

Annual variations in grass pollen seasons in London 1961–1990: trends and forecast models

J. EMBERLIN, M. SAVAGE* and S. JONES

*Pollen Research Unit, University of North London, and *St. Mary's Hospital Medical School, Paddington, London, U.K.*

Summary

The record of daily average grass pollen concentrations monitored at St Mary's Hospital, Paddington, London, U.K. since 1961 is the longest duration pollen data set in Europe. Analysis of the results identifies the trends and characteristics of grass pollen seasons over three decades. During this time seasonal allergic rhinitis has increased significantly in Britain. The annual start dates, length of season and severity are examined in relation to the main meteorological variables of cumulated temperatures above 5.5°C and precipitation measured at one site within London and two in the surrounding rural areas. Land-use changes are also considered. Significant decreases have taken place in both the duration and severity of the seasons, particularly between the 1960s and the early 1970s but also through the last 20 yr. This is largely a result of a decrease in pollen abundance in the region. The decline in pollen counts has slowed in recent years due to the increase in flowering grasses caused by the set-aside policy and by uncut verges. Grass pollen seasons have tended to start later over the last two decades, despite an increase in the cumulated temperature profiles during late winter and spring. Empirical models have been developed using multiple regressions to incorporate meteorological and pollen data for the last 20 yr in order to forecast the start dates, duration and severity of the grass pollen seasons. These models were applied successfully using the data for 1991 and 1992. Predictions of the main characteristics of the pollen seasons can be obtained relatively early in the year through the use of these models by employing the monthly weather forecasts in conjunction with long-term average weather profiles.

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Introduction

Long-term trends in pollen concentrations have not been examined in London since the work of Davies and Smith in 1973 [1]. Their research was amongst the first to consider in detail the controls which govern the start of the grass pollen season. The model which they developed to forecast start dates in London formed an important landmark in aerobiology. However, since the early 1970s advances in both computing and aerobiology have facilitated the construction and interpretation of larger data bases. The record of grass pollen counts taken from St Mary's Hospital, Paddington since 1961 is now the

longest data set for any pollen monitoring site in Europe, and probably worldwide. It provides an interesting opportunity to examine trends in the characteristics of the grass pollen seasons, such as the start dates and severity, over three decades. During this time considerable changes in the land-use patterns have taken place in the region and fluctuations in climate have occurred that may be related to global warming.

Evidence suggests that the incidence of seasonal allergic rhinitis in Europe has increased significantly over the last few decades [2,3]. Research in several countries has indicated that the incidence of this disease is greater in urban areas than in rural areas and has implicated a link with patterns in the concentrations of air pollutants [4–6]. Information from the long-term trends in grass pollen

Correspondence: Dr J. Emberlin, Pollen Research Unit, Life Sciences, University of North London, 166–220 Holloway Road, London N7 8DB, U.K.

concentrations in London will provide valuable insight in this context.

This paper presents some aspects of an analysis of the variations and trends in the grass pollen seasons in London over the period 1961–1990 in relation to land-use changes and the main meteorological variables. It builds predictive models for start dates, duration and severity, with the aim of developing reliable methods of forecasting the characteristics of grass pollen seasons pertinent to current environmental conditions.

Materials and methods

The pollen data

The pollen data record comes from St Mary's Hospital, Paddington in Central London. This is a densely built-up district with few open spaces apart from well tended parks. Most grass pollen present in the atmosphere at the site is thought to emanate from rural areas outside the conurbation. The main source areas are at least 20 km from the sampling site although flowering grasses within London, such as on railway embankments and derelict land, do make some contribution.

The daily average concentrations of grass pollen were recorded using a volumetric spore trap of the Hirst design [7] situated on the flat roof of a six-storey building in an unobstructed airflow. Details of the method of slide counting were changed slightly during the study period but the essential parameters of the sampling system and the location of the trap have remained constant.

Definition of the pollen season

Annual records of daily average grass pollen concentrations in Britain typically exhibit long periods at the beginning and end of the season when values are low. In order to overcome the problem of the bias that this may introduce to the analysis it is necessary to eliminate these tails by defining the period when most of the pollen is released. Various methods have been developed, especially for the definition of the start of the season [8]. These include the sum 100 and sum 75 methods, that is when the cumulated sum for the daily average concentrations reaches 100 and 75 respectively [9], and the method used by Davies and Smith [1] in which the first day of the season is taken as that when the daily average grass pollen count is equal to or greater than 50 grains/m³. This approach is based on an observation by W. Frankland and R. Davies that all of their diagnosed hay fever patients in London exhibited symptoms when the daily average pollen count was equal to or exceeded 50 grains/m³ [1]. However, evidence suggests that many susceptible people suffer symptoms at much lower thresholds than this [10].

