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An examination of the main characteristics of the pollen seasons in Budapest, Hungary (1991–1996)

ZOLTÁN FEHÉR and MAGDA JÁRAI-KOMLÓDI

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Aeropalynological methods are used to examine the flowering seasons of 18 different plant taxa in Budapest between 1991–1996. Start dates, end dates, length of flowering season and yearly totals of pollen grains are computed and the main characteristics of the pollen seasons are examined in relation to meteorological factors.

The aim is to obtain a picture of phenological characteristics of these taxa, the order of their flowering, the length of their seasons, the amount of pollen emitted and the year-to-year variability in these parameters. By analysing phenological data in relation to meteorological data, conclusions can be drawn, which may be applicable in other cities, and which can help to create models for predicting phenological events in the future. Of the allergenic taxa, *Ambrosia*, Poaceae, *Quercus*, *Betula*, *Fraxinus* and *Platanus* emitted the largest amounts of pollen during the period examined.

In general, pre-seasonal temperature had the greatest influence on the start of the season, where as higher temperature seems to promote pollination. In the cases of woody plants, pre-seasonal precipitation had no effect on pollen production. These results are in agreement with observations in areas with an atlantic climate. However the start of the grass season is influenced more by pre-seasonal precipitation, than temperature. The total yearly pollen count for the grasses also correlates with pre-seasonal precipitation. Thus, precipitation is an important limiting factor for the pollination of grasses, since the upper parts of the soil usually dry out during the spring.

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The increasing prevalence of pollen allergies in recent times has increased the importance of phenological research into allergenic plants in Hungary. Phenological data have been collected since the 50's but these data are based on field observations (Csapody et al. 1966).

Despite the numerous advantages of this method, its considerable disadvantage is that flowering – like other phenophases—is highly influenced by microclimatic factors. Thus, the observed specimens do not always represent the area as a whole. However, an increase in sample size requires disproportionally more effort and expense, compared to the extra information gained.

The flowering status of a given anemophilous taxon in a given area can be easily studied by aeropalynological methods. Since some of the pollen grains travel far from their source via middle-range pollen transport (Mandrioli et al. 1977) an air sample at a given point represents a considerably larger area than could be examined by traditional methods.

At first, airborne pollen grains were studied only by sedimentation (Simoncsics et al. 1970). The first volumetric pollen trap in Budapest was installed in 1989. Since 1991, continuous monitoring has been carried out by the Natural History Museum, and since 1992 three stations have been measuring atmospheric pollen concentrations in Budapest. This phenological information is important not only for practical allergology, but for plant geography, ecology and palaeopalynology too.

In the present work, the airborne pollen concentrations of 18 taxa (Table I) were examined between 1991 and 1996. Total numbers of pollen grains, start dates, end dates and length of the seasons were computed. We aimed to achieve a picture of the phenological characteristics of these taxa, of the order of their flowering, of the length of their seasons, of the amount of pollen emitted and of the year-to-year variability in these parameters. By analysing phenological data in relation to meteorological and plant-geographical data, we aimed to draw conclusions, which would be applicable in other cities, and which would help to create models for predicting phenological events in the future.

MATERIALS AND METHODS

Three Hirst-type volumetric pollen samplers (Burkard Manufacturing Co.) were used. The first was operated by the Natural History Museum (NHM) from 1991 to 1996. The others were operated by the National Institute of Public Health (NIPH) and by the Paediatric Hospital of Svábhegy (PHS) from 1992 to 1996. The NHM and NIPH samplers were located in the centre of Budapest, about one km apart (47°30'N.lat. 19°5'E.long.), 14 m (NHM), and 22 m (NIPH) above the ground level. The third (12 m a.g.l.) was placed in the hilly part of Budapest, about 8 km to the west of the other traps.

