ORIGINAL ARTICLE

Annals of Agricultural and Environmental Medicine 2014, Vol 21, No 4, 681–688
www.aaem.pl

Pollen grains as allergenic environmental factors – new approach to the forecasting of the pollen concentration during the season

Dorota Myszkowska[1], Renata Majewska[2]

[1] *Department of Clinical and Environmental Allergology, Jagiellonian University Medical College, Cracow, Poland*
[2] *Chair of Epidemiology and Preventive Medicine, Jagiellonian University Medical College, Cracow, Poland*

Myszkowska D, Majewska R. Pollen grains as allergenic environmental factors – new approach to the forecasting of the pollen concentration during the season. Ann Agric Environ Med. 2014; 21(4): 681–688. doi: 10.5604/12321966.1129914

Abstract

Introduction and objectives. It is important to monitor the threat of allergenic pollen during the whole season, because of practical application in allergic rhinitis treatment, especially in the specific allergen immunotherapy. The aim of the study was to propose the forecast models predicting the pollen occurrence in the defined pollen concentration categories related to the patient exposure and symptom intensity.

Material and methods. The study was performed in Cracow (southern Poland), pollen data were collected using the volumetric method in 1991–2012. For all independent variables (meteorological elements) and the daily pollen concentrations the running mean for periods: 2-, 3-, 4-, 5-, 6- and 7 days before the predicted day were calculated. The multinomial logistic regression was used to find the relation between the probability of the pollen concentration occurrence in the selected categories and meteorological elements and pollen concentration in days preceding the predicted daily concentration. The models were constructed for each taxon using data in 1991–2011 (without 1992 and 1996 due to missing data in these years) and 1998–2011 pollen seasons.

Results. The days classified among the lowest category (0–10 PG/m^3) (pollen grains/m^3 of air) dominated for all the studied taxa. The percentage of the obtained predictions of the pollen occurrence fluctuated between 35–78% which is a sufficient value of model predictions. Considering the studied taxon, the best model accuracy was obtained for models forecasting *Betula* pollen concentration (both data series), and Poaceae (both data series).

Conclusions. The application of the recommended threshold values during the predictive models construction seems to be really useful to estimate the real threat of allergen exposure. It was indicated that the polynomial logistic regression models could be a practical tool for effective forecasting in biological monitoring of pollen exposure.

Key words

allergenic pollen, forecast models, multinomial logistic regression analysis, daily pollen concentration

INTRODUCTION

Pollen is one of the natural bioaerosol elements, threatening to the sensitive individuals. The increase in pollen allergy (allergic rhinitis, AR) observed from the 30ties of the 20th century, is associated with the natural allergen exposure [1]. It is assumed that the grass pollen (Poaceae) is the strongest pollen allergen in central and Eastern Europe, followed by tree allergens, especially birch allergens [2]. In Poland, plant pollen is the second source of inhalant allergens following house dust mites. According to the multicenter study ECAP (*Epidemiology of Allergic Diseases in Poland*) performed in 2006–2008, allergic rhinitis was confirmed on the basis of the allergological diagnostics in 28.3% of patients (both children and adults) [3]. The study performed in Cracow pointed out, that more than 80% of patients suffering from allergic rhinitis is sensitive to grass pollen [4].

The indication of the relationship between the pollen concentration in the air and the level of allergic rhinitis symptoms, and the demonstration of the seasonal variability of pollen concentration allow to monitor and estimate the pollen allergy treatment [5]. The practical application of pollen monitoring is of a great importance in specific allergen immunotherapy to avoid the accumulation of the natural allergen exposure and applied allergen doses as it is recommended in a statement of the World Allergy Organization (WAO) [6]. The authors of this statement stressed that allergen exposure should be monitored during any SIT (*Specific Immunotherapy*) trial.

In view of the threat to sensitive people, the definition of the pollen season beginning is really important. However, in case of alder and hazel pollen seasons in Poland it is difficult to predict the season start precisely, because of unstable weather conditions at the beginning of the year, where the alder and hazel pollen season starts fluctuate from the middle of January to the middle of March [7].