In the current analysis the most satisfactory method in terms of investigating relationships between the duration of the season, its severity, and climatic variables was found to be the 98% definition in which the season is deemed to have started when 1% of the total season's catch has been recorded and deemed to have finished at the 99% level. This technique is useful in the examination of trends but does have two main disadvantages. Namely, it can be applied only retrospectively and it is relative to the total pollen catch. Consequently the sum 75 method was used to give an absolute method to determine start dates and the 98% method was used to examine overall trends in seasonal characteristics (the correlation coefficient for the relationship between start dates determined by the two techniques, $r=0.4$, $P=0.05$).

Meteorological data

Three sets of meteorological data were used in the analysis of the pollen record. Daily records of the climatic variables from St James' Park, Central London were used to indicate conditions near to the pollen monitoring site. These would be a function of the urban climate [11] and could differ from those prevailing in the surrounding rural areas, especially with respect to temperatures in the areas to the north. Data sets to represent the weather conditions in the rural source areas were taken from Rothamsted Experimental Station, Harpenden, located approximately 39 km north of the pollen monitoring site and 21 km to the west from Heathrow. Temperature and precipitation conditions would be expected to vary slightly around London, but the annual trends would be similar.

Previous research [12,13] has established that the main variables controlling the timing of the start of pollen release from grass plants are temperature and precipitation but that photo-periods play an important role in the initiation of flowering in some species [14]. In the current analysis the specific parameters used were, daily average temperatures compiled to monthly means, cumulated temperatures as day degrees above 5.5°C, and total monthly precipitation. Sunshine hr and relative humidity were not included because these are auto-correlated with the main variables. Wind direction, wind speed and synoptic situation adopt importance once the seasons have started and need to be considered in the detailed analysis of the duration and severity of the seasons.

Land-use information

Information about land-use changes, especially the areas of grassland in the regions around London during the 30 yr study period were obtained from the Agricultural Statistics for England and Wales, June returns [15].

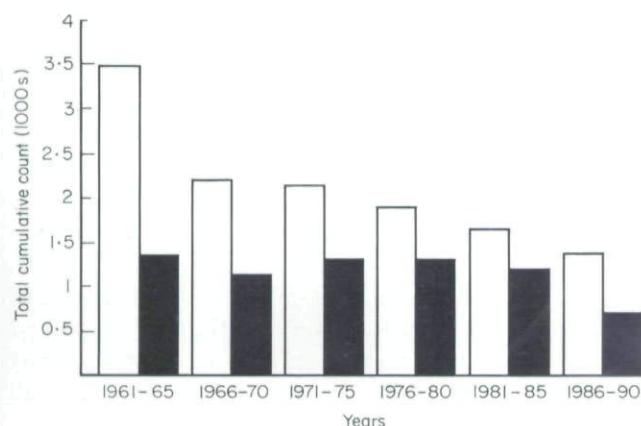


Fig. 1. 5-year means for grass pollen for □, June and ■, July at St Mary's, Paddington. Cumulative count recorded in grains per cubic meter of air.

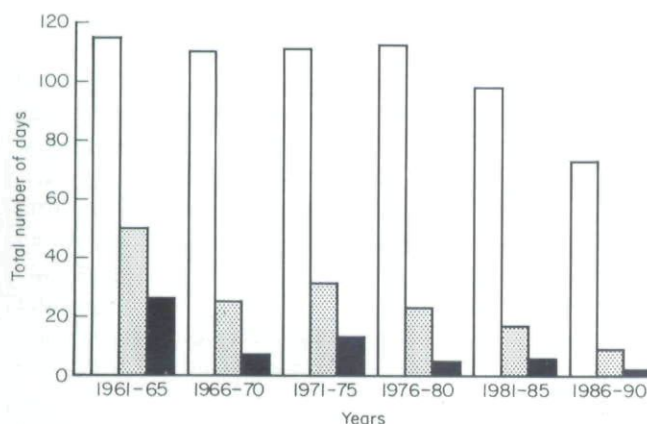


Fig. 2. Severity of grass pollen season at St Mary's, Paddington 1961–1990. Daily average pollen counts; □, > 50 as high, ▨, > 150 very high and ■, > 250 as extremely high.

