

Forecasting the Poaceae pollen season in eastern Poland

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Abstract

The aim of the present study was to develop forecast models for the grass pollen season by using regression analyses to predict such characteristics as onset, duration and peak pollen concentration (values and timing). The study shows a negative correlation between seasonal pollen index (SPI) and season duration as well as strong correlations between some features of the pollen season and meteorological data. The forecasting models may predict 86–98% of the variation in pollen onset and duration of the pollen season. Less satisfactory results were obtained for the peak date and peak value. The best prediction was obtained for the season duration. The mean minimum temperature of March and cloud cover in the first 10-day period of May were the best variables for forecasting the start of the grass pollen season in Lublin. The rainfall in May was the most important factor to determine season duration. When the developed models are applied for pollen season forecasting, it is possible to predict the season onset and duration with an accuracy of up to one or two days.

Keywords: *aerobiology, grass pollen, meteorological factors, forecast models, regression analysis, Poland*

Grasses (family Poaceae) are widespread across the globe with grassy habitats accounting for 24% of the Earth's vegetation cover (Falkowski, 1982). Among the 11 000 species occurring in different climatic zones, about 160 are known from Poland (Szweykowska & Szweykowski, 2003). Grass pollen is the main cause of pollinosis in Poland as well as in Europe as a whole (Weeke & Spiekma, 1991; Sánchez-Mesa et al., 2003). According to d'Amato et al. (2007), more than 80% of allergy sufferers are allergic to grass pollen. The list of allergenic grasses may differ for different regions and is primarily dependent on species distribution and density in the particular area. However, high cross-reactivity has been found between allergens of different grass species (Ong et al., 1995; Knox & Suphioglu, 1996). The most important allergenic species found in the temperate climate belong to the subfamily Pooideae: *Phleum pratense* L., *Dactylis glomerata* L., *Festuca elatior* L., *Lolium perenne* L., *Poa pratensis* L. (Ong et al., 1995).

In Poland, 10–15% of the population suffers from pollinosis, whereof more than 90% suffer from grass

pollen allergies (Obtułowicz et al., 1991; Szczeklik et al., 1991; Jurkiewicz, 1999). Grass pollen monitoring is, therefore, important and conducted in many regions in Poland. Depending on the region, large differences are observed in the dates of first appearance of grass pollen grains in the air as well as in pollen season duration and concentrations recorded (Chłopek, 2007; Kasprzyk & Walanus, 2010; Myszkowska, 2010; Puc, 2011). This has a significant influence on the period of occurrence and severity of disease symptoms in people allergic to the grass pollen. The grass pollen season lasts long as compared to other taxa. It results from the varied flowering times of numerous species belonging to family Poaceae. The longest seasons are in the southern part of Europe (six months), while the shortest ones occur in the northern part (two months; Weeke & Spiekma, 1991). Due to its allergenic potential, predicting of grass pollen occurrence in the air is very important.

The aim of this study was to analyse the characteristics of the grass pollen seasons in Lublin and their correlation with meteorological factors and to

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develop forecast models for the prediction of onset, duration, peak value and peak date of the grass pollen season.

Material and methods

Study area

Grass pollen monitoring was carried out in Lublin, the largest city in eastern Poland with a population of around 350 000. The climate of the study area is temperate and characterised by high variability in climatic parameters between years (Kaszewski, 2008).

The growing season in Lublin lasts 215 days (Woś, 1999). Mean annual air temperature is 8.2 °C (1951–2010), the coldest month of the year is January (mean temperature –2.8 °C), while the warmest month is July (mean temperature 19.0 °C). Mean annual total precipitation amounts up to 551 mm. Maximum rainfall is recorded in July with 79 mm, minimum precipitation in January with 28 mm (Piotrowska & Kaszewski, 2011). Grasses appear in parks, gardens and lawns in the vicinity of the pollen monitoring site. Large areas covered by grasses growing wild, contributing considerable amount of pollen, occur c. 3 km away from the monitoring site, but still belong to Lublin. Many of the grass species identified in the Lublin Upland, such as *Agropyron repens* (L.) Beauv., *Agrostis alba* L., *Dactylis glomerata*, *Deschampsia caespitosa* (L.) P.B., *Holcus lanatus* L., *Festuca rubra* L., *Lolium perenne*, *Poa annua* L. and *P. pratensis*, are common (Falkowski, 1982).