For this reasons, it is important also to monitor the threat of allergenic pollen during the whole pollen season. The „short-time forecasts" are drown up on the basis of the defined relationship between meteorological elements and pollen concentration [8]. Some papers indicate the relatively high accuracy of the models predicting the exact pollen concentration in the following 3–5 days [9,10]. In spite of the different statistical methods used to construct the predicting models, like regression analysis [11,12], time series analysis (e. g. ARIMA models) [13], artificial neural networks [14] the obtained results do not indicate, which meteorological elements

Address for correspondence: Dorota Myszkowska, Department of Clinical and Environmental Allergology, Jagiellonian University Medical College, 31-531 Cracow, Sniadeckich 10
E-mail: dmyszkow@cm-uj.krakow.pl

Received: 20 May 2013; accepted: 24 June 2013

influence the pollen concentration explicitly. It is assumed that the analyses of these problems should be performed in a regional scale using the local meteorological and pollen data, considering the impact of the local microclimate, although the spatial interpolation technique can provide the reliable estimation of daily pollen concentrations in areas where monitor do not exist, as Della Valle et al. [15] suggested.

The authors of the presented paper suggest that the prediction of the probability of the pollen occurrence in the defined pollen categories related to the patient exposure to allergenic pollen seems to be more effective than the daily concentration prediction. The individual patient sensitivity plays a great role in allergic symptoms provoking and the progression of the pollen season affects the risk of symptoms developing [16]. Viander and Koivikko [17] reported, that in 90% of patients sensitive to birch pollen allergens, the first symptoms of allergic rhinitis occurred at the beginning of the season when the daily concentration did not exceed 80 PG/m^3 (pollen grains per 1 m^3 of air). Then the exposure to 30 PG/m^3 was sufficient to keep the allergic symptoms. The effect of the pollen exposure on the sensitization in population is still unclear [18]. The studies on a regional scale indicating the opposite results are often citied: one of them showed positive correlation between the pollen exposure and the symptom manifestation [19], while a worldwide study involving children reported a weak inverse relation, suggesting that the high exposure to pollen in the early life stage may give some protection against a risk of acquiring respiratory allergy [20]. In Poland, the pollen threshold values included in the "Standards in Allergology" are recommended [21].

The presented analyses were carried out by the authors dealing with the problem of the threat of biological environmental elements to patient health in Cracow. The aim of the study was to propose the forecast models predicting the pollen occurrence in the defined pollen concentration categories related to the patient exposure and symptom intensity. The present paper was prepared on the basis of a 20 year pollen observation performed in Cracow using the volumetric method.

MATERIAL AND METHODS

Study site and climate. The study was performed in Cracow (φ 50°04'N, λ 19°58'E, h 220 m a.s.l.), located in the Małopolska province (Southern Poland) (Fig. 1). The city is surrounded by farmlands and forests, which prevailed to the west of the city. Cracow is influenced by the air masses of the polar-maritime origin coming from over the Northern Atlantic, which bring thaw, an increase in cloud cover and snow in winter and cloud cover and rainfall in summer [22].

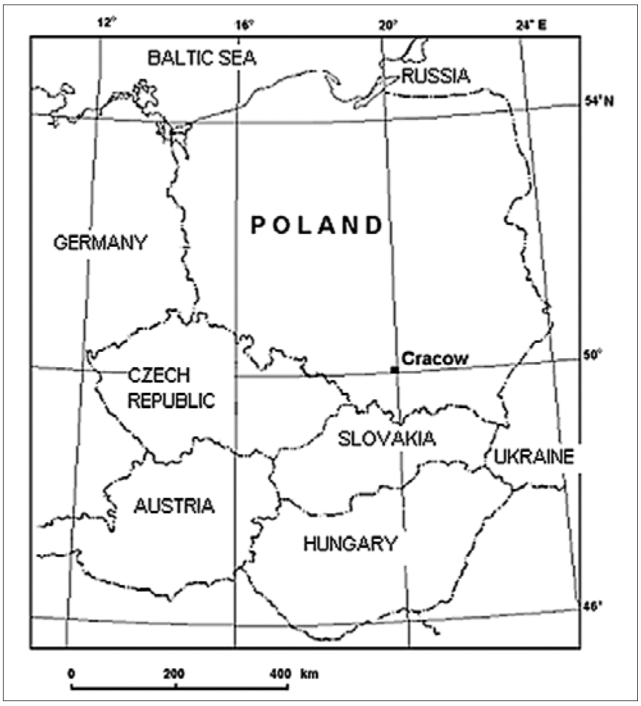

Figure 1. Study site localization

Meteorological and pollen data. Meteorological data were provided by the Research Station of the Dept. of Climatology, Institute of Geography and Spatial Management, Jagiellonian University (φ 50°04'N, λ 19°58' E, h 206 m a.s.l.). The Station is located in the immediate vicinity of the monitoring site. The following meteorological elements were taken into analysis: minimum (T_{min}), maximum (T_{max}) and mean daily temperature (T_{mean}), rainfall (Rain), relative humidity (RH), cloudiness (Cloud), relative sunshine (RS).

