

Constructing a 7-day ahead forecast model for grass pollen at north London, United Kingdom

M. Smith and J. Emberlin

National Pollen and Aerobiology Research Unit, University College, Worcester, UK

Summary

Background A number of media outlets now issue medium-range (~ 7 day) weather forecasts on a regular basis. It is therefore logical that aerobiologists should attempt to produce medium-range forecasts for allergenic pollen that cover the same time period as the weather forecasts.

Objective the objective of this study is to construct a medium-range (≤ 7 day) forecast model for grass pollen at north London.

Method the forecast models were produced using regression analysis based on grass pollen and meteorological data from 1990 to 1999 and tested on data from 2000 and 2002. The modelling process was improved by dividing the grass pollen season into three periods; the pre-peak, peak and post-peak periods of grass pollen release. The forecast consisted of five regression models: two simple linear regression models predicting the start and end date of the peak period, and three multiple regression models forecasting daily average grass pollen counts in the pre-peak, peak and post-peak periods.

Results overall, the forecast models achieved 62% accuracy in 2000 and 47% in 2002, reflecting the fact that the 2002 grass pollen season was of a higher magnitude than any of the other seasons included in the analysis.

Conclusion this study has the potential to make a notable contribution to the field of aerobiology. Winter averages of the North Atlantic Oscillation were used to predict certain characteristics of the grass pollen season, which presents an important advance in aerobiological work. The ability to predict allergenic pollen counts for a period between five and seven days will benefit allergy sufferers. Furthermore, medium-range forecasts for allergenic pollen will be of assistance to the medical profession, including allergists planning treatment and physicians scheduling clinical trials.

Keywords aerobiology, forecast models, grass pollen counts, London, North Atlantic Oscillation

Submitted 27 September 2004; revised 3 June 2005; accepted 8 August 2005

Introduction

Aerobiologists have often been engaged in the construction of forecast models for allergenic pollen, either as an aid to allergy sufferers directly, or to assist those working in the medical profession. Historically, forecasters have endeavoured to predict pollen concentrations for the next day or the next few days (short-term forecasts) or the principal characteristics of the main pollen season, such as the start date or severity (long-term forecasts) [1]. A number of different media outlets now issue medium-range (~ 7 day) weather forecasts on a regular basis. Therefore, the next logical step for aerobiologists is the production of a medium-range forecast for allergenic pollen that covers the same time period as the weather forecast.

The main objective of this paper is to construct a medium-range (≤ 7 day) forecast model for grass pollen in north London. This study focuses on grass pollen because it is considered to be one of the most important aeroallergens in Europe [2]. The production of an effective forecast model for

allergenic pollen requires an understanding of the relationship between atmospheric pollen concentrations and the environmental factors that influence them for the duration of the model. This will be achieved by examining correlations between grass pollen counts and a number of environmental (meteorological and pollen) parameters.

Material and methods

Pollen monitoring sites

Daily average grass pollen counts were obtained from two pollen-monitoring sites in north London that operated consecutively from 1990 to 2002 (Fig. 1). Grass pollen data were collected by Burkard volumetric spore trap of the Hirst design [3]. The two sites were: the University of North London, Holloway Road (1990–1994), height of trap 18 m above ground level, and the Environmental and Public Protection offices, Islington (1995–2002), height of trap 15 m above ground level. The sites were approximately 2 km apart. Most of the immediate area around the pollen-monitoring sites lies below 30 m above sea level but this rises gradually to above 110 m at Hampstead Heath in the north and Crystal Palace in the south. The area is described as being

Correspondence: Jean Emberlin, National Pollen and Aerobiology Research Unit, University College, Worcester, UK.

E-mail: j.emberlin@worc.ac.uk

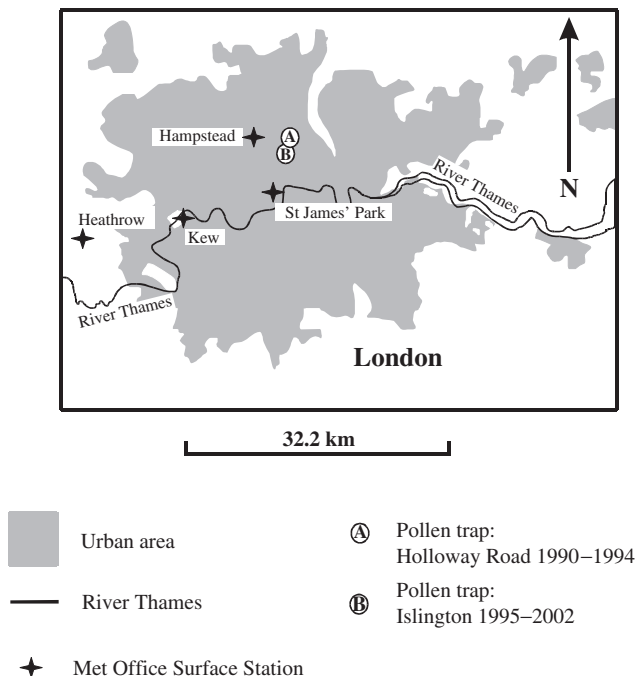


Fig. 1. Pollen-monitoring sites and Met Office Surface Stations used in this study.