Near the NIPH and the NHM samplers the amount of vegetation is small, consisting mainly of ornamental plants of parks and alleys. In the middle-range area, to the south of these traps there are abundant ruderal plant communities. The natural vegetation of the

Table I. Species that comprise the 18 taxa studied.

Species of minor contribution to the pollen emission of the taxon are given in brackets.
*indicates non-native species in the Carpathian Basin.
#indicates insect pollinated species.

<i>Alnus</i>	<i>A. glutinosa</i> , (<i>A. incana</i>)
<i>Corylus</i>	<i>C. avellana</i> , (<i>C. colurna</i> *)
<i>Ulmus</i>	<i>U. laevis</i> , <i>U. glabra</i> , <i>U. procera</i> , <i>U. minor</i>
<i>Taxus</i> - <i>Cupressaceae</i>	<i>T. baccata</i> , <i>Chamaecyparis lawsonia</i> *, <i>Thuja occidentalis</i> *, <i>Biota orientalis</i> *, <i>Juniperus communis</i>
<i>Populus</i>	<i>P. x canescens</i> , <i>P. alba</i> , <i>P. tremula</i> , <i>P. deltoides</i> *, <i>P. x canadensis</i> *, <i>P. nigra</i> *, and several other hybrids
<i>Fraxinus</i>	<i>F. excelsior</i> , <i>F. pennsylvanica</i> *, <i>F. ornus</i> #
<i>Acer</i>	<i>A. negundo</i> *, (<i>A. platanoides</i> #, <i>A. tataricum</i> #, <i>A. campestre</i> #, <i>A. pseudoplatanus</i> #)
<i>Betula</i>	<i>B. pendula</i> , (<i>B. pubescens</i>)
<i>Carpinus</i>	<i>C. betulus</i>
<i>Platanus</i>	<i>P. hybrida</i> *, (<i>P. occidentalis</i> *)
<i>Quercus</i>	<i>Q. robur</i> , <i>Q. petraea</i> , <i>Q. pubescens</i> , <i>Q. cerris</i> , (<i>Q. rubra</i> *)
<i>Fagus</i>	<i>F. sylvatica</i>
<i>Juglans</i>	<i>J. regia</i> *, (<i>J. nigra</i> *)
<i>Moraceae</i>	<i>Morus alba</i> *, (<i>M. nigra</i> *, <i>Broussonetia papyrifera</i> *)
<i>Aesculus</i>	<i>A. hippocastanum</i> *#
<i>Poaceae</i>	about 200 species in 75 genera
<i>Artemisia</i>	<i>A. vulgaris</i> , (<i>A. absinthium</i> , <i>A. campestris</i> , <i>A. annua</i>)
<i>Ambrosia</i>	<i>A. elatior</i> *

Buda Mountains (Fagion medio-europaeum, Quercetea pubescenti-petraeae, Festuco-Brometea) (Soó 1964) also contributes somewhat to the atmospheric pollen at these sites. At the Svábhegy-site, vegetation is more abundant, there are more parks and gardens in the trap's environment, and the influence of the natural vegetation of the Buda Mountains is more significant. The climate of this area is continental, but the yearly distribution of precipitation often shows a submediterranean pattern (Zólyomi 1958).

Pollen slides were mounted in glycerine jelly and coloured with pararose-anilin. For NHM 12 transverses, and NIPH and PHS 2 longitudinal bands, were read at a magnification of 400X. Daily pollen counts were expressed as pollen grains/m³. (Járαι-Komlódi 1991, Farkas et al. 1994)

Daily pollen concentrations were calculated as the average of the measurements of the three stations. The start-date of the season was defined as the day when a concentration of 3 grains/m³ was consistently exceeded, i.e. the pollen concentration was above 3 grains/m³ on at least 5 days during the following week. However, there are some taxa where concentrations do not consistently reach this value even in the middle of their season. Taking this into account, when the consistent 3 grains/m³ concentration was reached later than when the cumulated number of pollen grains reached 5% of the total yearly count, the start date was calculated by the 5% method (Nilsson & Persson 1981). The end-date of the season was defined inversely, i.e. the last day on which the concentration was still consistently over 3 grains/m³, or the date calculated by the 5%-method. The start- and end-dates were also calculated by the Σ25, Σ50, Σ75, Σ100 (Dreissen et al. 1990), 1% (e.g., Emberlin et al. 1993), 2.5% (Andersen 1991) and 5% methods, and were compared to the results achieved by the above mentioned definition.