Pollen data were collected in Cracow using the volumetric method recommended by the European Aerobiology Society (EAS) and the procedures for Polish aerobiological stations [23] in 1991–2012. The Hirst type sampler located on the roof of the Collegium Sniadeckiego building in the city centre 20 m above ground level was used to collect air samples. The samples were examined using a light microscope at 400× magnification. Pollen grains were counted along 4 longitudinal transects (recommendation of the European Aerobiology Society).

Statistical analyses. Curves of the seasonal dynamics for particular taxa were presented using the Gaussian smooth curves (2 degrees of freedom). The following percentage methods were applied to calculate the pollen seasons: the 98% method for *Alnus* and *Corylus* seasons (the season start and end were calculated as days when 1% and 99% of annual total were achieved, respectively), the 98/95% method for *Betula* seasons (the season start and end were calculated as days when 1% and 97.5% of annual total were achieved, respectively), the 95/90% method for Poaceae seasons (the season start and end were calculated as days when 2.5% and 95% of annual total were achieved, respectively). The proposed combined methods were described previously by Myszkowska [24].

For all independent variables (meteorological elements) and the daily pollen concentrations the running mean for periods: 2-, 3-, 4-, 5-, 6- and 7 days before the predicted day were calculated, also the daily pollen concentrations and daily meteorological elements in a given day (1st-7th before the predicted day) were considered. The multinomial logistic regression was used to find the relation between the probability of the pollen concentration occurrence in the selected categories and meteorological elements and pollen concentration in days preceding the predicted daily concentration. The multinomial (polytomous) logistic regression model is a simple extension of the binomial logistic regression model. Introduction of multinomial logistic regression was an alternative regression analysis to cater for conditions that do not necessarily obey the assumptions of ordinary least squares (OLS) regression or linear regression analysis with the exception of multicollinearity [25]. Selected categories, according to the recommendation of the Polish Standards of Allergology [21], of daily pollen concentrations provoking the allergic rhinitis symptoms were used for the studied taxa (Tab. 1). Categories were modified due to the pollen concentrations in the studied period in Cracow and personal observation of symptoms in outpatients of the Allergology Clinic, University Hospital (unpublished results).

Table 1. Pollen concentration categories recommended by Samoliński et al. [21] modified by the authors of the present paper

Taxon / Symptom categories	Category of pollen daily concentration (PG/m^3)		
	Cat. 1 (symptoms in single patients)	Cat. 2 (symptoms in about 25% of patients)	Cat. 3 (symptoms in all patients)
Alnus	1–10	11–45	> 45
Corylus	1–10	11–35	> 35
Betula	1–10	11–75	> 75
Poaceae	1–10	11–50	> 50

Multinomial logistic regression models were constructed for each taxon using data in 1991–2011 (without 1992 and 1996 due to missing data in these years) and 1998–2011 pollen seasons. The proposed data series were singled out because of the observed increase in the total pollen concentration of all studied tree taxa since 1998. Only statistically significant variables (p<0.05) after the stepwise selection and checking for multicollinearity entered the models, due to the big amount of variables possibly associated with the risk of higher pollen concentrations. Odds Ratios (OR) with 95% confidence intervals (CI), p values and models pseudo-R^2 were presented. The models were validated for data in 2012. All analyses were performed using IBM SPSS Statistic 20 software.