Pollen monitoring

Pollen monitoring was carried out with the volumetric method using a Hirst-type sampler (Lanzoni VPPS 2000). The sampling site was located near the city centre (51° 14' 37" N, 22° 32' 25" E; 197 m above sea level). The pollen trap was placed on the roof of a building of the Lublin University of Life Sciences 18 m above ground level. Pollen grains were identified and counted along four longitudinal transects. Microscopic analysis of the slides was performed following the recommendations of the International Association for Aerobiology (Mandrioli et al., 1998).

Mean daily pollen counts were expressed as number of pollen grains/m³. The 98% method was used to determine the start and end of the pollen season. The start of the season was defined as the date when 1% of the seasonal cumulative pollen count was trapped, while the end of the season when the seasonal cumulative pollen count reached 99% (Emberlin et al., 1994; Spieksma & Nikkels, 1998).

Meteorological data

The meteorological data was retrieved from the Meteorological Observatory of the Meteorology and Climatology Department, Marie Curie-Skłodowska University in Lublin (51° 14' 55" N, 22° 33' 37" E; 194 m above sea level). The observatory is located about 1.5 km from the pollen sampling site. The following data were used for the analysis: mean, minimum and maximum air temperatures, relative air humidity, rainfall, cloud cover, wind speed. The average monthly meteorological data (March–May) and mean weather conditions during the pollen season were analysed.

Statistical analysis

The classical statistical parameters [arithmetic mean, minimum and maximum values, standard deviation (SD) and coefficient of variation (V%)] were used to characterise the features of the grass pollen season. Spearman's rank correlations were calculated among season parameters as well as between season parameters and meteorological data. The certain relationships (e.g. the dependence of second degree – when the changes of two features can be described by parabolic function) could exist despite the low correlation values (Ferguson & Takane, 1989). Therefore, the non-linear or the multivariate regression analyses include some of the variables for which the Spearman's correlation was not statistically significant.

The aim of the study was to fit the shape of the curve to the experimental data and the degree of fitting was determined by R^2 . The regression models were constructed using linear and non-linear function of one variable (polynomial formula of the two and three degrees) as well as the multivariate linear regression. The models were constructed based on the results obtained from the years 2001–2010 and were tested with the data of 2011. All statistical calculations were performed with the STATISTICA and SPSS software packages.

Results

Pollen season

During the period of investigation, the grass pollen season started in Lublin on average on 17 May (Table I). The difference between the earliest and latest date was 17 days. The earliest onset of the pollen season was in 2001 (9 May), the year in which the highest total rainfall was recorded in the months preceding the pollen season (March and April), whereas temperatures (minimum and maximum) during that time, prior to the pollen season 2001, were slightly

Table I. Characteristics of the grass pollen season in Lublin (2001–2010 and 2011).

Statistics	Pollen season			Peak		SPI (pollen grains)
	Start	End	Duration (days)	Value (P/m ³)	Date	
Mean	17.05.	3.09.	110	459	2.07.	6599
Minimum	9.05.	22.08.	92	276	21.06.	5177
Maximum	26.05.	12.09.	122	643	9.07.	8146
SD	5.8	6.7	8.3	122.5	5.9	962.6
<i>V</i> (%)	4.2	2.7	7.6	26.7	3.2	14.6
2011	17.05.	12.09.	119	234	8.07.	4226

higher than the 10-year mean. The latest onset date was recorded for 2005 (26 May) and was preceded by low minimum temperature and low precipitation in March and April.