approximately 82% urban/suburban, with a mix of residential, commercial, retail and institution uses. A small proportion of the total land area is semi-natural vegetation, including 10% grassland and 1.6% secondary deciduous woodland [4].

Climate

The British Isles has a maritime temperate climate that is influenced throughout the year by low-pressure zones moving in from the Atlantic. The climate is characterized by the following: weather that fluctuates rapidly, related to the passage of fronts and anticyclones; a relatively small annual range of temperature; high rainfall and humidity; and rainfall that is relatively evenly distributed throughout the year, but tends towards a winter maximum [5, 6]. In London, the mean annual temperature (1971–2000 average) is approximately 11 °C, and the mean annual rainfall is about 600 mm [7].

London has an urban climate that has a pronounced effect on airflow patterns, which consequently influences pollen dispersion, transport and deposition. The presence of high buildings and complex surfaces within cities also increases turbulence, thereby causing pollen counts to differ considerably over short distances both vertically and horizontally [8–11]. In addition, cities create a microclimatic change in temperature known as an urban heat island. This thermal increase in the city tends to promote upward movement of air and turbulence, and produces a local circulation created by the temperature difference between cities and the surrounding areas. This heat island circulation has a generating mechanism similar to that of the sea-breeze circulation seen in coastal areas during the warmest months [12, 13]. Furthermore, the urban heat island also influences the phenology of plants within the city, typically resulting in plants flowering earlier in urban areas [6, 11].

Grass pollen data

The methodology used for collecting the grass pollen data followed the standard method of the UK National Pollen Monitoring Network described in the British Aerobiology Federation guide for trapping and counting airborne pollen and spores [14]. The two grass pollen datasets used in this investigation were spliced together to make a single dataset running from 1990 to 2002. Two years (1991 and 2001) were omitted from the study because they contained insufficient data for analysis due to trap failure. The results of a Mann–Whitney *U* non-parametric test showed that there was no significant difference ($P = 0.276$) in the amount of grass pollen recorded annually at the two sites and the datasets could therefore be treated as one population. Normality tests were performed on the grass pollen data using the Explore function in SPSS. Datasets that were not normally distributed were square rooted (normalized) [11, 15].

Defining the limits of the grass pollen season

The limits of the grass pollen season were calculated by using the Threshold 30 method whereby the start and end of the grass pollen season is defined as the first and last days when the pollen count is greater than or equal to 30 grains/m³. The Threshold 30 method is based on the results of several clinical studies that indicate that this is a general concentration at which hayfever patients are likely to experience symptoms [16, 17]. This technique also eliminates the long tails of low values at the start and the end of the seasons that may introduce bias to the results during statistical analysis [2]. Other methods have been proposed for defining start and end dates but most can only predict the start retrospectively, and it was felt that developing a model that could be used as soon as a certain threshold had been passed would have more practical applications.

The division of grass pollen seasons prior to analysis has become an accepted methodology because the relationship between grass pollen counts and environmental data tends to change during the pre-peak and post-peak periods [2, 18, 19]. For example, Toro et al. [19] split the grass pollen season into two and defined the pre-peak period as dating from the beginning of the main pollen season to the peak day itself. For this study, the grass pollen season was split into three (pre-peak, peak and post-peak periods of pollen release) because it was found that pollen counts around the peak day behaved as one population, whereas pollen counts from the pre-peak and post-peak periods could be treated separately.

A number of studies have used arbitrary figures to define different characteristics, usually the start or end, of pollen seasons. For example, the start and end of pollen seasons have been defined using the 90% [1, 20, 21], 95% [19, 22, 23] and 98% [24–26] methods. In this study, an attempt was made to find a figure (percentage of pollen released during the season) that could reliably define the start and end of the peak period of pollen release.

Following the method outlined by Gutiérrez et al. [27] and Iglesias et al. [28] the peak period of pollen release was first determined graphically using a method similar to the one proposed by Pathirane [29]. Cumulative percentages of daily pollen counts were graphically depicted, and the main period

of pollen release lies between the inflections of a sigmoid curve. The aim of determining the peak period in this way was to verify the accuracy of the arbitrary figures chosen in the study [27–29].