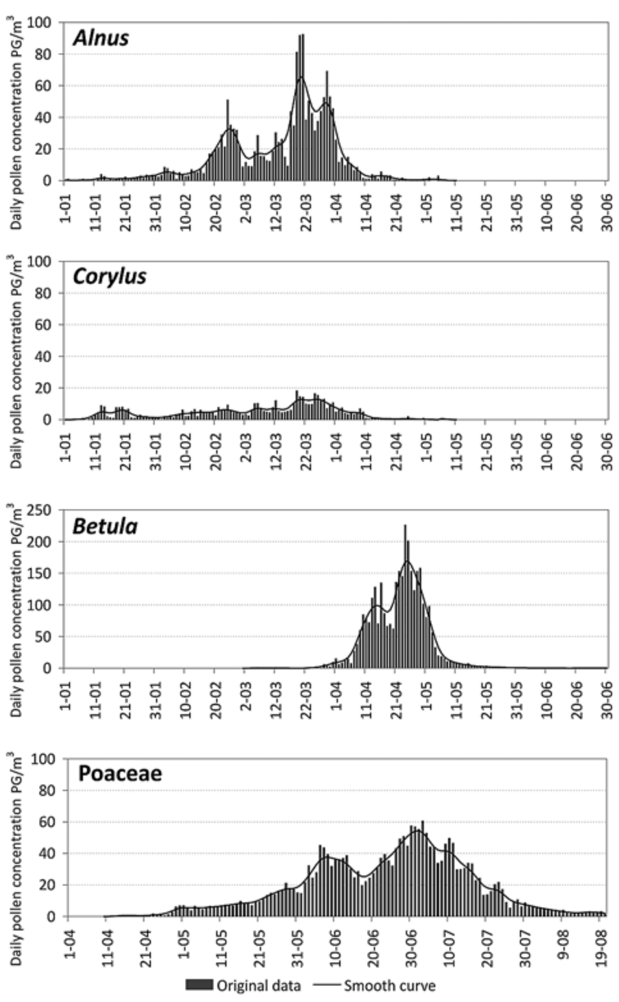

Figure 2. Pollen seasons of *Alnus*, *Corylus*, *Betula* and Poaceae in Cracow in 1991–2011 (black line – Gaussian smooth curve; black bars – mean daily pollen concentrations). Note the different scales for *Betula* and Poaceae.

RESULTS

Pollen season dynamics. The pollen season curves of the selected taxa were presented using the Gaussian smooth curves to highlight the seasonal dynamics (Fig. 2). The first pollen grains of *Alnus* and *Corylus* can be observed from the beginning of January to the third decade of April. The *Alnus* season dynamics curve is skew to the right and is characterized by the two main periods of high pollen daily concentrations. The first period occurs in the second half of February and the second one in March (Tab. 2). *Corylus* pollen reaches generally lower values of daily concentrations, and time of the pollen occurrence in the air is a bit longer. The dynamics curve is more flat, with less distinct peak periods. In case of *Corylus* pollen seasons, the concentrations up to 10 PG/m^3 can occur before the main season, in the second decade of January.

Betula pollen seasons last on average 1.5 months (from the beginning of April to the middle of May). Its pollen season is more dense than *Alnus* and *Corylus* seasons, the season curve indicates two peaks, in the middle of April and in the second decade of April. Single pollen grains are observed also in June. The seasons started approximately on the 100th day of the year (10 – 11th of April) (Tab. 2). Poaceae pollen dynamics is characterized also by two fairly distinct periods of high daily concentrations. The curve is more flat comparing to the tree pollen curves. The seasonal pollen sum, SPI value and the maximum concentration day were the most variable season characteristics of the *Alnus* and *Corylus* pollen seasons. In comparison with *Alnus* and *Corylus* season start, the season start of *Betula* pollen was more stable in the studied period and it was less variable than the season end.

The days classified among the lowest category (0–10 PG/m^3) dominated for all the studied taxa. The number of days assigned to the medium category of *Alnus* (11–45 PG/m^3) and *Corylus* (11–35 PG/m^3) was higher than the number of days in the highest category (PG > 45 and PG/m^3 > 35 for both taxa, respectively). On the other hand, the average number of days with medium and high concentrations was comparable during *Betula* pollen seasons (11–75 PG/ m^3 and PG/m^3 > 75, respectively) (Tab. 3). Moreover, the number of days in each category varied from year to year strongly. In case of Poaceae, daily pollen concentrations classified as the low and medium categories prevailed in 1991–2011 (Tab. 3).

The multinomial logistic regression models. The multinomial logistic regression models were constructed on the basis of selected categories of pollen concentrations and

Table 2. Descriptive statistics of season characteristics of the analysed taxa in Cracow, in 1991–2011

Statistics	*Alnus*						*Corylus*					
	Season start*	Season end*	Season duration**	SPI***	Maximum concen-tration***	Date of max. concen-tration*	Season start*	Season end*	Season duration**	SPI***	Maximum concen-tration***	Date of max. concen-tration*
Min	13	78	15	255	25	34	11	78	19	35	11	40
Median	46.00	94.00	39.00	988.00	199.00	73.00	43.00	96.00	49.00	415.00	48.00	71.00
Max	86	106	72	5012	1345.67	90	85	115	99	1252	221	90
$\bar{x}$	49.74	92.37	43.63	1453.53	314.98	70.68	46.10	96.89	51.79	428.00	68.13	66.53
SD	21.93	8.56	18.25	1225.77	338.85	14.04	21.84	10.12	22.12	321.20	58.32	15.99
V%	44.09	9.27	41.84	84.33	107.58	19.86	47.36	10.44	42.72	75.04	85.61	24.03
[–95%]	39.16	88.24	34.83	862.53	154.48	63.04	35.58	92.02	41.13	273.18	40.01	58.82
[+95%]	60.31	96.49	52.43	2044.33	497.71	77.18	56.63	101.77	62.45	582.81	96.24	74.23