Results

Severity of the seasons

A distinct overall trend of a decrease is apparent in the total cumulative daily average grass pollen counts for the seasons over the 30 yr period (Fig. 1). This is most pronounced in the 1960s but is sustained through the 1970s and early 1980s. At the extremes, the range of differences in the annual totals extends from 8210 in 1964 to 940 in 1981. In most years the totals for June exceed those for July but exceptions occurred as in 1972 and 1977, when cool, wet weather featured in June (lowest monthly temperature averages for June in the data set).

The pollen count record shows a decline in the number of 'peak' days per season, that is the number of days on

which the average daily concentrations exceeded 'high' thresholds. These were set subjectively for this analysis at 50, 150, and 250 grains/m³ to represent 'high', 'very high' and 'extremely high' respectively (Fig. 2). In this aspect the most marked decreases occurred in the 1980s. During this decade only four seasons experienced days with counts over 250/m³, compared with seven in the 1970s and nine in the 1960s. Similarly, the number of years with more than 20 days on which average counts exceeded 50 grains/m³ was seven in the 1960s, nine in the 1970s but only two in the 1980s. There is no evidence from the meteorological records of factors which would account for this trend.

In the case of the London data set the decrease in the annual totals of grass pollen counts seem to be related directly to land-use changes. Evidence from the Agricultural Statistics June returns (Table 1) shows a substantial decrease in the areas of grassland in all regions around the conurbation culminating in an overall decrease of 37% over the 30 yr period. The greatest rates of change occurred in the 1960s levelling off throughout the next two decades.

Duration of the seasons

The length of the seasons (98% definition) (Fig. 3) has differed by 45 days over the 30 yr, having a mean of 65 days and a range from 89 days in 1965 (which was also the year of the earliest start of the season) to 44 days in 1984 (which was also the year of the latest start date). When pollen season durations are averaged over 10 yr to overcome the influence of annual fluctuations in weather, the means decrease progressively from 72 days in the 1960s to 63 days in the 1970s and 59 days in the 1980s. All of the shortest seasons (those below 60 days duration) have occurred during the last 15 yr and seven of the 11 in this set have occurred in the last decade. There is no obvious explanation for this from the records of climatic factors.

Start of season

The grass pollen season in London usually starts in late May or early June. Depending on the definition used, the range in start dates over the 30 yr period is between 38 and 45 days (Table 2). Examination of the 5 yr running means of the start dates indicates a trend towards later start dates after 1970 (Fig. 4). Analysis of variance conducted on the results for individual decades shows that the data set for the 1960s is significantly different from that of the 1970s and 1980s, although these two are similar ($F=5.96$, $P=0.007$). By the sum 75 method the average start date in the 1960s was 143 days from January 1st, whereas it was

Table 1. Decline in areas of grassland around London

Region	Total area of grassland in acres			% decline
	1961	1975	1990	
North west (Buckinghamshire and 1/2 Hertfordshire)	231,406	163,849	148,284	36
North east (East and 1/2 Hertfordshire)	202,294	117,216	101,442	50
South-west (Hampshire and Surrey)	324,761	293,955	227,033	30
South east (Kent)	239,732	195,207	167,758	30
Overall totals	998,193	770,267	644,517	37

Source: Agricultural Statistics for England and Wales, June Returns 1961/1962, 1975 and 1990.

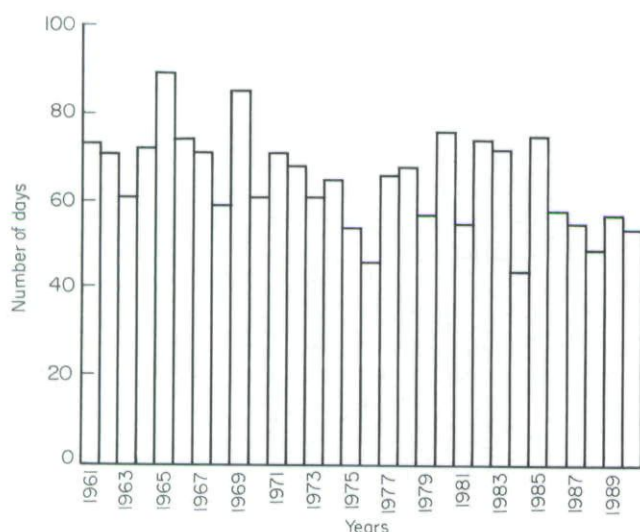


Fig. 3. Duration of grass pollen season at St Mary's, Paddington 1961–1990. Length of season defined as 98% of the total catch.