On average, the grass pollen season ended in the beginning of September. The lowest coefficient of variation was observed for this season parameter (Table I). The earliest end date for the season was recorded in 2010 (22 August), which was one of the warmest years of the study period and the year with highest mean temperature during the pollen season, while the latest end date was in 2004 (12 September), which was the coldest year with the lowest average temperature during the pollen season. Season duration varied between years with a difference of up to 30 days, the shortest season being observed in 2010 (92 days) and the longest in 2002 (122 days). The coefficient of variation was almost twice as high as for the onset date of the season (Table I). The shortest season was characterised by highest temperatures, relatively low rainfall and high air humidity. The longest season was also characterised by high temperatures, but rainfall was higher during this period.

The seasonal maximum pollen counts were noted between 21 June (2007) and 9 July (2004), the difference between the peak dates was 18 days. During this period, the mean temperature was 18.2–26.0 °C. Maximum daily grass pollen concentration showed the highest variation of all season parameters (Table I). Two peaks usually occurred during the grass pollen season in Lublin, the first occurring some time by the end of May to mid-June and the second with much higher concentrations, from end of June to mid-July. Several peaks were noted in 2002 and 2007 in connection with high rainfall, but there was no distinct maximum peak. The seasonal pollen index (SPI) was the lowest in the coldest pollen season (2004) and the highest in the warmest pollen season (2010).

The Spearman's rank order correlation showed a statistically significant correlation between selected

season parameters. Thus, the peak concentration value and the SPI value were higher when the season ended earlier. The value of SPI was also higher when the season was shorter (Table II).

Regression analysis

To verify consistency of variation between season parameters and meteorological conditions, Spearman's correlation coefficients were calculated (Table III). The linear and non-linear correlation was examined using regression analysis, where the degree of fit is determined by R^2 . In some cases, when the correlation between the variables was non-linear or was described by a multivariate model, the correlation coefficient was statistically insignificant. The best-fitting regression models were chosen based on the value of R^2 . The best prediction of the onset of the grass pollen season (adjusted $R^2 = 0.91$) was obtained in the model in which two variables were used: mean minimum temperature in March ($T_{\min \text{ III}}$) and mean relative humidity in May (H_V). The predicted and observed season onset in 2011 was on the same day. Nevertheless, the model that includes data from the previous period will be more useful for predictions. To verify the model, meteorological data from the first ten-day period were additionally used (Table IV). When these two variables (mean minimum temperature in March and cloud cover in the first ten-day period of May) were incorporated, the obtained model was very well fitted to the data and it explained over 85% of total variation (adjusted $R^2 = 0.857$). The mean difference between the value observed in the years 2001–2010 and the value calculated according to the model was 1.3 days. Testing the model in 2011 gave very good results with a difference of only a single day (Figure 1A).

The regression analysis showed that the duration of the grass pollen season was most dependent on rainfall in May (R_V ; Table IV). A percentage of explained variance by linear function of this single factor was at a level of almost 80%. The difference between the value observed in 2011 and the predicted value was three days. After two more variables [i.e. mean relative humidity in April (H_{IV}) and mean minimum temperature in May ($T_{\min V}$)] were added,

Table II. Significant Spearman's correlations between the parameters of the grass pollen season in Lublin (2001–2010).

Parameters of pollen season	Spearman coefficient
SPI and end of season	−0.8207**
Peak value and end of season	−0.5228*
Duration and SPI	−0.6359*

Note: Level of significance *0.05, **0.01.

Table III. Significant Spearman's correlations between the parameters of the grass pollen season and meteorological factors.

Season parameter	Meteorological data	Spearman's coefficient
Start of season	No significant correlation	
Duration of season	Sum daily rainfall in May	-0.871**
Peak date	Mean daily average temperature in season	-0.640*
	Mean daily maximum temperature in season	-0.683*
	Mean daily humidity in March	0.739*
	Mean daily cloud cover in March	0.757*
	Sum daily rainfall in April	0.757*
	Mean daily maximum temperature in May	-0.640*
Peak value	Mean daily humidity in April	0.636*
SPI	No significant correlation	

Note: Level of significance *0.05, **0.01.

Table IV. Results of regression analyses between parameters of the grass pollen season and meteorological conditions in Lublin.