Statistics	*Betula*						Poaceae					
	Season start*	Season end*	Season duration**	SPI***	Maximum concen-tration***	Date of max. concen-tration*	Season start*	Season end*	Season duration**	SPI***	Maximum concen-tration***	Date of max. concen-tration*
Min	87	114	17	847	119	96	122	191	57	1808	83	149
Median	99.00	127.00	29.00	2417.00	451.00	107.00	132.50	198.78	73.50	2482.00	116.50	176.50
Max	114	190	77	11099	2009	123	143	230	102	3904	198	190
$\bar{x}$	100.33	130.62	31.29	3481.19	672.47	109.29	132.20	206.40	75.00	2529.20	122.60	172.20
SD	7.28	14.91	13.61	2862.26	527.68	6.77	7.22	10.65	14.33	616.19	38.99	13.92
V%	7.26	11.41	43.51	82.22	78.47	6.19	5.46	5.16	19.11	24.36	31.81	8.08
[–95%]	97.02	123.83	25.09	2178.31	432.28	106.21	127.03	198.75	64.75	2088.40	94.71	162.24
[+95%]	103.65	137.40	37.48	4784.07	912.67	112.37	137.37	214.02	85.25	2969.99	150.49	182.16

*consecutive day from the 1st of January; **number of days; ***PG/m^3 – pollen grains in 1 m^3 of air

Table 3. The frequency of days with the pollen concentrations in the proposed categories counted in the defined pollen seasons in the analysed period (1991–2011) in Cracow

Taxon Statistics	*Alnus*			*Corylus*			*Betula*			Poaceae		
	0–10	11–45	> 45	0–10	11–35	> 35	0–10	11–75	> 75	0–10	11–50	> 50
$\bar{x}$	25.26	9.47	6.42	23.95	8.42	3.00	23.42	8.89	10.47	56.89	42.28	12.67
Min	8	0	0	9	1	0	6	2	2	30	15	1
Max	47	27	14	50	17	12	42	22	23	79	70	35
SD	11.83	7.35	4.27	11.73	5.31	3.35	8.75	4.36	5.43	10.84	16.01	9.37

pollen allergy symptoms. The model parameters estimation indicates some differences in the model fitting regarding the pollen concentration category and selected data period (Tabs 4,5). Temperature both mean and min as well as relative humidity were among those which indicated significant association with membership to higher pollen category of studied taxes. In case of *Corylus* and *Betula* pollen seasons the same meteorological parameters were introduced into the models.

The percentage of the obtained predictions of the pollen occurrence in built models fluctuated from 58.8% for *Betula* pollen to 68.5% for *Corylus* pollen in 1991–2011 series and from 64.2% to 66.5% (*Betula* and Poaceae pollen, respectively) in 1998–2011 series. Models validation made for 2012 showed lower consistency varied between 38–78%. The worst prediction was related to *Corylus* pollen. The others were above 65% which is a sufficient value of model predictions. Considering the studied taxon, the best model accuracy in 2012 (over 75%) was obtained for models forecasting *Betula* pollen concentration (both data series). They also worked well for the highest category consistency, reaching 90% (Tab. 5). *Alnus* models showed also fairly satisfactory results in 2012 with adequacy of 67% (for both series) and outcomes for higher category equaled 30 and 43%, based respectively on longer and shorter models. The models predicted the highest percentage of correct pollen concentrations for the category of the lowest concentrations. Generally, the percentage of accurate predictions was found at the following levels: 64.2% and 64.7% for alder (both series), 68.5% and 65.9% for hazel (both series), 58.8% and 64.2% for birch (both series) and 65.0%, 66.5% for Poaceae (both series). The forecasts for 2012 indicated rather fair consistency with the observed data for the studied taxa, except at hazel. The highest accuracy was found for models predicting the birch daily concentrations.