153 in the 1970s and 157 in the 1980s. Overall the main factors which influence the start of the grass pollen season are winter temperatures, cumulated air temperatures over 5.5°C during the spring, especially in March, April and May, photo-period and precipitation.

The cumulated temperatures from January 1st through to the end of May were calculated for each of the three meteorological stations used in the study. The average cumulated temperatures for this part of the year were compared for each decade. In all cases, there was a marked increase from the 1960s to the 1980s for the total cumulated temperatures January 1st to the end of May.

For example, at Heathrow it increased from 448 in the 1960s to 492 in the 1980s. Examination of profiles for individual months reveals that the main increases were due to shifts in the means for January, March and May. Cumulated temperatures for the other months did not display significant patterns. In the case of precipitation there are no sustained patterns of contrasts between the decades although monthly totals exhibit great fluctuations.

From these results it can be surmised that the trend towards later dates for the grass pollen season is not a function of climatic shift. Overall the recent temperature trends towards increasing warmth would encourage earlier start dates not later ones. It is reasonable to suppose that the later starts and shorter duration derive from a combination of lower pollen abundance and a change in the species spectrum towards later flowering types.

Discussion

The patterns evident in the grass pollen record for Central London are relevant in general outline for the whole metropolitan area and its surrounding countryside. Concentrations of grass pollen vary across the city even within short distances [16] and are much higher in rural areas but the main trends in start dates, duration and severity will be similar to those recorded at Paddington.

Analysis of the 30 yr data set has shown a marked decrease in both the length and severity of the grass pollen seasons from the early 1960s to the early 1970s with a continued decline through to the mid 1980s when the trend levelled off. The decline in the areas of grassland

Table 2. Comparison of start dates for the grass pollen season using different definitions, London

Definition	Earliest start*	Latest start*	Range	Mean start*	Mode*	s.d.
(a) 1961–1990						
98%	123 (1965 and 1969)	162 (1964)	39	142	143	9.32
Sum 100	128 (1965)	166 (1986)	38	154	158	9.32
Sum 75	125 (1969)	165 (1981 and 1984)	40	151	154	10.94
1st day over 50 grains/m ³	123 (1965)	168 (1972 and 1979)	45	157	multi modal	10.59
(b) 1971–1990						
98%	134 (1982)	162 (1984)	28	145	143	7.33
Sum 100	140 (1982)	166 (1984 and 1986)	26	157	158	6.19
Sum 75	136 (1982)	164 (1981 and 1984)	28	155	158	7.23
1st day over 50 grains/m ³	151 (1978 and 1982)	168 (1972 and 1979)	17	161	multi modal	5.38

* Days taken from 1st January; s.d. = standard deviation.

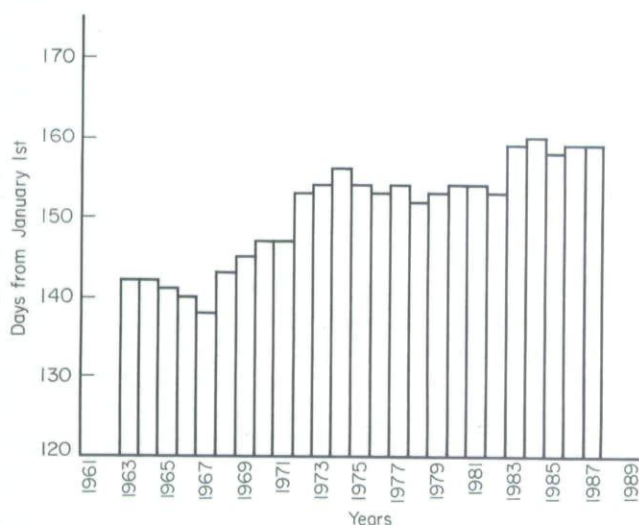


Fig. 4. 5-year running means of start dates for grass pollen at St Mary's, Paddington 1961–1990. The start of the season is defined as the first day when the cumulative total reaches 75 grains per cubic meter of air.

does not account fully for the decrease in the pollen catches. A number of contributing factors are important here, most notably the change in agricultural practice from haymaking in the 1960s to silage production in the 1970s, whereby grasses are cut before they flower. At the same time there was a change in the seed mix of sown pastures from species such as *Dactylis glomerata*, which produce abundant pollen, to species such as *Lolium perenne* which produce less.