Unfortunately, because of the high degree of variation between years, an arbitrary figure for defining the start of the peak period could not be found. However, the method described by Pathirane [29] was able to follow these year-to-year variations, and it was therefore decided to use this method to determine the start of the peak. Conversely, because of the long tail at the end of the grass pollen season, the method described by Pathirane [29] proved rather subjective when it came to judging the end of the peak period; in other words, it was not possible to identify the exact day on which the peak ended. As a result, it was decided to use an arbitrary figure (80% of grass pollen released in the season) to define the end of the peak. This second method allowed for more quantitative analysis.

Grass pollen season statistics

There was a marked decrease in the length and severity of the grass pollen seasons in London from the early 1960s to the early 1970s, with a continued decline through the mid-1980s when the trend levelled off. This decline was explained by a number of factors, including the general reduction in grassland area, the preference of silage over hay production and the change in seed mix of sown pastures to *Lolium perenne* [24].

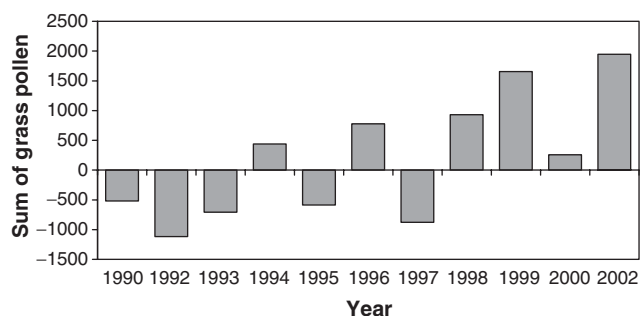


Fig. 2. Sum of grass pollen recorded during the grass pollen season in north London (Threshold 30 method), distributed about the 1990–1999 mean. It should be noted that 10 grass pollen counts were missing from the 1995 season, adding a degree of bias into the analysis.

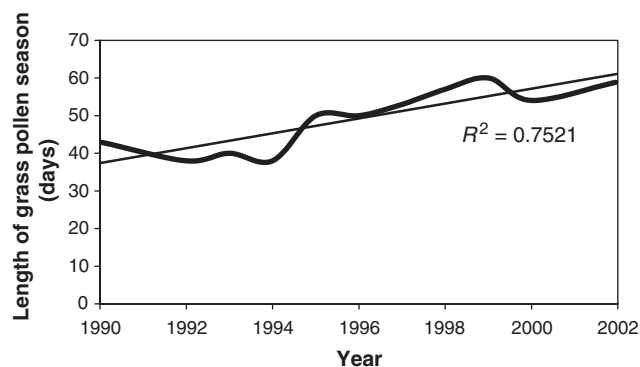


Fig. 3. Grass pollen season length in north London 1990–2002, start and finish of season defined by the Threshold 30 method.

There has been a perceived increase in the severity of the grass pollen season at London in recent years (Fig. 2), but it is not known whether this is a short-term increase or a long-term trend. Figure 2 shows that the sum of grass pollen recorded in 2000 and 2002, the years used to test the models, was higher than the 1990–1999 mean. Furthermore, the 2002 grass pollen season was also of a higher magnitude than any of the other years included in the analysis.

The grass pollen season in north London has increased in length since 1990 (Fig. 3). This may be caused, in part, by the fact that the grass pollen season is starting earlier (Fig. 4) and partly because the season is continuing later into the year (Fig. 5). The end of the peak period of pollen release is also becoming later (Fig. 5).

Forecasting methods

The medium-range forecast model is designed to start on one of the following days (whichever is the earliest): the first day that grass pollen counts are ≥ 30 grains/m³, the day indicated by a forecast model predicting the start of the grass pollen season (Threshold 30 method). Forecast models predicting the start of the grass pollen season have already been produced for the UK [11, 24] and could easily be adapted and used to predict the first day that grass pollen counts are ≥ 30 grains/m³.

The method of forecasting used throughout this investigation has been regression analysis, which is an empirical

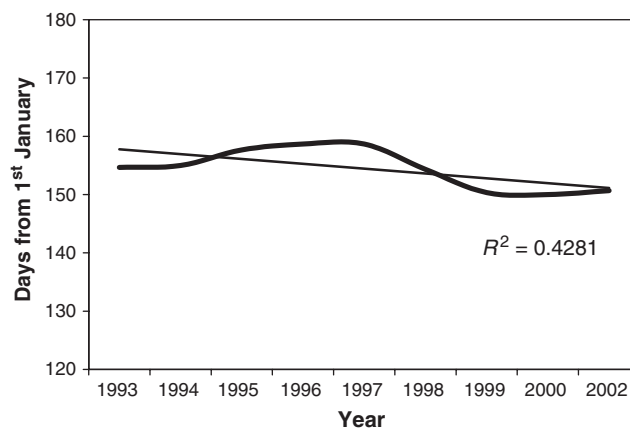


Fig. 4. Three-year-running-means (1990–2002) of start dates of the grass pollen season (determined using the Threshold 30 method) at north London, expressed as number of days from 1 January.