The length of a season is the number of days between the start

and the end dates, while the severity is characterised by the total yearly count.

Meteorological data were provided by the NIPH and by the station of the National Meteorological Service, about 5 km to the South of the city.

RESULTS

When comparing start dates with those calculated by the 1% and 5% methods, in the case of the 5 taxa with the lowest pollen emissions, the consistent 3 grains/m³ concentration was often reached after the 5% start date, and was never reached before the 1% start date. In the case of the other 13 taxa, the start occurred mostly on the same day as the 1% start date, but sometimes occurred before it. (Table II)

The main characteristics of the seasons are shown in Tables III–VI. It is evident that the order of flowering is almost the same every year, however, there are differences in the length

Table II. Relationship between the start dates calculated by the 5% and 1% methods and the method which was used in this study.

≥ 5%: Consistent 3 grains/m³ concentration was reached later than the 5% start date.
1%–5%: Start occurred between the dates calculated by the 5% and the 1% methods.
= 1%: Start occurred on the same day calculated by the 1% start date.
< 1%: Start occurred before the day calculated by the 1% start date.
Taxa at low pollen emission: *Ulmus*, *Carpinus* *Fagus*, *Juglans* and *Aesculus*

	≥5%	1%–5%	=1%	<1%
5 taxa of low pollen emission	14	3	11	–
the other 13 taxa	4	3	55	16
sum	18	6	66	16

Table III. Descriptive statistics for the season start of the 18 taxa studied.

Numbers indicate the number of days from 1st of January. Years, when the earliest and the latest season start occurred are indicated in brackets.

Taxa	mean	median	latest	earliest	S.D.
<i>Corylus</i>	56	53	83 (1996)	37 (1995)	19
<i>Alnus</i>	57	54	85 (1996)	37 (1995)	19
<i>Taxus</i> - <i>Cupr.</i>	66	64	95 (1996)	44 (1995)	18
<i>Ulmus</i>	72	66	97 (1996)	52 (1995)	18
<i>Populus</i>	73	73	97 (1996)	50 (1995)	16
<i>Fraxinus</i>	75	75	99 (1996)	54 (1995)	16
<i>Acer</i>	87	85	100 (1996)	78 (1994)	9
<i>Betula</i>	92	92	102 (1996)	83 (1994)	7
<i>Carpinus</i>	98	94	113 (1996)	84 (1994)	11
<i>Platanus</i>	108	108	116 (1996)	99 (1994)	6
<i>Quercus</i>	110	111	116 (1996)	103 (1994)	5
<i>Fagus</i>	114	116	118 (1996)	103 (1994)	6
<i>Juglans</i>	116	116	120 (1996)	111 (1994)	3
<i>Moraceae</i>	118	118	121 (1991)	114 (1994)	3
<i>Aesculus</i>	121	119	127 (1996)	117 (1995)	5
<i>Poaceae</i>	128	127	138 (1991)	118 (1994)	7
<i>Artemisia</i>	208	208	212 (1994)	206 (1993)	3
<i>Ambrosia</i>	215	213	224 (1991)	210 (1992)	6

of the periods between the start of consecutive species (Fig. 1). The greatest variation in the start dates occurred in the case of the first flowering taxa (*Alnus*, *Corylus*, *Ulmus*, *Populus* and *Fraxinus*); for the later flowering taxa, this variation was smaller. It can also be seen (Fig. 1) that the earliest start dates for *Corylus*, *Alnus*, *Ulmus*, *Populus* and *Fraxinus* occurred in 1995, but there was a long period between the start of *Fraxinus* (Feb.-23) and *Betula* (Apr.-02), so the earliest start of *Betula*, *Carpinus*, *Platanus*, *Quercus*, *Fagus* and *Juglans* occurred in 1994. The latest start dates for most of the taxa were in 1996.