Season parameters	Regression equation	Regression method	R ²	Observed minus obtained +/-
Start	$= 94.514 - 1.987 \times T_{\min \text{ III}} + 0.635 \times H_V$	m.r.	0.930	2/2
	$= 122.5997 + 2.368 \times C_{\text{IV}} - 1.646 \times T_{\min \text{ III}}$	m.r.	0.889	5/2
Duration	$= 152.554 - 0.247 \times R_V - 0.628 \times H_{\text{IV}} + 1.3 \times T_{\min \text{ V}}$	m.r.	0.986	2/2
	$= 121.004 - 0.128 \times R_V$	u.r.	0.794	5/7
	$= 133.949 - 0.851 \times R_V + 0.01 \times R_V^2$	n.r.	0.817	5/5
Peak date	$= 124.456 + 0.173 \times R_{\text{IV}} + 0.71 \times H_{\text{III}}$	m.r.	0.812	5/5
	$= -1209.957 + 36.071 \times H_{\text{III}} - 0.232 \times H_{\text{III}}^2$	n.r.	0.738	8/5
	$= 771.719 + 18.575 \times H_{\text{III}} - 0.001 \times H_{\text{III}}^3$	n.r.	0.741	6/5
Peak value	$= 3778.809 - 1453.691 \times T_{\min \text{ IV}} + 153.816 \times T_{\min \text{ IV}}^2$	n.r.	0.661	123/95
	$= 2606.125 - 709.637 \times T_{\min \text{ IV}} + 10.4 \times T_{\min \text{ IV}}^3$	n.r.	0.646	120/98

Note: $T_{\min \text{ III}}$, mean minimum temperature in March; H_V , mean relative humidity in May; C_{IV} , cloud cover in the first ten-day period of May; R_V , rainfall in May; H_{IV} , mean relative humidity in April; $T_{\min \text{ V}}$, mean minimum temperature in May; R_{IV} , rainfall in April; H_{III} , mean relative humidity in March; $T_{\min \text{ IV}}$, mean minimum temperature in April; u.r., univariate regression; m.r., multivariate regression; n.r., non-linear regression.

a very good fit was obtained (adjusted $R^2 = 0.979$; Figure 1B). Non-linear estimation that took into account rainfall in May (R_V) also produced good results. The predicted season duration differed from the actual duration observed in 2011 by two days in the case of both multiple regression and non-linear regression.

The model used to predict the date of occurrence of maximum daily grass pollen concentration includes two variables: rainfall in April (R_{IV}) and mean relative humidity in March (H_{III}). An adjusted R^2 of 0.76 was obtained for the earlier-mentioned formula (Table IV). The difference between the observed and predicted dates in 2011 was eight days (Figure 1C).

Discussion

The occurrence of pollen in the atmosphere is correlated with meteorological factors, predicting the timing of pollen seasons and pollen concentrations

is, therefore, usually based on meteorological data. Accurate prediction of the onset, duration and intensity of pollen seasons has become increasingly important with the rapid increase in pollen allergy incidence recorded in recent years. Forecasting the occurrence of airborne allergenic pollen facilitates planning for those with allergic problems and for the medical section (Myszkowska et al., 2006).

Regression analysis is a recognised method applied in aerobiology to predict certain characteristics of pollen seasons based on meteorological data (Spieksma & Nikkels, 1998; Smith & Emberlin, 2006; Stach et al., 2008; Kasprzyk & Walanus, 2010). The regression models derived in this study predict the onset and duration of the grass pollen season with great accuracy. Satisfactory results were also obtained in predicting the date of the maximum pollen concentration. Several models were created for specific season parameters and can now be used for pollen season forecasting (Table IV). In addition to the models with the best fit, the present paper

