

Airborne grass pollen in Leiden, The Netherlands: annual variations and trends in quantities and season starts over 26 years

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Abstract

The long-term, 26 years' data set of observations on daily concentrations of airborne grass pollen in Leiden is analyzed to present the variations and trends in quantities, and season starting dates. Monitoring of airborne pollen has been done continuously at one location, with a volumetric pollen trap. Annual totals of daily average grass-pollen concentrations are within a normal range of an urban site between 3690 and 9277, averagely 5510. The annual totals are irregularly fluctuating from year to year, and show no increasing or decreasing trend. Each year's seasonal fluctuation is different, probably under the influence of changing weather conditions. The typical grass-pollen month is June. Using the $\Sigma 75$ criterium, the average starting date is on 16 May, whereas with the 1% threshold criterium the start of the grass-pollen season averagely is on 3 June. The mean air temperature in the preceding period is taken as the main factor for the timing of the season start. Analyzing the relationships of the two different criteria for the season starts with a number of temperature observation periods, the best relations were found between the mean air temperature in the period 11 April to 20 May and the $\Sigma 75$ criterium season start on 16 May ($r = -0.78$); and between the mean air temperature in May and the 1% threshold criterium season start on 3 June ($r = -0.76$). Forecasts of the season start which are significantly better than the average starting date are only possible with the mean air temperature up to a few days before the actual start. This limits the practical usefulness of the forecasting system. © 1998 Elsevier Science Ireland Ltd. All rights reserved.

Keywords: Aerobiology; Forecast; Grass pollen; Pollen season

1. Introduction

The inhalation of airborne grass pollen by allergically sensitized individuals is the main cause of pollinosis or hay fever in Europe. That is why in many places all over the continent observations are carried out on the atmospheric presence of grass pollen. The great majority of pollen monitoring stations using continuous volumetric sampling methods have started in the 1980s or later. There are only a few stations with an uninterrupted series of data dating back from

the 1960s: London, from 1961; and Basle and Leiden, from 1969. These data sets are now thought to be long enough to provide reliable information on certain long-term trends and variations in quantities and season starts on airborne pollen (Emberlin et al., 1993a,b; Spieksma et al., 1995). Such information might be of interest for studies on relationships with trends in the prevalence and severity of pollinosis, and on the predictability of quantitative fluctuations and starting dates of the pollen season and the hay-fever season.

This report presents some aspects of these annual and seasonal variations and trends in the airborne grass-pollen presence over a period of 26 years, from 1969 to 1994, in Leiden, The Netherlands.

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2. Materials and methods

2.1. Assessment of airborne pollen

For the volumetric sampling of airborne pollen two types of Hirst-type traps (Hirst, 1952) have been used. Between 1969 and 1978 the daily operated Casella trap (London, UK), with an external pump, has been employed from March to October. From 1979 to 1990 it has been operated between 1 May and 17 July, during the main grass-pollen season. This Casella trap was located on the roof of the E.N.T. clinic of the University Hospital Leiden, approximately 20 m above street level.

From 1977 the newly installed Burkard trap (Rickmansworth, UK) has been operated the whole year round, until 1987, at the same location as the Casella trap at 5 m distance. In 1985 a second Burkard trap was placed on the roof of the new central building of the University Hospital, approximately 25 m above street level, and about 500 m from the first location. To compensate for the difference in efficiency between the Casella and the Burkard trap, the data from the period 1977–1987 were used, when both traps were operated next to each other between 1 May and 17 July. Based on the results from these 11 grass-pollen sampling seasons, it appeared that the Casella-trap results have to be multiplied by 1.5 to make them quantitatively equal to the Burkard-trap counts. Comparison of the results from 1985, 1986 and 1987, when two Burkard traps were at the two locations, and from the years 1985–1990, when the Casella trap was at the first location and the second Burkard trap at the second location, showed that no correction had to be made for the change of location.

Information about the situation and the environment of the sampling location has been published elsewhere (Nikkels et al., 1996).

For the annual totals of the daily grass-pollen concentrations the data for the period 1 April to 31 August are taken (data available also before 1977), in which 97% of the whole year's total are recorded.

Exposed sticky-faced slides or tapes are mounted for microscopy, and scanned for pollen grains along three longitudinal bands covering a surface area which corresponds to 1 m³ of air. Detailed descriptions of the traps and the methods for preparation and scanning of the slides can be found in Leuschner (1974), Ogden et al. (1974), K  pyl   and Penttinen (1981).

The existence of trends in the annual totals has been investigated by calculating the regression of 5-years overlapping means. Seasonal fluctuations are presented as 5-days running means for each individual year, and for the overall average of all 26 years.

2.2. Season starting dates

For the definition of the start of a pollen season a number of different criteria are used by various authors (Mullenders et al., 1972; Mullenders, 1974; Pathirane, 1975; Lejoly-Gabriel, 1978; Nilsson and Persson, 1981; Driessen et al., 1989; Frenguelli et al., 1991; El-Ghazali et al., 1993; Spijksma et al., 1995). For this study two of these criteria are applied: the 1% threshold (Mullenders et al., 1972), and the Σ 75 (Driessen et al., 1989). With the 1% threshold criterium the pollen season starts on the date when the 5-days running mean reaches or exceeds 1% of the annual total. To avoid the inconsistency of having a different threshold for each individual year and to be able to determine the starting date not only retrospectively after completion of the season, 1% of the average of the annual totals, amounting 5510, was taken being 55. So, the date on which the 5-days running mean reaches 55 is the starting date of the grass-pollen season.

With the Σ 75 criterium the starting date is on the day when the accumulative sum of the daily grass-pollen concentrations reaches or exceeds 75. In this study the accumulative counting of grass-pollen grains begins from 15 April because, according to phenological observations, at this time of the year no grasses are flowering, and most of the very few airborne grass-pollen grains recorded before that date are supposed to be resuspended grains from earlier years.

The criterium for the starting date of the hay-fever symptom season has been derived from the data of the daily hay-fever warning system which is based on the relationship between the flowering development of the wild grasses (phenology), the actual weather situation, and on hay-fever symptoms reported by a group of patients under treatment, recorded since 1975 (Spijksma, 1980; Spijksma et al., 1985). In these earlier studies it had been suggested that particularly in the first part of the season the relationship of hay-fever symptoms with actual weather is better than with the pollen concentration. The starting date of the hay-fever season is defined as the first day when the hay-fever forecast was 'not very favourable'.

The criterium for the start of the birch-pollen season, used in a prediction model, is Σ 100 (Driessen et al., 1989), counting from 1 March.