The incidence of frosty days (daily minimum temperature; $T_{\min} < 0^{\circ}\text{C}$) and the incidence of days of mean temperature below 4.5°C ($T_{\text{avg}} < 4.5^{\circ}\text{C}$) show a positive correlation with the start dates (Figs. 1 & 2). To ascertain which is the period when temperature is the most important factor in determining the season start, correlation coefficients between mean temperature data of 20, 30 and 40 day periods from 1st of January to 31st of July and season start dates were computed, following the method of Reiss & Kostic (1976). In general, pre-seasonal temperature correlates negatively with the start dates (i.e., higher pre-seasonal temperature seems to promote pollination) and, with the exception of the grasses, significant correlation coefficients were usually found. In contrast, the amount of precipitation in March and April is the variable which significantly correlates with the start dates (negative), and with the yearly total counts (positive) of Poaceae. Fig. 3 shows which period was found to be the most determinative for some taxa. The high variance of the start dates of *Alnus*, *Corylus*, *Populus*, *Ulmus*, and *Fraxinus* are possibly due to the high variance in the mean monthly temperatures of February and March in the period examined.

In terms of the end dates and season length (Tables IV & V) it can generally be said that seasons are longer in years when the start of a species occurred earlier (e.g., *Corylus* and *Alnus* in 1995, *Betula*, *Platanus*, *Juglans*, and Moraceae in 1994). However, there are other factors which influence the end date and, therefore also, the length of the seasons. Of course this phenomenon could not be observed if the end date is earlier than anticipated due to a long, cold, rainy period (e.g., *Corylus* in 1993). In the cases of *Artemisia* and *Ambrosia* the end of the season is determined mostly by the weather in October, and not by the start date.

Greater variance was found for the season length in the cases of pollen taxa which are composed of more than one species, and for which there can be great differences in the flowering period (*Populus*, *Taxus-Cupressaceae*, *Fraxinus*, and Poaceae). In these groups, "season" means the period between the start of the first and the end of the last species' flowering. The pollen distribution of *Artemisia* shows a bimodal pattern with a main peak in August and a smaller one in September. In the case of this genus, it is still unclear if the second peak results from one or more of the other species flowering one month later than *A. vulgaris* (Reissenberger 1895); or if the majority of this pollen results from a secondary flowering of *A. vulgaris*.

During the period examined, the largest amounts of pollen were emitted by *Ambrosia*, Poaceae, *Populus*, *Quercus*, Moraceae, *Betula*, *Taxus-Cupressaceae*, *Fraxinus*, and *Platanus*. Of these, *Ambrosia* and Poaceae are the most important taxa from an allergological point of view (Mezei et al. 1992, Járαι-Komlódi & Juhász 1993), however *Corylus*, *Alnus*, *Platanus*, *Quercus*, *Betula*, *Fraxinus*, and *Artemisia* can also cause severe symptoms (Subiza et al. 1994, Eriksson