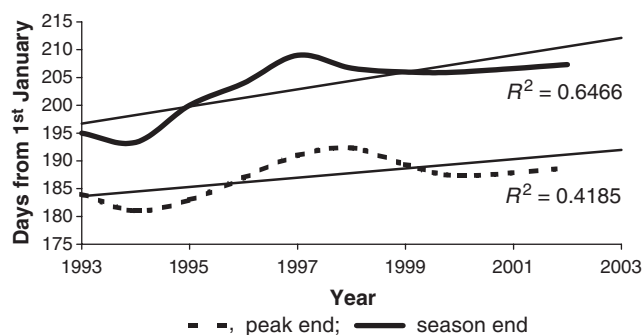


Fig. 5. Three-year-running mean (1990–2002) end dates of the peak and post-peak periods of pollen release (the latter is the end of the grass pollen season) in north London, expressed as the number of days from 1 January.

Table 1. Threshold used by the NPARU when forecasting grass pollen counts

Daily average grass pollen count (grains/m ³)	Threshold	Numerical score
0–29	Low	1
30–49	Moderate	2
50–149	High	3
≥ 150	Very high	4

NPARU, United Kingdom, National Pollen and Aerobiology Research Unit.

technique often used in aerobiological studies. The medium-range forecast was constructed using five regression models. Two simple linear regression models were used to predict the start and end of the peak period of pollen release and three standard multiple regression models to predict daily variations in grass pollen counts during the pre-peak, peak and post-peak periods. The regression models were constructed using data from 1990 to 1999 inclusive and tested using data from the 2000 and 2002 grass pollen seasons.

The multiple regression models predicting daily grass pollen counts were tested using the threshold used by the United Kingdom National Pollen and Aerobiology Research Unit (NPARU) when producing forecasts for daily grass pollen concentrations. These thresholds were given numerical scores on a scale ranging from 1 to 4 (Table 1). The predicted values were squared and then both actual and predicted grass pollen counts were transformed into numerical scores. The number of times that the grass pollen threshold for each day was successfully predicted was used to judge model accuracy.

Independent variables entered into the analysis

The simple linear regression models contained variables from winter and spring (day 1 to day 150 from 1 January) that are known to affect grass pollen production and the timing of grass pollen seasons. These were 10-day mean maximum and minimum temperatures taken from Heathrow and St James' Park and rainfall taken from Hampstead, Heathrow and Kew Royal Botanical Gardens. Also entered into this analysis, and related to winter and spring temperatures and rainfall, were winter averages of the North Atlantic Oscillation (NAO). The NAO is a mode of interannual variability in atmospheric circulation that is associated with changes in the surface westerlies across the North Atlantic and into Europe [30]. The relationship between the NAO and terrestrial ecosystems is well known [31–34] and D'Odorico et al. [34] suggested using phases of the NAO to predict the onset of pollination. The link between temperatures and precipitation and the NAO is particularly evident, in the United Kingdom, during the period starting December or January through to March [30, 34]. Data for the NAO were obtained from the NAO index, calculated from Gibraltar and southwest Iceland (Reykjavik), which is maintained by P. D. Jones at the University of East Anglia [34, 35]. Six variables derived from averages of NAO indices from December, January, February and March were used in this study.

The main objective of this study is to construct a medium-range forecast model for grass pollen for north London. Therefore, only those variables available in medium-range weather forecasts (≤ 7 day) were considered for entry into

the multiple regression models used to predict daily variations in grass pollen counts during the pre-peak, peak and post-peak periods.

The Met Office via the British Atmospheric Data Centre (BADC) supplied the meteorological data used to construct the forecast models. Meteorological data were taken from a number of different sites, situated in and around the city, in order to take into account spatial and temporal differences in the production, release and dispersal of grass pollen (Fig. 1). The variables considered were: maximum daily temperatures recorded at Heathrow and St James' Park; daily rainfall recorded at Hampstead, Heathrow and Kew Royal Botanical Gardens; and midday wind speed and relative humidity recorded at Heathrow. Where practicable, meteorological recordings were taken at midday because this is the time of greatest pollen release [36, 37].

Because of the problems associated with multicollinearity, it was decided not to enter more than one temperature or rainfall variable into the regression models simultaneously. Maximum and minimum daily temperatures are highly correlated and therefore unsuitable to be entered into regression analysis together. Furthermore, Galan et al. [18] found that maximum and average temperatures are the main factors that affect daily concentrations of grass pollen in London, and not minimum temperatures. Therefore, only maximum daily temperatures were entered into the multiple regression models used to forecast daily grass pollen concentrations.