2.3. Mean air temperatures

Mean air temperatures in a number of preceding periods of different lengths have been correlated with the three above defined season starts. As is usually done in meteorological work, the lengths of the periods are taken as 10 days, also called 'decades'. The periods chosen are: 1–31 May (3 decades: nrs 13–15); 21 April to 31 May (4 decades: nrs 12–15); 1 April to 31 May (6

Table 1
Annual totals, peak days of 26 grass-pollen seasons; and starting dates of 26 grass-pollen seasons (two criteria), 20 hay-fever seasons, and 26 birch-pollen seasons

Quantities				Starting dates							
Year	Annual total	Peak-day		Grass pollen				Hay fever		Birch p. Σ 100	
				1%		Σ 75					
		Conc.	Date	Date	Day nr.	Date	Day nr.	Date	Day nr.	Date	Day nr.
1969	6500	398	16-VI	8-VI	159	14-V	134			30-IV	120
1970	4754	399	18-VI	4-VI	155	21-V	141			5-V	125
1971	6249	506	9-VI	29-V	149	13-V	133			22-IV	112
1972	5291	311	26-VI	10-VI	162	20-V	141			22-IV	113
1973	6932	492	20-VI	8-VI	159	18-V	138			1-V	121
1974	3779	230	14-VI	4-VI	155	9-V	129			2-IV	92
1975	5988	356	12-VI	6-VI	157	11-V	131	30-IV	120	22-IV	112
1976	5583	456	9-VI	5-VI	157	17-V	138	1-V	122	18-IV	109
1977	5451	395	14-VI	8-VI	159	19-V	139	7-V	127	21-IV	111
1978	5156	328	15-VI	29-V	149	22-V	142	10-V	130	26-IV	116
1979	5202	403	21-VI	2-VI	153	28-V	148	14-V	134	27-IV	117
1980	5606	477	14-VI	3-VI	155	14-V	135	11-V	132	15-IV	106
1981	3692	337	9-VI	31-V	151	13-V	133	11-V	131	10-IV	100
1982	4227	212	7-VI	29-V	149	19-V	139	10-V	130	20-IV	110
1983	6580	325	11-VI	2-VI	153	14-V	134	6-V	126	17-IV	107
1984	4224	310	20-VI	15-VI	167	22-V	143	15-V	136	23-IV	114
1985	4897	406	4-VI	1-VI	152	18-V	138	12-V	132	19-IV	109
1986	5022	317	15-VI	11-VI	162	25-V	145	16-V	136	1-V	121
1987	3928	253	6-VII	12-VI	163	24-V	144	23-V	143	18-IV	108
1988	3690	241	11-VI	12-V	133	7-V	128	7-V	128	18-IV	109
1989	6479	384	12-VI	24-V	144	11-V	131	15-V	135	30-III	89
1990	4624	245	1-VI	30-V	150	4-V	124	15-V	135	19-III	78
1991	5959	364	4-VII	19-VI	170	30-V	150	19-V	139	2-IV	92
1992	9277	651	6-VI	19-V	140	12-V	133	13-V	134	12-IV	103
1993	8002	600	5-VI	19-V	139	30-IV	120	9-V	129	5-IV	95
1994	6157	335	24-VI	12-VI	163	7-V	127	11-V	131	8-IV	98
Average	5510	374	15-VI	3-VI	154	16-V	136	12-V	132	17-V	107
S.D.					8.67		7.29		5.44		11.21

decades: nrs 10–15); 11 April to 20 May (4 decades: nrs 11–14); 1 April to 10 May (4 decades: nrs 10–13).

For the temperature data use has been made of the observations from two meteorological stations of the Royal Netherlands Meteorological Institute (KNMI), at approximately 50 km distance, situated in the main grass-pollen source regions, and representative of the conditions in the region: De Bilt and Vlissingen (KNMI, 1969–1994).

3. Results

3.1. Variation and trend of annual totals

The annual totals of the daily average airborne grass-pollen concentration of the 26 years of observation, from 1969 to 1994, are given in Table 1 (second column), and in Fig. 1. The mean value of these annual totals is 5510, with a highest total of 9277 in the year

1992, and a lowest annual total of 3690 in the year 1988.

Upon visual inspection of Fig. 1, the year-to-year variation in the annual totals is irregular, and does not show any distinctive pattern.

The existence of a trend is investigated by calculating the regression of the 5-years running mean. The equation of this regression is: $a = 8.33y - 11.19$, where a is the annual total and y is the year number. The correlation coefficient of this regression is low: $r = +0.08$ (ns). This means that any existing trend is very weak. Its direction is positive (see Fig. 1), with a year-to-year increase of the annual total of only 8.33 pollen grains, or 0.15%.

3.2. Seasonal course of daily concentration

The seasonal fluctuations in the daily grass-pollen concentrations for the 26 individual years is shown in Fig. 2 as 5-days running means. From this Figure it