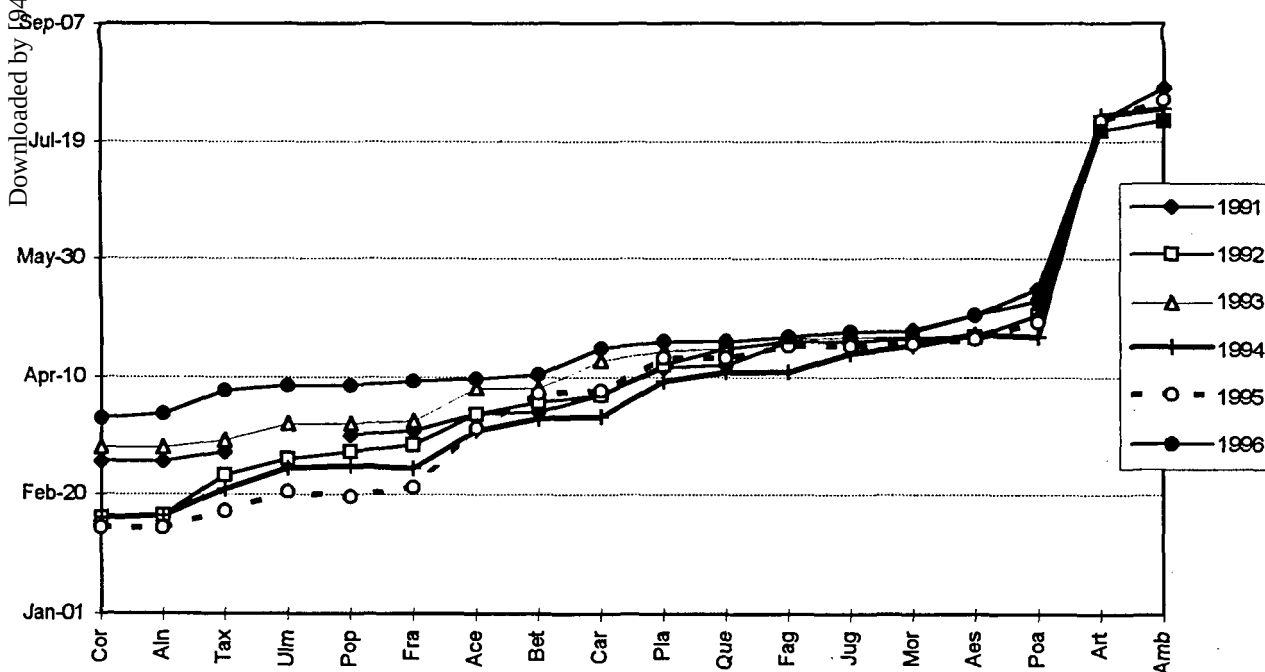


Fig. 1. Season start for the 18 taxa studied in Budapest between 1991–1996. Cor – *Corylus*, Aln – *Alnus*, Tax – *Taxus*, Ulm – *Ulmus*, Pop – *Populus*, Fra – *Fraxinus*, Ace – *Acer*, Bet – *Betula*, Car – *Carpinus*, Pla – *Platanus*, Que – *Quercus*, Fag – *Fagus*, Jug – *Juglans*, Mor – Moraceae, Aes – *Aesculus*, Poa – Poaceae, Art – *Artemisia*, Amb – *Ambrosia*.