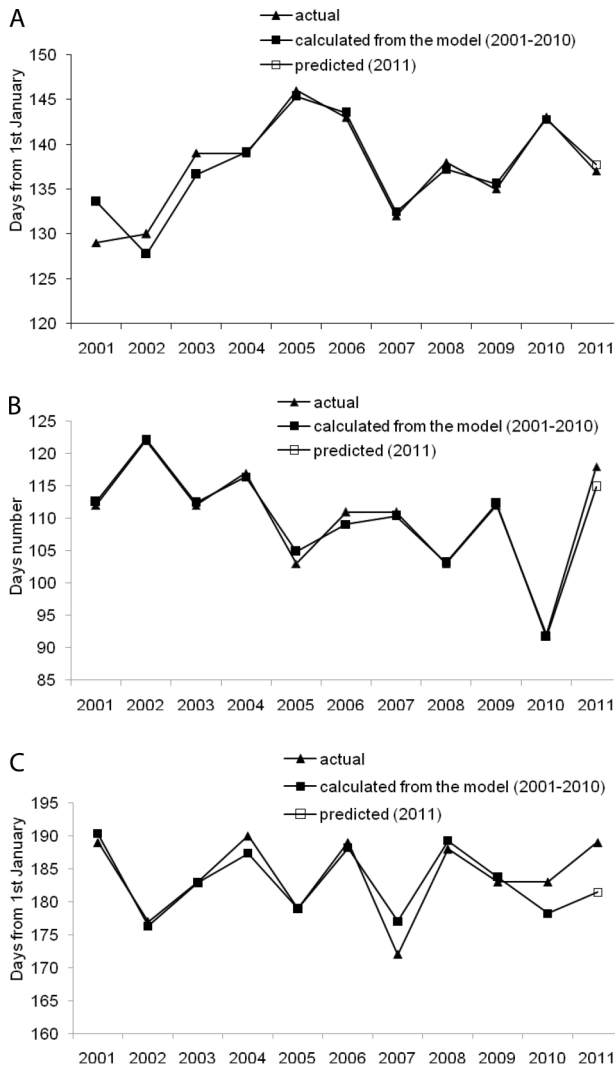


Figure 1. Visualisation of the statistical results from the developed models from Lublin, Poland. **A.** The start dates of the grass pollen season; actual versus regression model (start = $122.5997 + 2.368 \times C_{IV} - 1.646 \times T_{min III}$), calculated values and predicted value in 2011. **B.** The duration of the grass pollen season; actual versus regression model (duration = $152.554 - 0.247 \times R_V - 0.628 \times H_{IV} + 1.3 \times T_{min V}$), calculated values and predicted value in 2011. **C.** The peak date of the grass pollen season; actual versus regression model (peak date = $124.456 + 0.173 \times R_{IV} + 0.71 \times H_{III}$), calculated values and predicted value in 2011.

also includes models that explain to a lesser degree the variation in individual season parameters, but include single meteorological factors.

Large differences in the grass pollen seasons are recorded from year to year at the same sampling site and it is, therefore, very important to accurately predict the development of pollen seasons. The difference in season starting date can, for example, be 35–37 days between years (Ong et al., 1997; Spielsma & Nikkels, 1998). The onset of the grass pollen season depends primarily on temperature

(Clot, 1998; Piotrowska, 2006). In the present study, two models using multiple regression were derived for the onset of the season. These models include the following independent variables: mean temperature in March, mean relative humidity in May and cloud cover in the first ten-day period of May. Both models are very well fitted to distribution of pollen season onset. In predicting the start date of the pollen season in Poznań (western central Poland), Stach et al. (2008) created regression models that produced good results when mean daily temperature in May and mean daily rainfall in March were included in the models. The temperatures of the second and third ten-day periods of April in Rzeszów (southeastern Poland) were the best variables for forecasting the onset of the grass pollen season (Kasprzyk & Walanus, 2010). Rainfall has a negative effect on daily airborne pollen concentrations. It is well known that rain removes pollen grains from the atmosphere (Rodríguez-Rajo et al., 2003; Kasprzyk & Walanus, 2010; Puc, 2011). However, in the months preceding pollen release, rainfall deficiency has an adverse impact on pollen production during plant growth and flower maturation. In Lublin, in the year in which rainfall was intense during the months prior to pollen release, the grass pollen season started earlier, whereas the latest onset of the pollen season was preceded by low rainfall. A study in Hungary revealed that the onset of the grass pollen season is more dependent on rainfall than on temperature. A 20-day delay in pollen shed was observed due to a lack of moisture in the soil (Fehér & Járαι-Komlódi, 1997). A completely reverse effect of humidity was noted in England, where in wetter years, grass pollen release was delayed by 17–31 days (Emberlin et al., 1994).

