peak hour at about 8.00–10.00 a.m. The somewhat latter peaks occur in Kraków and Turku (10.00–12.00 o'clock). According to the data presented by Kämpylä (1981) and Spieksma & Wahl (1981) there is only slight difference of about two hours between the *Artemisia* peak pollen concentration at the sampling stations located close to the ground (1.5 and 1.8 m) and those located at the higher elevation (15 and 18 m respectively).

CONCLUSIONS

As shown by some authors using various sophisticated methods, the detailed diurnal pollen patterns are dependent on many variables. Weather factors may change distribution of hourly pollen concentration at the same place from day to day (Emberlin & Norris-Hill 1991b, Berggren et al. 1995), distance from a pollen source and location of sampling station at different heights have impact on the peak hours and the magnitude of pollen counts (Norris-Hill & Emberlin 1991, Hart et al. 1994, Galán Soldevilla et al. 1995). Taxonomic complexity of a pollen type may differentiate diurnal pattern at the same station in following stages of the pollen season (Fornaciari et al. 1992, Norris-Hill 1999). The aim of the present paper was, however, to search for more

general characters of the diurnal patterns of the selected taxa.

The data from different stations shows that the general diurnal patterns of pollen occurrences of particular taxa have at least some similar characters, even when comparing records from different regions. The patterns of *Alnus*, *Betula* and Poaceae are the most variable with only slight similarities between different sites. The individual curves do not present any well-expressed trend. High pollen concentrations occurring day and night, as well as frequent night peaks due to thermal convection and air turbulence, are typical for all three taxa. In the case of *Alnus* and *Betula* such behaviour is probably conditioned by strongly diversified weather during early pollen seasons and by the specific factors of pollen dispersal – i.e. the high starting point of pollen emission (crown of a tree) and the relatively light pollen (Sugita et al. 1999, after Eisenhut 1961) that may stay buoyant for a longer time in the atmosphere. The various Poaceae patterns seem to have the one common feature i.e. the relatively low pollen counts from late evening to early morning. As already mentioned, the variation of hourly distribution of grass pollen counts among different sites is mainly due to the complex taxonomical composition of this family gathering species of various phenology, different light and climatic requirements and individual pollen liberation rhythm. It should be also underlined that Poaceae pollen type is not uniform as concerns formation of pollen grains – their dimensions and density of exine (Beug 1961). This results in different ability of pollen dispersal by particular grass species.

The diurnal patterns of *Pinus*, *Urtica*/Urticaceae and *Artemisia* pollen show very clear trends that are similar or almost identical when comparing the data for each taxon among different sampling stations. There are several reasons for such conformity. In the case of *Pinus* pollen, both stations are located on the Baltic coast in similar climatic conditions during the *Pinus* pollen season and in both areas *Pinus sylvestris* is the only species represented by this pollen type. It means approximately the same processes of anthesis and pollen dispersal.

The very similar trends in *Urtica*/Urticaceae pollen patterns are much more surprising considering different taxonomical composition of the pollen type and distinctly different climates in the compared geographical regions. It seems that among the main factors controlling the diurnal Urticaceae pollen pattern it should be mentioned: the uniform pollen within this family (Punt & Malotiaux 1984), similar timing of anthesis and the same active mechanism of pollen shading (Podbielkowski & Podbielkowska 1992).

The almost identical diurnal variation of the *Artemisia* pollen counts in all the compared stations is remarkable. In this case, during the *Artemisia* pollen season (late summer) all stations lie within the range of similar climatic parameters. Although in this part of Europe several species of *Artemisia* occur, *Artemisia vulgaris* L. is the dominant one. The distribution of diurnal pollen counts suggests that the main factors responsible for this pattern are: the exact and short time of pollen release and the thick exine,

inadequate pollen dispersal resulting in a high fall speed (Wolf et al. 1998).

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