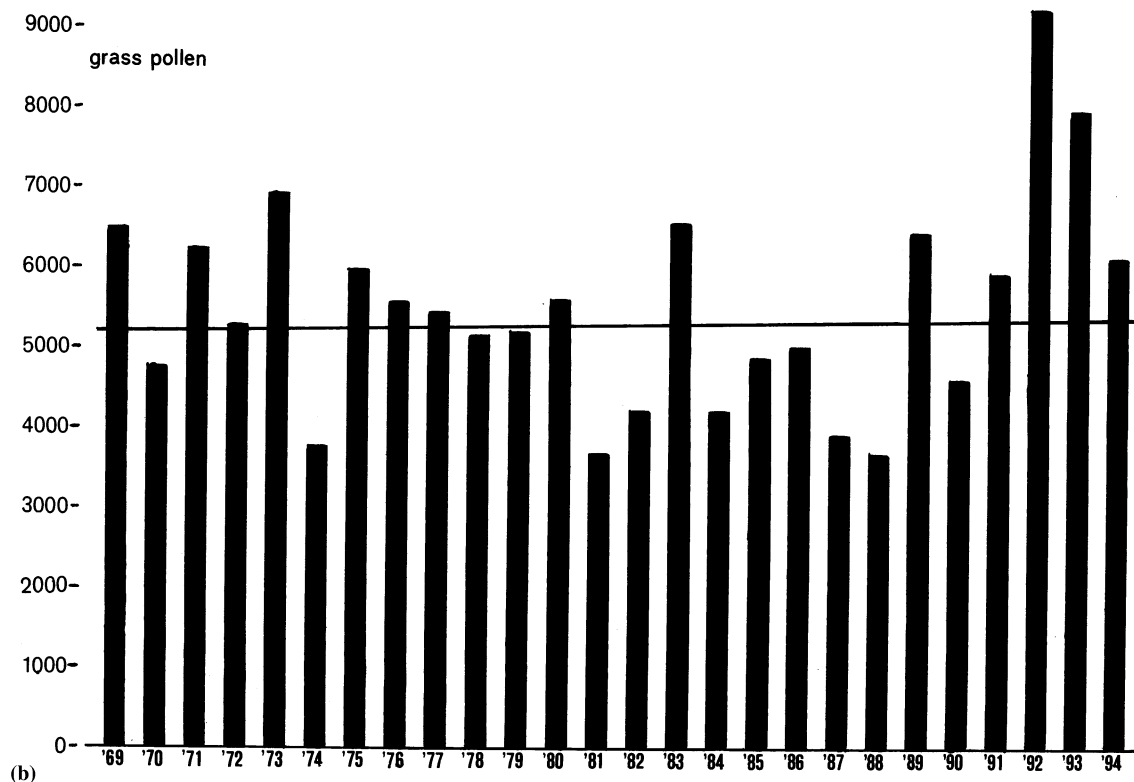


Fig. 1. Annual totals of daily average airborne grass-pollen concentrations in 26 individual years (1969–1994), at Leiden, The Netherlands. Regression line indicates the trend calculated over 5-years overlapping means: $a = 8.33y - 11.19$ (a = annual total; y = year number).

becomes clear that every year has its own characteristic course, with variable periods of high and low airborne grass-pollen concentrations, very often with multiple peaks. Years with one dominant peak period are 1969, 1973, 1991, and 1993. Two peaks are observed in 1970, 1975, 1978, and 1986. More complicated patterns are seen in 1971, 1977, 1983, and 1989. Years without clear seasonal peaks are 1981, 1985, and 1990, while the seasons of 1973, 1976, and 1987 are short, and those of 1978, 1983, 1985, and 1989 are relatively long.

After totalling and averaging the data from the 26 years, an overall seasonal course can be constructed which is shown in Fig. 3. Clearly the main peak is in the middle of June, with a smaller secondary peak in the first week of July.

The individual season's highest daily airborne grass-pollen concentrations, and the dates these are observed, are given in Table 1 (third and fourth columns). The average daily maximum is 374, with the highest maximum of 651 in the season of 1992, and the lowest in 1982 with 212. Averagely, this season's maximal daily concentration occurs on 15 June, which is in accordance with the position of the seasonal peak (Fig. 3). The earliest seasonal peak is on 1 June in 1990, and the latest is on 6 July in 1987.

3.3. Season starting dates

The dates and day numbers of the starts of the grass-pollen season according to the 1% threshold criterium are given in Table 1 (columns 5 and 6). The season starting date averagely is on day nr 154, 3 June. The year 1988 had by far the earliest start on day nr 133, 12 May. The latest starting date was in 1991, on 19 June, day nr 170.

Using the $\Sigma 75$ criterium for the start of the grass-pollen season the average starting date is 16 May, day nr 136 (Table 1, columns 7 and 8). The earliest start was in 1993 on 30 April, day nr 120; and the latest start was on day nr 150, 30 May, in 1991.

The average season starting date according to the 1% threshold criterium (3 June, day nr 154) is 18 days later than that following the $\Sigma 75$ criterium (16 May, day nr 136). Yet, there is a relationship between the two sets of starting dates, with a correlation coefficient $r = +0.59$ ($p < 0.002$).

The two differently defined starting dates are indicated in Fig. 2 with symbols: one inverted triangle for the $\Sigma 75$ criterium; two stacked inverted triangles for the 1% threshold criterium.

The starting dates of the season of the hay-fever symptoms are also indicated in Fig. 2 with spheres. In Table 1 the dates and day numbers are given in