The rates of decline in grassland areas in south-east England have decreased through the 1980s, mainly as a result of the introduction of set-aside and the prevalence of uncut verges. In south-east England, the main hedge-

row and verge grasses include *D. glomerata*, and various species of *Festuca* and *Agrostis*, all of which produce prolific pollen. The increased abundance of flowering of these species in recent years would account in part for the levelling off in the trends of decline in pollen catches. Another factor which may contribute to the long-term patterns in the magnitude of pollen counts at the St Mary's site is the growth of towns in the London area. During the 30 yr since 1961, peripheral development on the urban fringe of London has largely been prevented by the green belt policy. However, building development beyond a distance of 24 km from London has significantly reduced the area under agriculture [17].

During the three decades of the study air pollution concentrations have changed significantly in the region. Some types, including ozone and nitrogen dioxide, have increased substantially because of the increase in vehicle exhaust emissions [18]. Evidence suggests that vehicle exhaust pollutants induce growth stress on plants and that this may decrease pollen production in grasses [19].

Several aspects need to be mentioned in this context although they are marginal to the central theme of this paper. The pollen record which has been analysed is for intact pollen grains. It does not consider allergens carried by smaller micronic and submicronic fractions, either as pollen fragments or as allergens transferred to atmospheric particles including pollutants. The origins and significance of these smaller fractions is not fully understood but it is known that they may contribute to symptoms especially during the early and late phases of seasons [20]. Increases in vehicle exhaust pollutants, especially suspended particulate matter, may have enhanced the importance of this fraction even though average daily counts of grass pollen grains have declined. Pollen counts do not always correlate directly with the

allergen load of the atmosphere [21]. Similarly, research utilizing exposure tests has revealed that free amino acid concentrations increase in pollen grains when in contact with NO₂, SO₂ and CO [22]. Electrophoretic studies revealed that these gaseous pollutants have a pronounced effect on the molecular weight of the allergens in a manner which would increase their potency. Undoubtedly, the concentrations of grass pollen have declined during the study period but it is conceivable that the allergenicity of the grass pollen grains has increased because of the interaction with air pollutants.

It is well known that various genera and species of grass have different phenologies and that their responses to environmental factors vary [23]. For instance, for rye grass (*Lolium* species) in temperate areas, spikelet emergence depends on photo-period but the rate of elongation of the fertile shoot and the development of the inflorescence are controlled mainly by temperature in March. Other genera respond to thermal time irrespective of daylight and so exhibit a closer relationship with temperature profiles through the spring. In order to ascertain whether the shift towards later dates observed in the grass pollen seasons could be due to climatic trends, it is necessary to examine monthly profiles as well as seasonal ones. The weather profiles for cumulated temperatures from the start of the year through to May indicate a progressive warming which would be expected to encourage earlier start dates. Considering that the decline in pollen abundance has apparently stabilized in the region, it is probable that start dates will feature earlier for the next few years. The recent tendency for warmer winters and springs in the south-east of England cannot be attributed conclusively to global warming as it may be just a minor climatic fluctuation. However, if the Department of Environment's predictions on global warming are correct [24] then annual average temperatures in Europe could increase by 0.5°C per decade. This could result in the start of the grass pollen season appearing 2 or 3 weeks earlier, over the next few decades, than the average at present.

Forecasting the characteristics of the seasons

Statistical examination of the pollen data set indicates that the period from 1960 to 1970 must be treated separately from that for 1971 onwards. This is largely because of the differences in the magnitude of the pollen catch. Detrending the data was not considered to be appropriate because the grass species mix has changed. Predictive models have been derived using data for the years from 1970 onwards since the pollen record for this period can be treated as one population.

Severity

The severity of the individual grass pollen seasons will depend partly on the weather conditions during the late spring when the pollen forms in the anthers and partly on the weather during anthesis. An estimate of the severity of the season can be made from a combination of these aspects.