The relationship between daily grass pollen counts and the amount of pollen released during the preceding days was also explored using correlation analysis. This was achieved by entering 2-, 3-, 4-, and 5-day-running mean grass pollen counts into the analysis with daily average grass pollen concentrations.

Results

Table 2 shows the results of correlation analysis between the start and end dates of the peak period of pollen release and the following independent variables:

- 10-day means of meteorological data (maximum and minimum daily temperatures and daily rainfall) from day 1 to day 150 from 1 January.
- Winter averages of the NAO.

Table 2. Significant correlations between start and end dates of the peak period of grass pollen release and meteorological variables

Dependent variable	Independent variable	Significance
Start day of peak period of pollen release	Heathrow minimum temperature days 81–90 from 1 January	– 0.710*
	Heathrow maximum temperature days 101–110 from 1 January	0.669*
	St James' Park maximum temperature days 101–110 from 1 January	0.715*
	North Atlantic Oscillation December–January average	– 0.764*
End day of peak period of pollen release	Heathrow minimum temperature days 141–150 from 1 January	– 0.679*

*Correlation is significant at the 0.05 level (two-tailed).

Table 3. Significant correlations between the daily average normalized grass pollen counts and environmental data, whole season (the Threshold 30 method)

Independent variable	Significance
5-day-running mean grass pollen count	0.346**
4-day-running mean grass pollen count	0.360**
3-day-running mean grass pollen count	0.356**
2-day-running mean grass pollen count	0.334**
Hampstead daily rainfall	−0.289**
Heathrow wind speed at 12:00	−0.188**
Heathrow relative humidity at 12:00	−0.287**
Heathrow daily rainfall	−0.275**
Heathrow maximum daily temperature	0.184**
Kew Botanical Gardens daily rainfall	−0.264**
Kew Botanical Gardens maximum daily temperature	0.251**
St James' Park maximum daily temperature	0.313**

**Correlation is significant at the 0.01 level (two-tailed).

A total of 111 independent variables were entered into the analysis. The results presented in Table 2 are therefore limited to those correlations that were significant ($P \leq 0.05$).

Data were taken from the whole of the grass pollen season as defined by the Threshold 30 method, to examine for significant correlations between daily average grass pollen counts and various environmental variables (Table 3). The datasets were then divided into three periods (pre-peak, peak and post-peak periods of grass pollen release), which were submitted to correlation analysis (Table 4). The results of correlation analysis were used to aid the selection of independent variables for entry into the regression models.

Simple linear regression models forecasting the start and end of peak period

Two simple linear regression models were developed and used to forecast the start and end dates of the peak period of pollen release for the 2000 and 2002 grass pollen seasons in north London (Tables 5 and 7). The predicted start of the peak period was 4 days late in 2000 and 5 days late in 2002, and the predicted end of the peak period was 4 days early in 2000 and 7 days early in 2002.

Multiple regression models predicting daily grass pollen counts for ≤ 7 days

Three multiple regression models, for the pre-peak, peak and post-peak periods of pollen release, were constructed and used to predict daily grass pollen counts throughout the 2000 and 2002 grass pollen seasons in north London (Tables 6 and 7). Model accuracy was judged in two ways: a real-time forecast using the Threshold 30 method to define the beginning and end of the grass pollen season and linear regression models to predict the start and end of the peak period of pollen release, and a retrospective assessment of the model using the Threshold 30 method to define the beginning and the end of the season, the start of peak period of pollen release as described by Pathirane [29] and end of peak calculated using the 80% method. Forecast accuracy was not

Table 4. Significant correlations between daily average normalized grass pollen counts and environmental data during the pre-peak, peak and post-peak periods of pollen release

Period of pollen release	Independent variable	Significance
Pre-peak	Hampstead daily rainfall	−0.288*
	Heathrow relative humidity at 12:00	−0.459**
	Heathrow maximum daily temperature	−0.489**
	Kew Botanical Gardens maximum daily temperature	0.407**
	St James' Park maximum daily temperature	0.736**
Peak	5-day-running mean grass pollen count	0.254**
	4-day-running mean grass pollen count	0.265**
	3-day-running mean grass pollen count	0.244**
	2-day-running mean grass pollen count	0.206**
	Hampstead daily rainfall	−0.367**
	Heathrow relative humidity at 12:00	−0.265**
	Heathrow wind speed at 12:00	−0.270**
	Heathrow daily rainfall	−0.315**
	Heathrow maximum daily temperature	0.276**
	Kew Botanical Gardens daily rainfall	−0.334**
Post-peak	Kew Botanical Gardens daily maximum temperature	0.411**
	St James' Park maximum daily temperature	0.443**
	5-day-running mean grass pollen count	0.350**
	4-day-running mean grass pollen count	0.358**
	3-day-running mean grass pollen count	0.373**
	2-day-running mean grass pollen count	0.375**
	Hampstead daily rainfall	−0.253*
	Heathrow relative humidity at 12:00	−0.299**
	Heathrow wind speed at 12:00	−0.190*
	Heathrow daily rainfall	−0.248**
	Heathrow maximum daily temperature	0.196*
	Kew Botanical Gardens daily rainfall	−0.280**
	Kew Botanical Gardens daily maximum temperature	0.250**
	St James' Park maximum daily temperature	0.424**