Table 4. The estimation of model parameters for: *Alnus, Corylus, Betula* (separately for two studied series: 1991–2011 and 1998–2011). The lowest category of pollen concentration (0–10 PG/m³) was treated as a reference category

Independent variable	*Alnus*							
	1991–2011				1998–2011			
	11–45 PG/m³		> 45 PG/m³		11–45 PG/m³		> 45 PG/m³	
	OR*	[-95%;+95%]	OR	[-95%;+95%]	OR	[-95%; +95%]	OR	[-95%; +95%]
Aln_{mean2}	0.997	0.991;1.003	0.991	0.984;.998	0.995	0.987; 1.004	0.989	0.979;.998
Aln_2	1.033	1.019;1.048	1.056	1.040;1.072	1.053	1.033; 1.073	1.083	1.061;1.106
T_{min1}	-	-	-	-	1.073	1.004; 1.004	1.033	0.998;1.070
T_{min3}	1.075	1.009;1.145	1.095	0.996;1.205	-	-	-	-
T_{mean1}	1.030	0.972;1.092	1.139	1.039;1.250	-	-	-	-
T_{mean5}	0.999	0.939;1.062	0.888	0.809;.974	-	-	-	-
T_{max7}	-	-	-	-	0.986	0.940; 1.034	1.109	1.002;1.228
RH_6	1.028	1.007;1.049	1.031	1.001;1.062	1.032	1.009; 1.057	1.033	0.998; 1.070
	Corylus							
Independent variable	1991–2011				1998–2011			
	11 – 35 PG/m³		> 35 PG/m³		11 – 35 PG/m³		> 35 PG/m³	
	OR	[-95%;+95%]	OR	[-95%;+95%]	OR	[-95%;+95%]	OR	[-95%;+95%]
Cor_{mean2}	1.066	1.045;1.088	1.092	1.065;1.119	1.059	1.038;1.081	1.085	1.058;1.112
T_{max7}	0.951	0.911;.993	0.883	0.812;.960	0.942	0.900;.987	0.871	0.799;.950
	Betula							
Independent variable	1991–2011				1998–2011			
	11 – 75 PG/m³		> 75 PG/m³		11 – 75 PG/m³		> 75 PG/m³	
	OR	[-95%;+95%]	OR	[-95%;+95%]	OR	[-95%;+95%]	OR	[-95%;+95%]
Bet_{mean2}	1.035	1.024;1.046	1.041	1.030;1.052	1.033	1.019;1.047	1.039	1.025;1.054
T_{min6}	1.014	0.948;1.086	0.927	0.856;1.004	0.986	0.900;1.088	0.867	0.781;.963
T_{mean4}	0.945	0.880;1.015	0.886	0.815;.962	0.871	0.790;.960	0.835	0.748;.932
RH_4	0.982	0.963;1.022	1.005	0.982;1.028	0.969	0.944;.994	0.991	0.963;1.032

Aln_{mean2}; Cor_{mean2}; Bet_{mean2} – mean *Alnus, Corylus, Betula* pollen concentrations in 2 days preceding the predicted day;
Aln_2 – *Alnus* pollen concentration in the 2nd day before the predicted day;
T_{mean1}, T_{mean4}, T_{mean5} – mean daily temperature in 1st, 4th, 5th day before the predicted day;
T_{min1}, T_{min3}, T_{min6} – minimum daily temperature in 1st, 3rd, 6th days before the predicted day;
T_{max7} – maximum daily temperature in 7th day before the predicted day;
RH_4; RH_6 – mean relative humidity in 4th and 6th day before the predicted day.
*OR (Odds ratio) – the ratio of a chance of pollen concentration occurrence in a given category to a chance of pollen concentration occurrence in the lowest category (0–10 PG/m³)

Table 5. The estimation of model parameters for Poaceae (separately for two studied series: 1991–2011 and 1998–2011). The lowest category of pollen concentration (0–10 PG/m³) was treated as a reference category

Independent variable	Poaceae							
	1991–2011				1998–2011			
	11–50 PG/m³		> 50 PG/m³		11–50 PG/m³		> 50 PG/m³	
	OR	[-95%;+95%]	OR	[-95%;+95%]	OR	[-95%;95%]	OR	[-95%; +95%]
$Poac_4$	1.017	1.009;1.025	1.021	1.012;1.030				
$Poac_{mean3}$	1.047	1.037;1.058	1.072	1.060;1.084	1.037	1.015;1.060	1.056	1.03;1.082
$Poac_{mean7}$					1.033	1.010;1.056	1.048	1.021;1.076
T_{min7}	0.952	0.917;.988	0.940	0.890;.994	0.917	0.877;.959	0.933	0.870;1.001
T_{max3}	0.962	0.935;.991	0.984	0.941;1.028				
RH_4	1.000	0.986;1.014	1.024	1.004;1.045	1.003	0.988;1.017	1.031	1.010;1.053
RH_5	0.983	0.970;.996	0.987	0.968;1.006				