Seasonal cumulative totals (98% season) for grass pollen counts are negatively correlated with start dates; for example using the sum 75 method $r = -0.68$, $P = 0.05$. Additional variables can be employed in a multiple regression to achieve 66.3% explanation in the empirical data (equation 1).

$$(1) \text{ Cumulative catch for season} = 21629 - 111a - 4.76b - 8.23c - 10.4d + 6.6e - 0.21f.$$

$P = 0.01$ where: a = sum 75 start date, b , c , d , e , are cumulative temperatures for March, April, May and June respectively considering results from Heathrow and Rothamsted; f = total precipitation for June in London.

This relationship gives an average error of 21%, reducing to 13.6% if 2 yr which had exceptionally wet weather in June are excluded. The insertion of additional variables did not increase the level of explanation significantly. The regression model can be applied for predicting the likely severity of the season at the end of May or when the sum 75 figure has been reached, by using the monthly forecasts of temperature and precipitation in June. If these parameters are excluded the level of explanation reduces to 58%, but the prediction can be made at the end of April by using the long-term weather forecasts for May.

Duration

The duration of the grass pollen season shows a positive correlation with severity ($r = 0.48$, $P = 0.05$), since both depend on common variables. Length of season defined by the 98% method has a significant negative correlation with the sum 75 start date; clearly, late seasons tend to be shorter ($r = -0.816$, $P = 0.01$). A regression equation for this single variable relationship gives an explanation of 66.6%, but this can be increased to 77.7% by including additional variables as in equation (2).

$$(2) \text{ Length of season (98\%)} = 257 - 0.916a - 0.0285b - 0.101c - 2.02d - 0.02e.$$

$P = 0.001$. a = sum 75 start date; b and c = cumulative temperatures considering results from Rothamsted and Heathrow; b runs from January 1st to April 30th and c is for May; d = cumulative temperatures for June in London; e = total precipitation for June in London.

By this relationship the average error of estimated

durations in the data set is 4.6 days with 63% of cases being within 5 days, and only 2% of cases being more than 7 days different. As in the case of severity, predictions about duration can be made once the sum 75 level has been reached and accuracy will increase if the monthly forecasts for June are included. When tested on the data for 1991 and 1992 the predicted durations fell within 5 days of the actual ones.

Start dates

Detailed analysis revealed that there were no significant correlations between start dates and individual monthly weather features but that explanation of the variation could be achieved by examining combinations of factors. Winter air temperatures are important in that they influence soil temperatures during the early spring growth of grass species with a thermal response not linked to photo-period. Temperatures in the period from early March to late May exert a great influence on growth rates and flower maturation in all grass species. Similarly precipitation during this time is important, although secondary to the influence of temperature.

Later than average start dates (by the sum 75 method) are associated with years in which at least one spring month had cumulated temperatures one standard deviation or more below the average for the last 20 yr.

This pattern is evident even in years in which other spring months had above average cumulated temperatures. A regression (equation 3) incorporating the main variables to the end of May achieves 42% explanation. If variables for June are included, 49% explanation is achieved. In the 20 yr data set start dates predicted by this model fall within 5 days or less of actual start dates in 80% of cases.

For use in predicting start dates in future years an estimate can be made from equation (3) at the end of April by using the monthly weather forecasts for May. Similarly, a more accurate estimate can be made towards the end of May when June weather forecasts are available. When tested on the data for 1991 and 1992 the model estimated start dates within 7 days and 5 days respectively of actual dates.

Increased accuracy can be obtained by using forecasts of airflow patterns and by direct observation of grass development, particularly the times of head emergence because the lag times between this and anthesis are well documented [26].

$$(3) \text{ Start of season (sum 75 method)} = 163 - 0.04a - 0.26b + 0.07c + 0.07d + 0.05e + 0.05f + 0.02g - 0.13h.$$

$P=0.05$. Cumulative temperatures considering results

from Heathrow and Rothamsted, a=January; b=February; c=March; d=April; e=May. Total monthly precipitation, London; f=March; g=April; h=May.

The forecast models developed in the current study provide a useful basis for the prediction of the main characteristics of the grass pollen season at a relatively early stage in the year. The models have the advantage of an empirical base which, in effect, has monitored the combined biotic response of the various grass species to annual fluctuations in the climate. It would be extremely difficult to build theoretical models of comparable accuracy because of the practical problems of quantifying the intricate relationships between phenology and environment for a mixture of species. If further shifts are detected in climatic variables or the pollen spectrum, the models can be adjusted to accommodate these.

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