*Correlation is significant at the 0.05 level (two-tailed).

**Correlation is significant at the 0.01 level (two-tailed).

Table 5. Results of simple linear regression analysis between start and end dates of the peak period of pollen release and selected meteorological variables

Predicted variable	Regression equation	Adjusted R^2
Day peak starts	$= 170.001 - (1.501 \times \text{Heathrow MinT } 81-90^*)$	0.433
Day peak ends	$= 187.556 - (2.037 \times \text{NAO DJ}^*)$	0.524

*Variable reached significance at the 95% level when included in the model. For an explanation of the abbreviated names of the variables, see Table 7.

affected by timing of the start and the end of the peak period of pollen release; the model achieved 62% accuracy in 2000 and 47% in 2002 in both assessments.

Discussion

In north London, the sum of grass pollen recorded during the 2000 season was slightly higher than the 1990–1999 mean, but the 2002 grass pollen season was of a higher magnitude than

Table 6. The results of multiple regression analysis between normalized daily grass pollen counts during the pre-peak, peak and post-peak periods of pollen release and selected environmental variables

Predicted variable	Regression equation	Adjusted R^2
Daily grass pollen count pre-peak period	$= (0.410 \times \text{St James' Park MaxT}^*) - (0.03346 \times \text{Heathrow RH}) - 1.704$	0.553
Daily grass pollen count peak period	$= (0.250 \times 4\text{DRM}^*) - (1.770 \times \text{Hampstead RF}^*) + (0.348 \times \text{St James' Park MaxT}^*) - 0.883$	0.292
Daily grass pollen count post-peak period	$= (0.351 \times 2\text{DRM}^*) + (0.249 \times \text{St James' Park MaxT}^*) - 2.839$	0.299

*Variable reached significance at the 95% level when included in the model. For an explanation of the abbreviated names of the variables, see Table 7.

Table 7. Full and abbreviated names of variables entered into regression analysis

Abbreviation	Variable
Heathrow MinT 81–90	Heathrow minimum temperature days 81–90 from 1 January
NAO DJ	North Atlantic Oscillation December–January average
St James' Park MaxT	St James' Park maximum daily temperature
Heathrow RH	Heathrow relative humidity
Hampstead RF	Hampstead rainfall
4DRM	4-day running mean grass pollen counts
2DRM	2-day running mean grass pollen counts

any of the other seasons included in the analysis (Fig. 2). This is reflected in the performance of the forecast models.

The linear regression model used 10-day means (or decades-of-days) of meteorological data to forecast certain characteristics of the grass pollen season, which is an accepted technique in aerobiological work [38–42]. A more novel approach, the use of winter averages of the NAO, also proved useful in forecasting the end of the peak period of grass pollen release. In the United Kingdom, the link between temperatures and precipitation and the NAO is particularly evident during the period starting December or January through March [30, 34], which this study has shown can affect the timing of certain characteristics of the grass pollen season.

The predicted start dates of the peak period of grass pollen release were only 4 days late in 2000 and 5 days late in 2002. Predictions for the end of the peak period were 4 days early in 2000 and 7 days early in 2002. Such inaccuracies are probably the result of the grass pollen seasons in north London starting earlier and finishing later. This amount of error did not unduly affect the accuracy of the forecast model as a whole.

There are a number of difficulties associated with producing a forecast model in such a built up urban environment. This study has attempted to overcome these difficulties by considering spatial and temporal variations in grass pollen and meteorological data. This was achieved by entering meteorological data from a number of different sites into the analysis. Emberlin et al. [41] conducted a study of grass pollen counts taken at St Mary's Hospital, Paddington from 1961 to

1990. The authors found that weather data from Heathrow gave significantly more explanation than data from St James' Park. Conversely, the results of this study show that, apart from variables where no alternative was available (relative humidity and wind speed), the best correlations were between grass pollen counts and meteorological data taken from sites nearer to the pollen trap.