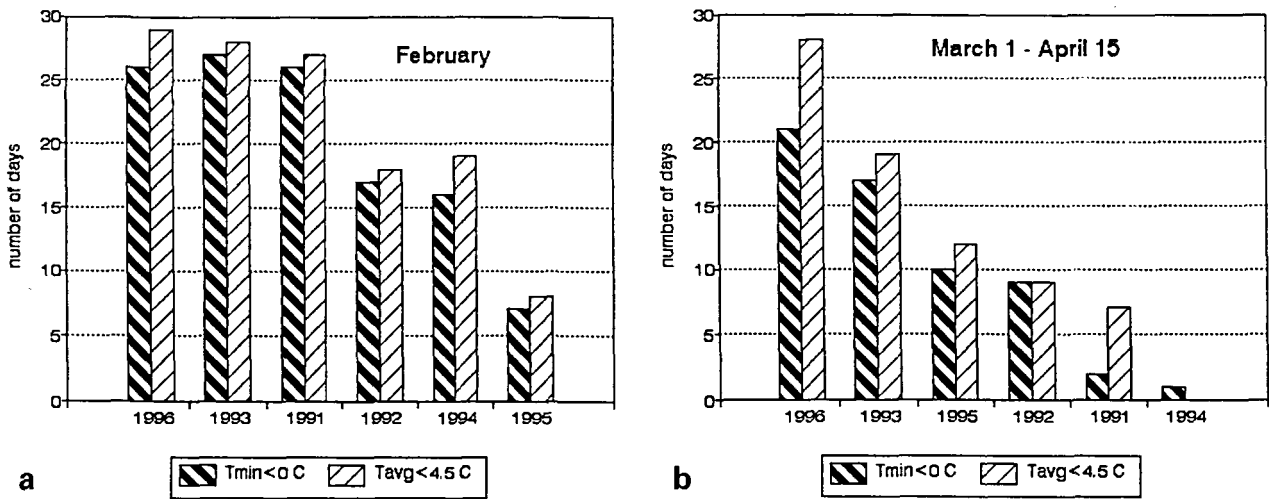


Fig. 2. a–b. Number of frosty days ($T_{\min} < 0^{\circ}\text{C}$) and the number of days of mean temperature below 4.5°C in February (a), and in the period between 1st March and 15th April (b).

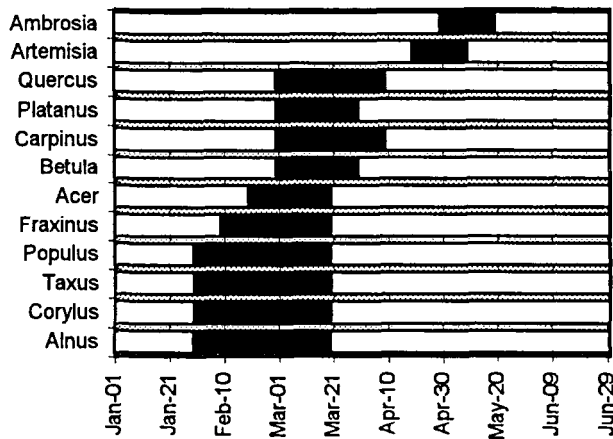


Fig. 3. Periods of highest correlation between the mean temperature and season start dates of some taxa.

et al. 1984, Fehér et al. 1995). Year to year variance was greatest for *Carpinus*, *Fagus* and *Moraceae*, while the most uniform amounts were emitted by *Acer*, *Poaceae*, *Populus*, and *Platanus* (Table VI).

No significant relationships were found between the total yearly pollen count of the trees and the amount of precipitation in the preceding autumn and winter. The number of years of observation were not enough to test the existence of biennial cycles.

DISCUSSION

More than one definition of “season” is in use. The 1% and 5% methods—whereby the season starts when 1% or 5% of the yearly total count has been recorded – and the $\Sigma 50$, $\Sigma 75$, $\Sigma 100$ etc. methods – whereby the start is defined as the first day when the cumulative daily count reaches 50, 75 or 100 grains – are the most widespread. Others (Davies & Smith 1973, Subiza et al. 1992) define the season start as the day when all of their patients have symptoms (100% symptom

Table IV. Descriptive statistics for the season end of the 18 taxa studied.

Numbers indicate the number of days from 1st of January. Years, when the latest and the earliest season end occurred are indicated in brackets.