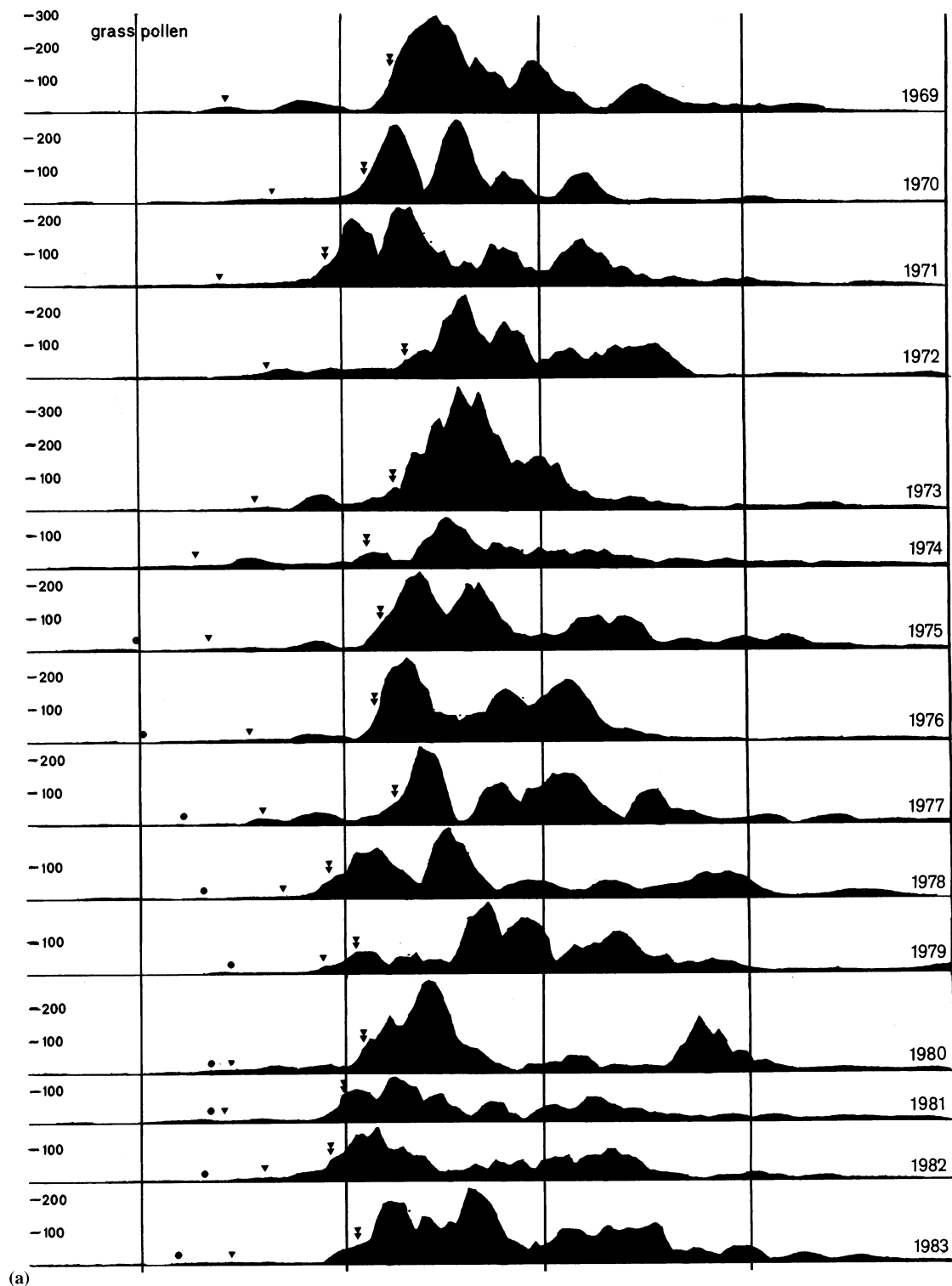


Fig. 2. Seasonal fluctuations of airborne grass-pollen concentrations in 26 individual years, at Leiden, The Netherlands. Data are presented as 5 days running means of daily average pollen concentrations. ▽: season's start following 1% threshold; ▼: following $\Sigma 75$; ●: start of hay-fever season.

columns 9 and 10. The start of the hay-fever season averagely is on 12 May (day nr 132). The earliest start was in 1975, on 30 April (day nr 120); the latest start was on 19 May (day nr 139) in 1991.

The average starting date of the hay-fever season (day nr 132) is 22 days before the average starting date of the grass-pollen season according to the 1% threshold criterium (day nr 154), and only 4 days before

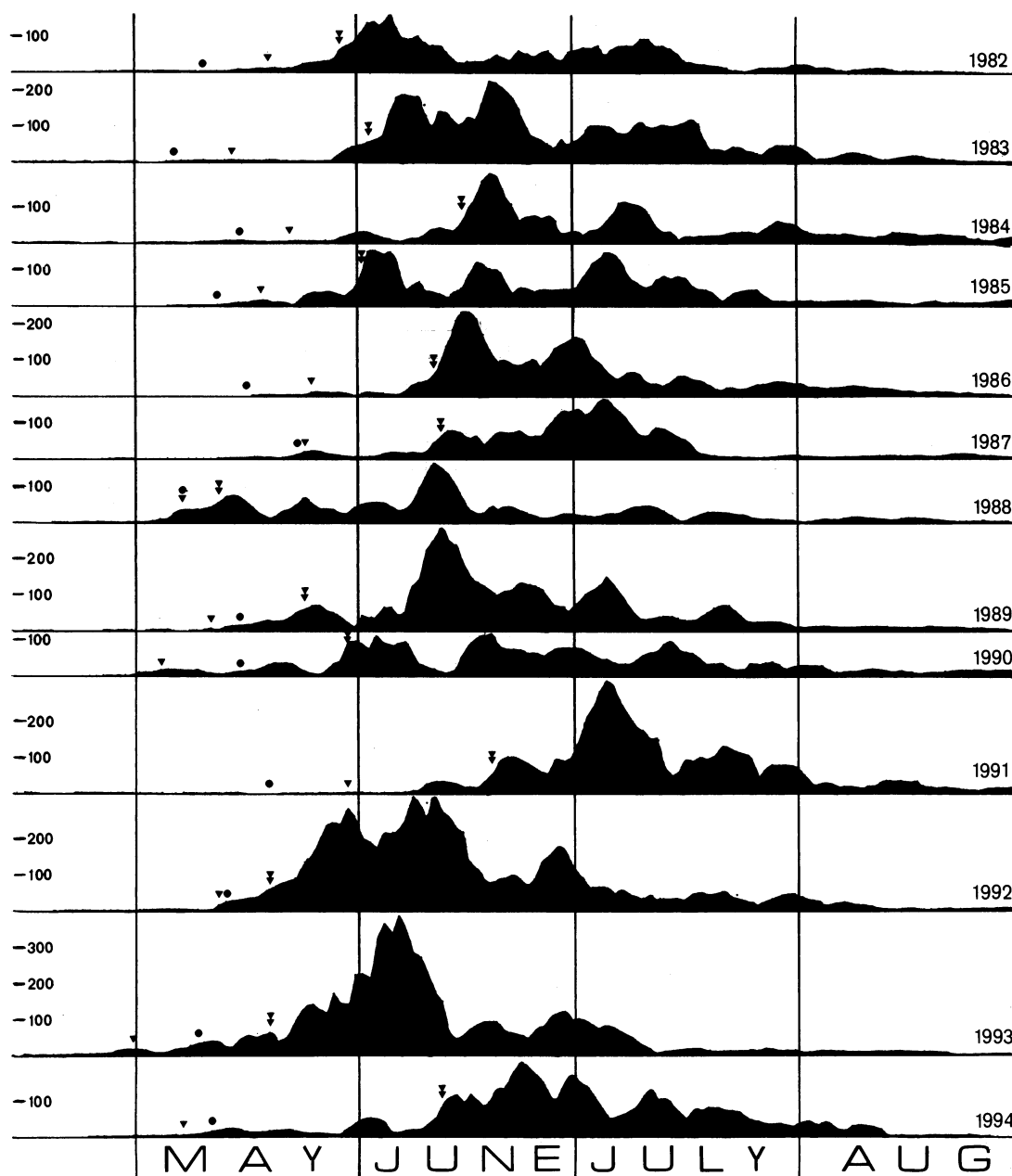


Fig. 2. (Continued)

that following the $\Sigma 75$ criterium (day nr 136). The coefficient for the correlation between the starting dates or the hay-fever season and the 1% threshold grass-pollen season is $r = +0.28$ (ns). For the starting dates of the hay-fever season and the $\Sigma 75$ grass-pollen season the correlation coefficient is $r = +0.40$ (ns).

3.4. Air temperature and starting dates

The influence of air temperature on the starting dates of the three above defined seasons (pollen 1% threshold; pollen $\Sigma 75$; hay fever) has been investigated by determining the correlations between these starting dates and the mean air temperatures during a

number of different periods preceding the average starting date. The numerical data of these mean air temperatures are given in Table 2. The results of the calculations of relationships and regressions of these temperature data to those of the three criteria season's starts, with the most significant correlations, are given in Table 3, and the graphical presentation is shown in Fig. 4(a) and (b).