The relationship between grass pollen counts and environmental conditions can alter as the season progresses, especially as a result of changing amounts of pollen production. The results of correlation analysis show that the strength of the relationship between the dependent and independent variables often increases when the grass pollen season is divided into three periods. This helps in the modelling process because the forecaster is able to determine when different variables have the most influence on grass pollen counts.

The method used to define the start of the peak period of pollen release, the method outlined by Pathirane [29], is probably the least satisfactory technique used in this study. The main reason for this is that it is too subjective; the start of the peak period is calculated by visually examining daily grass pollen counts and cumulative percentages of grass pollen concentrations plotted over time. It is, however, the most reliable method for determining the start of the peak period of pollen release that has been considered because it was able to follow year-to-year variations. Further work is required to produce a more effective method for determining the start of the peak period.

Conclusion

The main objective of this paper was to construct a medium-range (≤ 7 day) forecast model for grass pollen for north London. The forecast model presented in this paper can, in theory, produce a prediction for each of the days covered in the medium-range weather forecast. This is because it only uses those meteorological variables that are present in weather forecasts of ≤ 7 days. However, the accuracy of the pollen forecast is intimately linked to the accuracy of the weather forecasts [18].

The production of the medium-range forecast was aided by the division of the grass pollen season into three parts. This resulted in a significant increase in the strength of the relationship between daily grass pollen counts and a number of the independent variables included in the analysis.

Dividing the grass pollen season into three periods is a novel approach. However, probably the most original method used in this paper was the use of winter averages of the NAO to predict certain characteristics of the grass pollen season. The relationship between grass pollen counts and the NAO has been examined [34] but there is room for further research in this area.

This study has the potential to make a notable contribution to the field of aerobiology. The ability to predict allergenic pollen counts for a period between 5 and 7 days will benefit allergy sufferers, especially those planning activities in advance. Furthermore, medium-range forecasts for allergenic pollen will be of assistance to the medical profession,

including allergists planning treatment and physicians scheduling clinical trials.

Acknowledgements

This work was partially supported by Andrew Kress, Surveillance Data Incorporated, Plymouth Meeting, Pennsylvania, USA. The authors wish to thank the BADC for providing access to the Met Office Land Surface Observation Stations Data. We also thank the Met Office, who supplied the initial data via the BADC.