$Poac_{mean3}$; $Poac_{mean7}$ – mean Poaceae pollen concentration in 3 and 7 days preceding the predicted day;
$Poac_4$ – Poaceae pollen concentration in the 4th day before the predicted day;
T_{max3} – the maximum daily temperature in the 3rd day before the predicted day;
T_{min7} – the minimum daily temperature in the 7th day before the predicted day;
RH_4; RH_5 – relative humidity in 4th and 5th day before the predicted day;
*OR (Odds ratio) - the ratio of a chance of pollen concentration occurrence in a given category to a chance of pollen concentration occurrence in the lowest category (0–10 PG/m³)

Table 6. The consistence of the observed pollen data in both studied series with predictive models and the consistence of the predictions in models in 2012

					Alnus					
Observed	Predicted in 1991–2011				Corrected in 2012	Predicted in 1998–2011				Corrected in 2012
	0–10	11–45	>45	Corrected		0–10	11–45	>45	Corrected	
0–10	306	19	3	93.3%	100%	211	23	0	90.2%	100%
11–45	136	41	7	22.3%	67%	94	55	6	35.5%	67%
>45	30	24	45	45.5%	30%	17	25	36	46.2%	43%
Total corrected	77.3%	13.7%	9.0%	64.2%	67%	69.0%	22.1%	9.0%	64.7%	67%
					Corylus					
Observed	Predicted in 1991–2011				Corrected in 2012	Predicted in 1998–2011				Corrected in 2012
	0–10	11–35	>35	Corrected		0–10	11–35	>35	Corrected	
0–10	324	15	1	95.3%	75%	259	14	1	94.5%	75%
11 – 35	110	18	1	14.0%	25%	98	18	1	15.4%	25%
>35	17	14	1	3.1%	0%	16	14	1	3.2%	0%
Total corrected	90.0%	9.4%	0.6%	68.5%	38%	88.4%	10.9%	0.7%	65.9%	38%
					Betula					
Observed	Predicted in 1991–2011				Corrected in 2012	Predicted in 1998–2011				Corrected in 2012
	0–10	11–75	>75	Corrected		0–10	11–75	>75	Corrected	
0–10	54	59	8	44.6%	67%	21	40	4	32.3%	58%
11 – 75	31	212	38	75.4%	69%	5	200	29	85.5%	69%
>75	9	102	87	43.9%	90%	2	85	75	46.3%	90%
Total corrected	15.7%	62.2%	22.2%	58.8%	78%	6.1%	70.5%	23.4%	64.2%	76%
Poaceae										
Observed	Predicted in 1991–2011				Corrected in 2012	Predicted in 1998–2011				Corrected in 2012
	0–10	11–50	>50	Corrected		0–10	11–50	>50	Corrected	
0–10	276	170	8	60.8%	38%	127	133	4	48.1%	46%
11–50	122	602	22	80.7%	85%	51	500	9	89.3%	89%
>50	8	175	58	24.1%	0%	2	126	19	12.9%	13%
Total corrected	28.2%	65.7%	6.1%	65.0%	66%	18.5%	78.2%	3.3%	66.5%	72%

DISCUSSION

The control and limitation of the natural inhalant allergens exposure is one of the main principle part of the pollen allergy treatment. For this reason, the environmental monitoring of allergenic pollen in the air has been performed in most of the European countries from several dozen years. It is assumed that daily pollen concentration is strictly related to the meteorological conditions and the pollen release in the previous days [26]. The most papers propose different models predicting Poaceae pollen concentration in the air, because of a long time of these pollen occurrence in the air (3–4 months depending on a region), what enhances the chance to find the strict relations between pollen counts and meteorological conditions.

Matyasovszky et al. [27] found that high Poaceae daily pollen concentrations are related to anticyclone synoptic situation, daily pollen concentration and mean daily temperature in a day before a forecasted day. Daily maximum temperature (optimum 21–25°C) in the day preceding the predicted day was reported as a main variable influencing the daily grass pollen concentration by Norris-Hill [28], daily mean temperature was indicated by Schäppi et al. [29], both maximum and minimum daily temperature were reported by Green et al. [30] and Aboulaich et al. [31].