For the start of the grass-pollen season according to the 1% threshold criterium, the relationship with the mean air temperature in the period 1–31 May (3 decades: nrs 13–15) is the best of the four tested (Table 3: A–D). The correlation coefficient is $r = -0.76$ ($p < 0.001$), and its regression is shown in Fig. 4(a), B.



Fig. 3. Overall seasonal course of the airborne grass-pollen concentration, calculated from 26 years of observation (see Fig. 2).

Table 2

Mean air temperatures during various periods preceding the starting dates of the grass-pollen season, in 26 years of observation

Year	3 decs: 13–15 1 to 31 May	4 decs: 12–15 21 April to 31 May	4 decs: 11–14 11 April to 20 May	4 decs: 10–13 1 April to 10 May	6 decs: 10–15 1 April to 31 May
1969	12.7	11.7	9.9	8.9	10.3
1970	12.8	11.7	10.6	8.1	9.5
1971	13.4	12.3	11.0	9.2	10.7
1972	11.7	10.6	9.4	9.1	9.9
1973	12.0	11.0	9.0	7.5	9.3
1974	11.7	10.7	9.8	9.4	10.6
1975	10.9	10.7	10.1	8.1	9.1
1976	13.2	11.6	10.7	9.2	10.4
1977	11.9	11.3	9.3	7.7	9.5
1978	12.0	11.3	9.2	8.3	9.6
1979	11.4	10.4	9.5	7.6	9.6
1980	12.2	11.0	10.6	8.5	10.2
1981	13.0	11.4	10.3	8.9	10.7
1982	12.8	11.5	9.3	7.9	10.3
1983	10.7	10.6	10.2	8.9	9.6
1984	10.4	10.7	10.0	8.4	9.3
1985	12.7	10.8	9.4	8.5	10.6
1986	12.8	11.9	9.9	7.8	9.5
1987	10.2	11.1	10.3	10.2	10.3
1988	14.0	12.6	11.8	9.9	11.5
1989	14.5	12.6	10.6	8.5	10.4
1990	14.1	13.6	12.3	10.9	11.6
1991	10.0	9.3	8.7	8.6	9.4
1992	15.4	14.1	11.2	9.3	12.2
1993	14.2	14.5	13.0	11.3	12.6
1994	12.4	12.4	11.3	9.2	10.5
Average	12.4	11.6	10.3	8.8	10.3

For the start of the grass-pollen season following the Σ 75 criterium, the relationship with the mean air temperature in the period 11 April to 20 May (4 decades; nrs 11–14) is the highest of all tested (Table 3: E), with a correlation coefficient of $r = -0.78$ ($p < 0.001$). In Fig. 4(b), E its regression is shown.

For the start of the hay-fever symptoms season no relationship with any of the mean air temperature data was found. The correlation coefficients for two of the periods most closely preceding the hay-fever start are

$r = -0.11$ (ns) (Table 3, F; Fig. 4(b), F), and $r = +0.12$ (ns) (Table 3, H; Fig. 4(b), H), respectively.

3.5. Starting dates of the birch-pollen and grass-pollen seasons

The starting dates of the birch-pollen season according to the Σ 100 criterium are given in Table 1 (columns 11 and 12). A graphical comparison with the starting dates of the grass-pollen season following the Σ 75

Table 3
Regressions and coefficients of correlation between mean air temperatures in different preceding periods and starting dates of the grass-pollen season (two criteria), and of the hay-fever season (see also Fig. 4)

Preceding period		Criterium	<i>r</i>	<i>p</i>	Regression, <i>d</i> (t)	Fig. 4
(4 decs: 12–15)	21 Apr to 31 May	1%	−0.68	<0.001	211.87–4.99	A
(3 decs: 13–15)	1 to 31 May	1%	−0.76	<0.001	214.05–4.83	B
(4 decs: 11–14)	11 Apr to 20 May	1%	−0.58	<0.002	203.96–4.85	C
(6 decs: 10–15)	1 Apr to 31 May	1%	−0.71	<0.001	224.35–6.84	D
(4 decs: 11–14)	11 Apr to 20 May	Σ 75	−0.78	<0.001	192.39–5.48	E
(4 decs: 11–14)	11 Apr to 20 May	hf	−0.11	ns	137.33–0.56	F
(4 decs: 10–13)	1 Apr to 10 May	Σ 75	−0.64	<0.001	179.11–4.87	G
(4 decs: 10–13)	1 Apr to 10 May	hf	+0.12	ns	125.73+0.65	H

criterium is shown in Fig. 5(a), while the correlation between the two sets of starting dates is shown in Fig. 5(b). The correlation coefficient is $r = +0.53$ ($p < 0.01$).

3.6. Predictability of the start of the grass-pollen season

To investigate the predictability of the start of the grass-pollen season using different criteria, the respec-

tive standard deviations (S.D.) are compared. For the mean air temperatures only those periods are taken into account that actually precede the average starting date.

For the 1% threshold criterium of the starting date the standard deviation from the average starting date (3 June; day nr 154) is S.D. = 8.67. The standard deviation from the predicted date using the mean air temperature in the preceding date with the best correlation (1–31 May; 3 decades: nrs 13–15) is S.D. = 5.50. This