Taxa	mean	median	latest	earliest	S.D.
<i>Corylus</i>	87	85	114 (1996)	70 (1994)	15
<i>Alnus</i>	93	93	116 (1996)	75 (1994)	15
<i>Taxus- Cupr.</i>	135	137	153 (1991)	116 (1995)	13
<i>Ulmus</i>	98	106	113 (1996)	80 (1995)	15
<i>Populus</i>	113	114	119 (1996)	106 (1994)	6
<i>Fraxinus</i>	141	139	172 (1991)	116 (1994)	19
<i>Acer</i>	117	117	125 (1991)	106 (1994)	7
<i>Betula</i>	129	129	130 (1993)	127 (1991)	1
<i>Carpinus</i>	123	127	131 (1993)	105 (1994)	10
<i>Platanus</i>	133	134	135 (1995)	129 (1993)	2
<i>Quercus</i>	140	140	147 (1992)	131 (1994)	6
<i>Fagus</i>	136	138	144 (1992)	127 (1994)	7
<i>Juglans</i>	136	135	142 (1993)	132 (1995)	4
<i>Moraceae</i>	140	140	146 (1991)	135 (1995)	4
<i>Aesculus</i>	137	136	142 (1991)	133 (1992)	4
<i>Poaceae</i>	258	259	268 (1992)	244 (1996)	9
<i>Artemisia</i>	270	271	280 (1993)	254 (1996)	10
<i>Ambrosia</i>	280	280	289 (1995)	269 (1996)	7

day). The $\Sigma 50$, $\Sigma 75$, $\Sigma 100$, etc. methods are completely unsuitable for comparing taxa with very different seasonal totals. The definition of start date as the 100% symptom day depends very much on the group of patients being studied. Further it can not be used to compare species of different allergenicity. The 1% or 5% methods seem to be preferable; however, using the 1% method, the start dates of taxa of low pollen emission (*Ulmus*, *Carpinus*, *Fagus*, *Juglans*, and *Aesculus*) occur too early, while using the 5% method, the starts of taxa of abundant pollen occur too late (e.g., *Ambrosia* can already cause severe symptoms a few days before its cumulative count reaches 200–300 grains). Using these definitions the start dates occasionally occur on days of very low pollen concentration, simply because the given

Table V. Descriptive statistics for the season length of the 18 taxa studied.

Years, when the shortest and the longest season occurred are indicated in brackets.

Taxa	mean	median	longest	shortest	S.D.
<i>Corylus</i>	31	30	43 (1995)	18 (1993)	9
<i>Alnus</i>	36	33	51 (1995)	30 (1993)	8
<i>Taxus-Cupr.</i>	70	73	90 (1994)	46 (1996)	17
<i>Ulmus</i>	26	25	40 (1992)	16 (1996)	9
<i>Populus</i>	40	39	57 (1995)	22 (1996)	12
<i>Fraxinus</i>	67	57	95 (1995)	43 (1996)	22
<i>Acer</i>	30	29	40 (1991)	19 (1996)	7
<i>Betula</i>	37	37	45 (1994)	27 (1996)	6
<i>Carpinus</i>	25	24	34 (1995)	15 (1996)	7
<i>Platanus</i>	25	27	35 (1994)	17 (1996)	7
<i>Quercus</i>	30	29	34 (1995)	24 (1993)	4
<i>Fagus</i>	22	23	28 (1992)	11 (1993)	6
<i>Juglans</i>	20	18	24 (1994)	17 (1992)	3
Moraceae	23	22	25 (1994)	20 (1995)	2
<i>Aesculus</i>	16	16	18 (1995)	15 (1996)	1
Poaceae	130	129	143 (1994)	111 (1996)	12
<i>Artemisia</i>	61	60	74 (1993)	48 (1996)	11
<i>Ambrosia</i>	66	67	77 (1993)	53 (1991)	9

Table VI. Descriptive statistics for the seasonal total number of pollen grains of the 18 taxa studied.

Years, when the highest and the lowest total counts were measured are indicated in brackets.