References

- Larsson KA. Prediction of the pollen season with a cumulated activity method. *Grana* 1993; 32:111–4.
- Sanchez Mesa JA, Smith M, Emberlin J, Allitt U, Caulton E. Characteristics of grass pollen seasons in areas of southern Spain and the United Kingdom. *Aerobiologia* 2003; 19:243–50.
- Hirst JM. An automatic volumetric spore trap. *Ann Appl Biol* 1952; 39:257–65.
- EA, Environment Agency. Thames Tideway (Teddington to Tower Bridge) local environment agency plan: action plan 1999.
- BBC, BBC Weather Centre. British Weather, part one. 2001. <http://www.bbc.co.uk/weather/features/britain1.shtml>
- Goudie A. The nature of the environment, 3rd edn. New York: Blackwell, 1996.
- METO, Met Office. 1971–2000 Averages. 2004. <http://www.meto.gov.uk/climate/uk/averages/index.html>
- Emberlin J, Norris-Hill J. Spatial variation of pollen deposition in North London. *Grana* 1991; 30:190–5.
- Goudie A. The human impact on the natural environment. New York: Blackwell, 1994.
- Emberlin J. *Aerobiology*. In: Busse WW, Holgate ST., eds. Asthma and rhinitis. New York: Blackwell Science, 2000.
- Jones S. Allergenic pollen concentrations in the United Kingdom. PhD Thesis, University of North London, 1995.
- Ohashi Y, Kida H. Local circulations in the vicinity of both coastal and inland urban areas: a numerical study with a mesoscale atmospheric model. *J Appl Meteor* 2002; 41:30–45.
- Gassman MI, Perez CF, Gardiol JM. Sea-land breeze in a coastal city and its effect on pollen transport. *Int J Biometeorol* 2002; 46:118–25.
- BAF, The British Aerobiology Federation., Airborne pollens and spores: A guide to trapping and counting. 1995. ISBN 0-9525617-0-0.
- Pallant J. SPSS survival manual. Open University Press, 2001.
- Davies RR, Smith LP. Forecasting the start and severity of the hay fever season. *Clin Allergy* 1973; 3:263–7.
- Antépara I, Fernández JC, Gamboa P, Jauregui I, Miguel F. Pollen allergy in the Bilbao area (European Atlantic seaboard climate): pollination forecasting methods. *Clin Exp Allergy* 1995; 25:133–40.
- Galan C, Emberlin J, Dominguez E, Bryant R, Villamandos F. A comparative analysis of daily variations in the Gramineae pollen counts at Cordoba, Spain and London, UK. *Grana* 1995; 34: 189–98.
- Toro FJ, Recio M, Trigo M, Cabezudo B. Predictive models in aerobiology: data transformation. *Aerobiologia* 1998; 14:179–84.
- Nilsson S, Persson S. Tree pollen spectra in the Stockholm region (Sweden), 1973–1980. *Grana* 1981; 20:179–82.
- Dahl A, Strandhede SO. Predicting the intensity of the birch pollen season. *Aerobiologia* 1996; 12:97–106.
- Goldberg C, Buch H, Moseholm L, Weeke EV. Airborne pollen records in Denmark, 1977–1986. *Grana* 1988; 27:209–17.
- Andersen TB. A model to predict the beginning of the pollen season. *Grana* 1991; 30:269–75.
- Emberlin J, Savage M, Jones S. Annual variations in grass pollen seasons in London 1961–1990: trends and forecast models. *Clin Exp Allergy* 1993; 23:911–8.
- Emberlin J, Savage M, Woodman R. Annual variations in *Betula* pollen seasons in London 1961–1990. *Grana* 1993; 32:359–63.
- Emberlin J, Jones S, Bailey J et al. Variation in the start of the grass pollen season at selected sites in the United Kingdom, 1987–1992. *Grana* 1994; 33:94–9.
- Gutiérrez AM, Saenz C, Cervigón P et al. Comparative study of the presence of aeropollen from *Plantago* sp. at several locations in Spain. *Pollen* 1999; 10:111–22.
- Iglesias I, Jato V, Aira MJ et al. Annual variations of *Castanea* airborne pollen at thirteen Spanish sites. *Pollen* 1999; 10:49–56.
- Pathirane L. Graphical determination of the main pollen season. *Poll Spores* 1975; 17:609–10.
- Hurrell JW. Decadal trends in the North Atlantic Oscillation: regional temperatures and precipitation. *Science* 1995; 269:676–9.
- Walther G-R, Post E, Convey P et al. Ecological responses to recent climate change. *Nature* 2002; 416:389–95.
- Stenseth NC, Mysterud A, Ottersen G, Hurrell JW, Chan K-S, Lima M. Ecological effects of climate fluctuations. *Science* 2002; 297:1292–6.
- Ottersen G, Planque B, Belgrano A, Post E, Reid PC, Stenseth NC. Ecological effects of the North Atlantic Oscillation. *Oecologia* 2001; 128:1–14.
- D'Odorico P, Yoo J, Jaeger S. Changing seasons: an effect of the North Atlantic Oscillation? *J Climate* 2002; 15:435–45.
- Osborn T. Climatic Research Unit. North Atlantic Oscillation. 2002. http://www.cru.uea.ac.uk/~timo/projpages/nao_update.htm
- Bringfelt B, Engstrom I, Nilsson S. An evaluation of some models to predict airborne pollen concentration from meteorological conditions in Stockholm, Sweden. *Grana* 1982; 21:59–64.
- Norris-Hill J, Emberlin J. Diurnal variation of pollen concentration in the air of north-central London. *Grana* 1991; 30:229–34.
- Spieksma FTM, Emberlin JC, Hjelmroos M, Jäger S, Leuschner RM. Atmospheric birch (*Betula*) pollen in Europe: trends and fluctuations in annual quantities and the starting dates of the seasons. *Grana* 1995; 34:51–7.
- Recio M, Cabezudo B, Trigo M, Toro FJ. Pollen calendar of Malaga (Southern Spain), 1991–1995. *Aerobiologia* 1998; 14:101–7.
- Spieksma FT, Nikkels AH. Airborne grass pollen in Leiden, the Netherlands: annual variations and trends in quantities and season starts over 26 years. *Aerobiologia* 1998; 14:347–58.
- Emberlin J, Mullins J, Cordon J et al. Regional variations in grass pollen seasons in the UK, long term trends and forecast models. *Clin Exp Allergy* 1999; 29:347–56.
- Adams-Groom B, Emberlin J, Corden JM, Millington W, Mullins J. Predicting the start of the *Betula* pollen season at London, Derby and Cardiff, United Kingdom, using a multiple regression model, based on data from 1987 to 1997. *Aerobiologia* 2002; 18:117–23.

ERRATUM

Constructing a 7-day ahead forecast model for grass pollen at north London, United Kingdom

M. Smith and J. Emberlin

In [1], on page 1404, there is an error in Table 4: the correlation coefficient between Heathrow maximum temperature and grass pollen counts in the pre-peak period (3rd line down) should read “0.489**” and not “–0.489**”

Reference

- 1 Smith M, Emberlin J. Constructing a 7-day ahead forecast model for grass pollen at north London, United Kingdom. *Clin Exp Allergy* 2005; 35:1400–6.