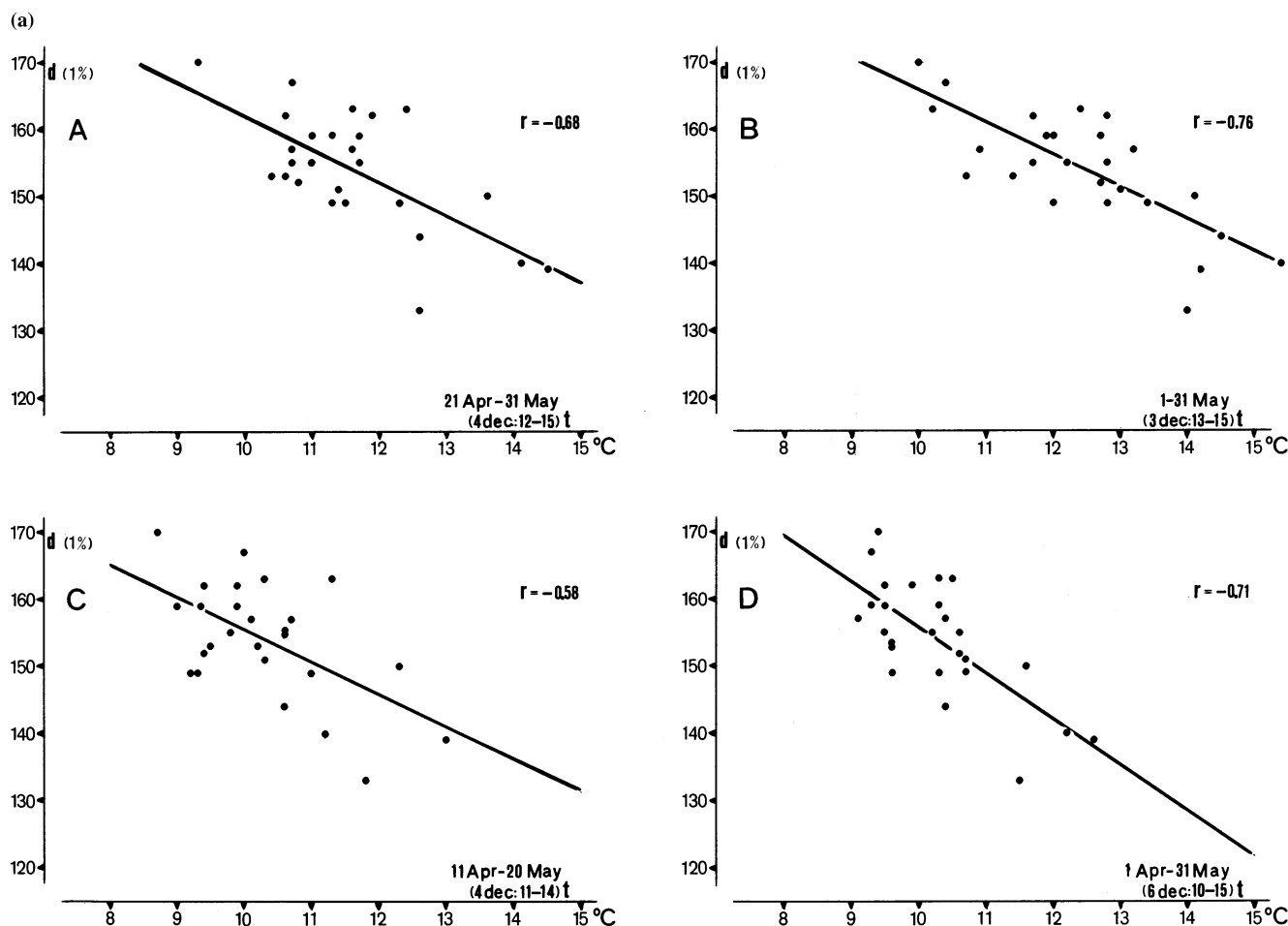


Fig. 4. Correlations between mean air temperatures (t) in different preceding periods and starting dates (d , as day number from 1 January) of the grass-pollen season (two criteria), and of the hay-fever season (see Table 3). (a) A–D: Starting dates of grass-pollen season following the 1% threshold criterium. (b) E, G: Starting dates of grass-pollen season following the Σ 75 criterium; F, H: Starting dates of hay-fever season.

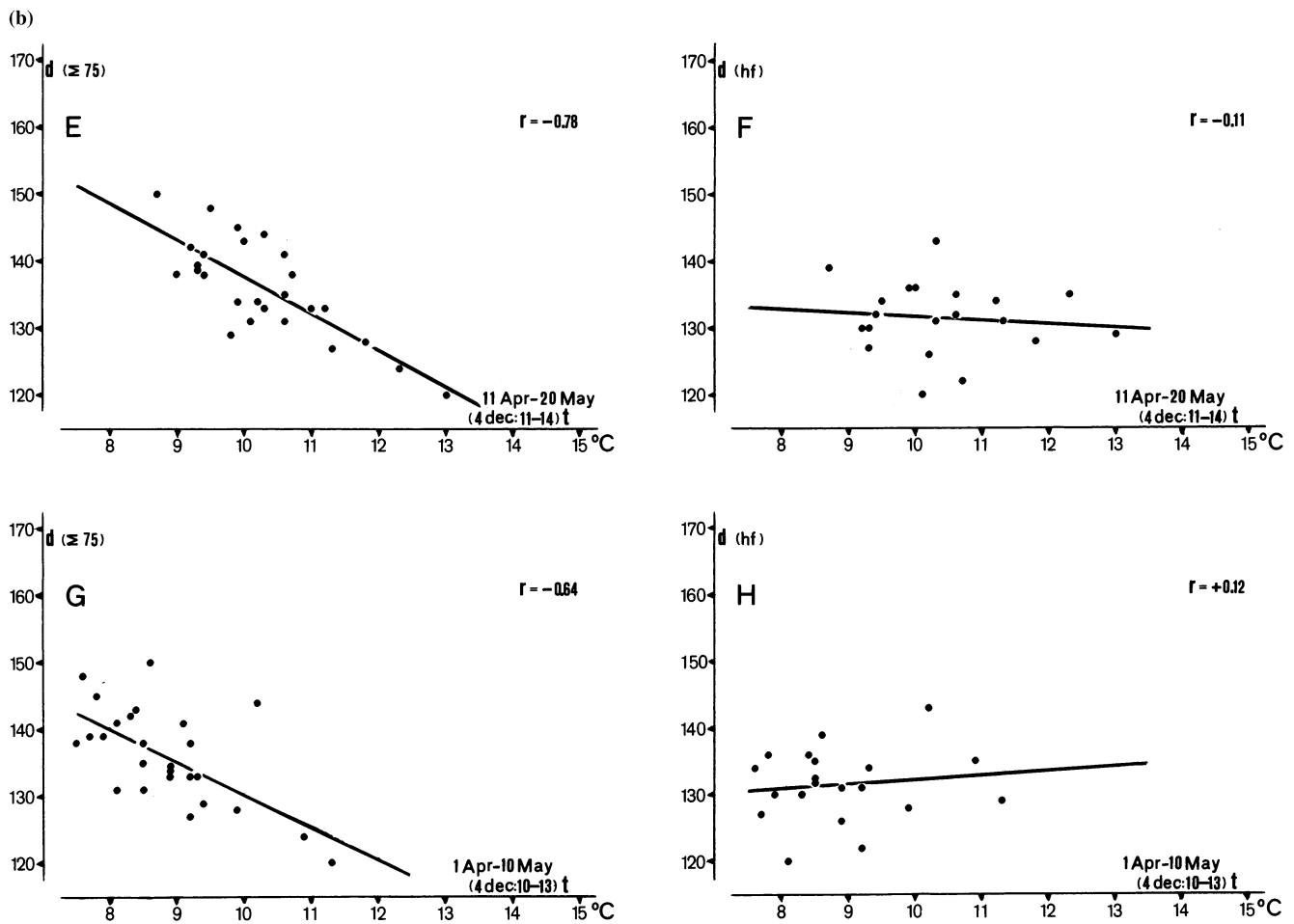


Fig. 4. (Continued)

smaller deviation means a better prediction than just taking the average starting date of 36.6%.