Taxa	mean	median	highest	lowest	S.D.
<i>Corylus</i>	366	343	595 (1995)	185 (1994)	149
<i>Alnus</i>	755	733	1669 (1993)	232 (1992)	504
<i>Taxus-Cupr.</i>	1328	1447	1933 (1996)	200 (1991)	625
<i>Ulmus</i>	98	76	157 (1996)	55 (1995)	45
<i>Populus</i>	2181	2256	2814 (1992)	1216 (1995)	611
<i>Fraxinus</i>	1060	963	2037 (1995)	509 (1992)	565
<i>Acer</i>	416	427	609 (1993)	270 (1995)	121
<i>Betula</i>	1433	1202	2649 (1996)	434 (1995)	993
<i>Carpinus</i>	369	120	1392 (1993)	55 (1992)	523
<i>Platanus</i>	1231	1244	1673 (1993)	717 (1995)	334
<i>Quercus</i>	1762	1730	3213 (1992)	589 (1994)	860
<i>Fagus</i>	136	70	417 (1994)	28 (1996)	146
<i>Juglans</i>	170	145	265 (1993)	107 (1995)	68
Moraceae	1615	1057	4493 (1996)	608 (1991)	1450
<i>Aesculus</i>	133	143	191 (1993)	53 (1994)	61
Poaceae	1328	1260	2071 (1994)	896 (1991)	417
<i>Artemisia</i>	793	844	1214 (1992)	435 (1994)	307
<i>Ambrosia</i>	3611	3519	6231 (1993)	1230 (1991)	1732

number of grains or the given percentage of total pollen count are reached at that point (Emberlin et al. 1994).

Our findings, that in the case of several taxa, significant correlation can be found between the pre-seasonal temperature and the start of pollination, agree with published data (Spieksma et al. 1995, Gonzalez Minero & Candau 1996, Frenguelli et al. 1991, 1992; Emberlin et al. 1993).

A knowledge of the periods of greatest importance for season start provides an opportunity for constructing predictive models based on heat accumulation. After dormancy break, the heat requirement of the first species to flower in the year is low enough to be fulfilled within only a few days

after the temperature consistently exceeds 4–5°C (Frenguelli et al. 1991, 1992). The accuracy of any predictive model is based on the accuracy of the weather forecast, and February and March are the two months with the most unpredictable weather (S.D.s of monthly mean temperatures are the highest) in the Carpathian Basin. We can still state – knowing the meteorological data of the last 115 years (Schirok-Kriston et al. 1996) – that the probability of a February warmer than that of 1995 (i.e. the start for *Alnus* and *Corylus* was before 6th February) is about 3%, while the probability of a March colder than that of 1996 (i.e., start for these taxa later than 24th March) is about 6%.

With respect to the effects of climate on the grass season, different authors have obtained different results. In Madrid, where the climate is dry-continental, Subiza et al. (1992) found that the season start was promoted by the pre-seasonal precipitation, but not by the temperature. In Bilbao (Atlantic climate) Antépara et al. (1995) observed quite the reverse, i.e. precipitation had no effect on the start of grass pollination, but higher pre-seasonal temperature promoted it. In Great Britain (Emberlin et al. 1994) precipitation in the 2 months preceding pollination seems to delay the start. So, season start is limited in dry, hot areas by soil humidity, but in rainy, Atlantic climate areas by temperature. Our results show that in late spring in Budapest soil humidity has a greater influence on grass pollination than temperature.

The yearly total pollen count is influenced on the one hand by pollen production, and on the other hand by with in-season meteorological events (e.g. wash out), which makes data interpretation difficult. Due to the shortness of the period of observation, we could not examine the possible existence of biennial cycles as reported by several authors (e.g. Spieksma et al. 1995).

If water is only available to the plants in limited quantities during floral induction, it will be a limiting factor for pollen production. In dry-continental and Mediterranean areas, this is generally observed in the case of both herbaceous (Subiza et al. 1992) and woody plants (Fairley & Batcheler 1986). In Budapest, the pollen production of trees does not show any correlation with pre-seasonal precipitation, probably due to the good ground water supply in spring which can be reached by the tree roots.

However, the upper part of the soil dries out rapidly during the spring, and at the time of floral induction of various grasses, soil water is only available in limited amounts, so that not only the start date, but also the severity of their season depends highly on pre-seasonal precipitation.

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