In the years 2001–2005, the grass pollen season lasted 3–5 months according to different research centres in Poland (Weryszko-Chmielewska, 2006). On the basis of the results of the present ten-year study it could be shown that the grass pollen season in Lublin lasts on average 110 days. Prediction of the length of the season gave the best results fusing regression models derived. The inclusion of three variables (rainfall in May, relative humidity in April and minimum temperature in May) allows the model to explain about 98% of the dependent variable total variance.

Considerable differences for peak values were recorded in Lublin for the 2001–2010 period in the same way as for the SPI. Compared to data from other cities in Poland, the grass pollen concentrations in Lublin are very high. A comparison of data from eight research centres in Poland shows that during the period 2001–2005 the highest maximum pollen concentrations (on average

444 grains/m³) and annual grass pollen counts (on average 6632 grains/m³) were recorded in Lublin. In different cities of Poland, the peak concentrations occurred during the period from early June to mid-July (Weryszko-Chmielewska, 2006). The regression model for the peak date in Lublin is well fitted to the data for the period 2001–2010; the difference between the observed and predicted values was on average two (multiple regression) or three days (non-linear regression). The results of model testing in 2011 were much worse, probably due to exceptionally high rainfall in 2011.

Estimation of the peak value was more problematic. A satisfactory value of R^2 for the variation in this parameter was obtained only when the model used non-linear estimation. However, the prediction exercise in 2011 did not yield the expected result; hence, the model is supposed to be verified in the subsequent years of this study. Minimum temperature in April proved to be most useful in forecasting maximum grass pollen concentrations in the conditions of Lublin. However, in Poznań, mean temperature in May was determined to be the most important factor for the peak value (Stach et al., 2008). The airborne pollen concentration is dependent primarily on temperature and rainfall (Emberlin et al., 1999; Sánchez-Mesa et al., 2003; Chłopek, 2007). However, the inclusion of rainfall in the model, along with the temperature, did not give the expected outcome. Despite the fact that the prediction of the maximum concentration in Lublin in 2011 did not produce a satisfactory result, the regression model was not rejected, but it will be further applied and verified. Extreme high rainfall in July (137.4 mm) was a highly likely cause of this large difference between the observed and predicted values in Lublin in 2011. The rainfall level was almost twice as high as the long-term mean for this period (79 mm). Due to this, the pattern of the grass pollen season was different from previous years. One distinct peak is generally observed during the pollen season in Lublin, whereas in 2011, there were four peak days with a concentration of c. 200 grains/m³. If the pollen concentration values for these four days were added up, the prediction would give a satisfactory result. Based on the regression equation derived for the year 2011, the highest maximum concentration was predicted in comparison with the other years of study. In most cities of Poland, the grass pollen season in 2011 was characterised by exceptionally high pollen concentrations which were recorded already at the beginning of June (Rapiejko et al., 2011).

The analysis would be stronger if two years for validation had been used. However, due to short data series, all the available study years were included to obtain a better fit to the regression models and the

models validated based on the data from only a single year (2011). The predictive models presented in this paper will be tested and improved in the next years of research.

Conclusion

Maximum pollen concentration is the parameter of the grass pollen season, which showed the greatest variation. The shortest pollen season was associated with high temperatures during grass pollen shed. A negative correlation was found between SPI and season duration as well as between peak value, SPI and season end date. The regression analysis showed that minimum temperature, rainfall and relative humidity are important factors controlling the occurrence of grass pollen in the air of Lublin. The obtained forecasting models may predict 86–98% of the variation in pollen season start date and duration. Less satisfactory results were obtained for the peak date and peak value. The best fit was obtained for the season duration. The mean minimum temperature of March and cloud cover in the first ten-day period of May were the most useful variables for forecasting the start of the grass pollen season in Lublin. The rainfall in May was the most important factor to determine season duration. When the developed models are applied for pollen season forecasting, we can predict the season start date and duration with an accuracy of up to 1–2 days. Results would be stronger if the models had been tested using data from two or more years.

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