The standard deviation from the average starting date, using the Σ 75 criterium, on 16 May (day nr 136) is S.D. = 7.29. Using the mean air temperature in the preceding period with the best correlation (1 April to 10 May; 4 decades: nrs 10–13), the standard deviation is S.D. = 5.82, meaning an improvement of the prediction of 20.2%.

The very poor correlations of the two preceding mean air temperature periods with the starting dates of the hay-fever symptoms season of $r = -0.11$ and $r = +0.12$ (Table 3 and Fig. 4(b): F and H), and the rather small standard deviation of these starting dates (S.D. = 5.44) makes an effective prediction of the hay-fever season starting date impossible, at least with the mean air temperature in the preceding period of some decades.

Using the starting date of the birch-pollen season (following the Σ 100 criterium) for the prediction of the grass pollen season (according to the Σ 75 criterium) the standard deviation is S.D. = 6.15. Compared to the standard deviation of the average starting date (S.D. = 7.29) this is an improvement of the prediction of 15.6%.

4. Discussion

4.1. Annual totals and seasonal fluctuations

The annual totals of the daily average airborne grass-pollen concentrations, with a mean of 5510, and extreme values of maximally 9277 and minimally 3690, are in the same range as in other urban locations in Europe (Spijksma et al., 1989a,b; Jäger et al., 1991; Emberlin et al., 1993a).

The very small year-to-year increase of the annual totals of only 0.15% or 8.33 pollen grains per year has a weak regression with a correlation coefficient of only $r = +0.08$ (ns). This increase can hardly be considered as a trend. It is interesting to note that in an earlier report (Jäger et al., 1991), presenting trends in Brussels, Leiden, and Vienna up to 1989, there was a slight but significant trend for grass pollen in Leiden, with a decrease of 104.5 pollen grains (1.86%) per year, but no significant trends for Brussels and Vienna. Obviously, rather long periods of observation are needed to conclude to real trends, like the marked decrease found for London over 30 years, between 1961 and 1990 (Emberlin et al., 1993a).

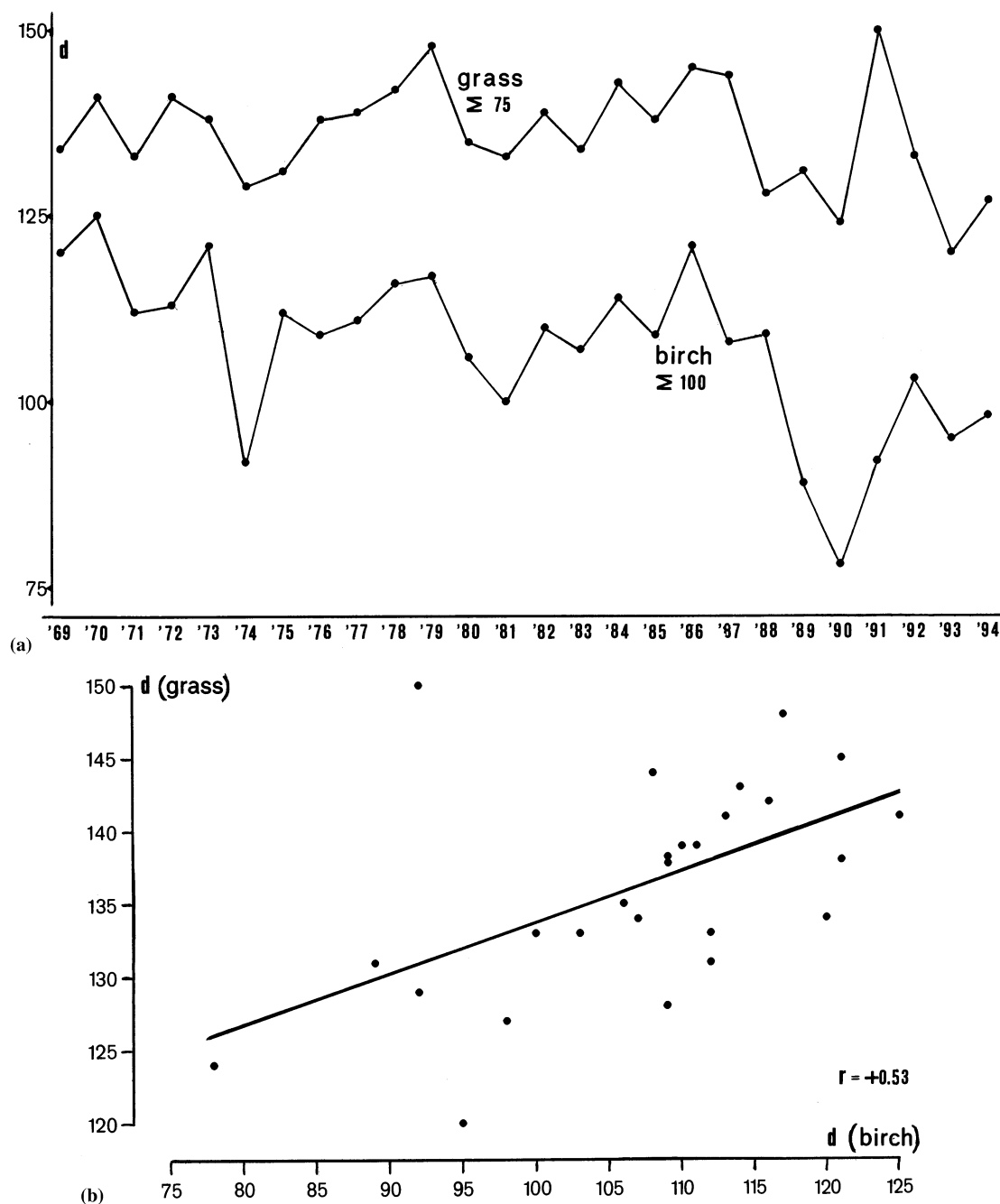


Fig. 5. Starting dates of birch-pollen season ($\Sigma 100$ criterium) and of grass-pollen season ($\Sigma 75$ criterium). (a) Year-to-year fluctuation of starting dates. (b) Correlation between the two pollen season's starting dates.

The presence of grass pollen in the atmosphere reflects the production and release by numerous species of grasses with different flowering characteristics and times over a period of more than three months: from the middle of May to the end of August. It is, therefore, not surprising that under the strongly changeable weather conditions in Northwestern Europe the variation in the seasonal fluctuation is rather great (Fig. 2). Each individual year has his own characteristic seasonal picture which seems not predictable more than a few days ahead. In general, in Leiden June is the most

typical grass-pollen month, but in some years, like 1987 and 1991, July has a higher monthly total.

4.2. Starting dates

The timing of the starting dates of the airborne grass-pollen season appears to be dependent on the definition of the start of a pollen season. Using the 1% threshold criterium, the average starting date is 3 June, which is 18 days later than when using the $\Sigma 75$ criterium with an average starting date on 16 May. The

biggest difference between the starting dates using the two different criteria was 36 days, 12 June and 7 May, respectively, in 1994. The smallest difference was 5 days: 2 June and 28 May in 1979; and 12 and 7 May in 1988. So, in spite of the correlation coefficient of $r = +0.59$ ($p < 0.02$) between the two differently defined starting dates sets, the interval is variable from year to year.

Based on these findings it is very hard if not impossible to decide which of the two criteria for determining the start of the grass-pollen season is the best. The 1% threshold criterium indicates the start of the main pollen period, whereas the $\Sigma 75$ criterium determines the start of the initial pollen period with regular be it still low airborne pollen concentrations. The start of the hay-fever symptoms season, averagely on 12 May, is much closer to the start of the grass-pollen season according to the $\Sigma 75$ criterium, averagely of 16 May, than to that following the 1% threshold criterium, averagely on 3 June. Yet, the relationship of the symptoms starting dates with the $\Sigma 75$ grass-pollen start is not very strong ($r = +0.40$; ns), though better than with the 1% threshold grass-pollen starting date ($r = +0.28$; ns). This is in agreement with earlier findings (Spieksma, 1980).

The dilemma of the choice between the two criteria is also recognized by other authors (Emberlin et al., 1993a), who use both methods for different purposes.

In several studies on factors determining the start of the pollen season air temperature in the preceding period is considered to play an important role (Davies and Smith, 1973; Frenguelli et al., 1989; Spieksma et al., 1989b; Frenguelli et al., 1991; Emberlin et al., 1993a; Spieksma et al., 1995). This is corroborated in this study for both of the starting criteria used (Table 3; Fig. 4). The correlation between air temperature and starting dates is better the closer the temperature observation period is to the starting date (Table 3 and Fig. 4: B and E). In the case of the latter correlation, the period of temperature observation ends on 20 May, which in fact is 4 days after the average starting date of 16 May.

A correlation between air temperature during two different preceding periods and hay-fever starting dates is not found: $r = -0.11$; $r = +0.12$ (Table 3; Fig. 4(b), F and H). It seems as if the first hay-fever symptoms of the season are triggered by the first exposure event to grass pollen above a certain level caused by an actual and local warm and dry weather condition, rather than by the start of the more general and wide-spread atmospheric pollen presence caused by massive flowering of grasses by along-period temperature condition.

Quite recently, for Melbourne, Australia (Ong et al., 1997), a correlation was reported between the amount of precipitation in a winter month (July on the southern hemisphere) and the start of the grass-pollen season.

This relationship has been tested with the data from Leiden (with January as a winter month), as an appendix to this study. The result was negative in the sense that for both the 1% threshold and the $\Sigma 75$ starting date criteria the correlations with the amount of precipitation in all of the preceding months (January to May) were very weak and not significant. The highest correlation found was between the amount of precipitation in May and the starting date according to the $\Sigma 75$ criterium, being $r = +0.30$ (n.s.). Possibly, the amount of precipitation in winter and spring in the oceanic humid climate of Leiden is always more than sufficient, therefore not constituting a limiting or determining factor for the development of grass plants and flowers.

4.3. Predictability of season starts

In a number of studies (Driessen et al., 1989, 1990; Bricchi et al., 1995) it has been shown that often there is a relationship between the starting dates of pollen seasons of taxa flowering at successive times of the year. These studies also explore the possibility of forecasting the start of the pollen season of the later taxon by the relation with the start of the earlier taxon. As far as the grasses is concerned Bricchi et al. (1995), using the 5% criterium for the season start (Lejoly-Gabriel, 1978) over 11 years in central Italy, found weak correlations with Polygonaceae ($r = +0.62$), and with *Pinus* (also $r = +0.62$), which were thought to be insufficient for accurately forecasting the start of the grass-pollen season. Driessen et al. (1989), in their first study using the $\Sigma 100$ criterium for grasses and $\Sigma 125$ for birch over 9 years in the West of The Netherlands, found a high correlation of $r = +0.86$, with a prediction 'efficacy' (=improvement compared to the average date) of 65.2%. In their second study for the South of The Netherlands Driessen et al. (1990), using the $\Sigma 75$ criterium for grasses and the $\Sigma 25$ criterium for birch over only 5 years, found a very high correlation of $r = +0.92$, with a prediction efficacy of 50.0%.

In this study, using the $\Sigma 100$ criterium for birch and the $\Sigma 75$ criterium for grasses, the correlation between the respective season starting dates over 26 years, is only $r = +0.53$. Consequently the improvement (or 'efficacy') of the prediction, measured by the reduction of the standard deviation from 7.29 to 6.15 is only 15.6%. It appears that over a longer period of years the starting date of the birch pollen-season is not a very good predictor for the start of the grass-pollen season.

Considering the air temperature in the period preceding the start of the pollen season, moderate improvements of the forecast, compared to the average starting date ('prediction efficacies'), can be achieved using the relationships found in this study. With the $\Sigma 75$ criterium for the start of the grass pollen season (aver-

agely on 16 May), using the mean air temperature in the 4 decades (nrs 10–13) between 1 April and 10 May, the improvement of the prediction is 20.2%. In this forecasting system the period of temperature observation precedes the average starting date of 16 May with only 6 days and in four individual years the starting date is even before the end of the temperature observation period. So, this system is only useful for rather short-term forecasts of the start of the grass-pollen season.

With the 1% threshold criterium (starting date averagely 3 June), the improvement of the forecast is 36.6%, using the mean air temperature in the 3 decades (nrs 13–15) of May. In this system the period of temperature observation precedes the average starting date with only 3 days. In 12 individual years the grass-pollen season had already started before the end of the temperature observation period. This seriously limits the practical usefulness of this system of forecasting starts of the pollen season by observing air temperature in preceding periods.

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