The results on the relations between meteorological parameters and tree pollen concentrations are definitely less frequent published. The pollen seasons of these taxa, including the most allergenic: alder, hazel, birch belong to the short pollen seasons, what makes difficult to determine the impact of weather conditions on the pollen occurrence and the relations between clinical symptoms and pollen concentration. Mendez et al. [32] analyzing birch pollen seasons in Ourense (Spain) in 1992–2000, found the positive correlation between daily *Betula* concentration and both temperature and sunlight, while negative correlation with relative humidity. Rodriguez-Rajo et al. [13] investigating the alder pollen seasons in several sites in Spain reported that daily pollen concentration in a pre-peak season mostly positively related to maximum temperature, while negative correlation with rainfall and relative humidity was found. Our results indicated that the daily pollen concentration is influenced by pollen occurrence and meteorological elements in the previous days (up to 7). Among the meteorological parameters, temperature and relative humidity prevailed. The highest number of independent variables was significantly related to the daily concentration in case of *Alnus*, probably because of several *Alnus* species occurring in the vicinity of Cracow.

The most reported models predicting the daily pollen concentration are based on the regression analysis, but it is difficult to find the results comparable to those published in a current paper, considering the method of model construction. Smith and Emberlin [10] constructed the models predicting the daily Poaceae pollen concentration with accuracy of 62 and 42% depending on the validated year. Stach et al. [11] presented the short forecasts models using the regression analysis for Poaceae pollen in Poznań, achieving 61–70% of accuracy. They indicated relative sunshine as the main element explaining the variability of the daily grass pollen concentration in the pre-peak season the strongest, while maximum temperature and relative sunshine in the post-peak season. Similarly to our results, the 2–5 day running means of meteorological elements were calculated. Piotrowska and Kubik [12] reported a poor fit for average concentration of birch pollen during the season (64%), while Norris-Hill [9] built the models predicting the daily concentration with 71% of accuracy. Considering the results mentioned above, the accuracy of models prediction rarely achieve more than 70%.

The authors of a presented paper intension was to find the relationship between pollen concentration and meteorological parameters as precise as it can useful to estimate the real threat of pollen occurrence with regard to the proposed threshold values. For this reason both the meteorological elements in the days preceding the pollen season and a running mean values of meteorological elements were considered. However, the meteorological elements in a given day were introduced into the models only, as independent variables. The problem of the clear threshold values is still widely discussed and worked out in frame of the European Aerobiology Society. As de Weger et al. [18] reported in the latest book on allergenic pollen, the threshold values for sensitization are not definitely described until now, although some results due to the threshold values were published for Finland and France [33,34]. Looking at the frequency of days with the concentration classified as a given category, the most often the lowest values (below 10 PG/m^3) are observed in Cracow. The most dangerous, high concentrations can be predict in a simple way, on the basis of descriptive statistics of maximum pollen concentration as it was presented in Table 2. The patients are at high or moderate risk of allergy symptom manifestation over several days (tree pollen seasons), up to 15 in case of Poaceae (on average; ranges from 1–35 days). In Spain, the *Alder* pollen concentration over 30 PG/m^3 is considered as sufficient to trigger the severe allergy symptoms [13], and up to 25 days in this category occur year to year.

Because the low and medium pollen concentrations dominate during the pollen seasons, the prediction of their occurrence can modify the specific immunology treatment. The presented models predict the probability of the days with pollen concentration classified according to the proposed categories occurrence. The obtained models demonstrated the satisfying efficacy, especially in case of low and moderate concentration values. The proposed models for *Corylus* are the less satisfying, probably because of low daily pollen concentrations and a short pollen season.

In case of *Betula*, more than 50% of predicted days in category >75 PG/m^3 was classified to a wrong category, but only 1.2%-4.5% of predicted days was assigned to the category of the lowest pollen concentrations. The similar relationship was observed in case of Poaceae pollen seasons. Considering the category of the highest pollen concentrations (> 50 PG/m^3) only 13–24% of predicted days was classified correctly, while the days with a lowest concentration (0–10 PG/m^3) were classified correctly in 1%-3% only (2 and 9 days of difference, respectively). The lowest accuracy of model prediction was obtained for *Corylus* pollen seasons, especially in addition to the category of the highest pollen concentrations. Probably, the value of the daily *Corylus* pollen concentration, not being strictly in accordance with the threshold values recommended by the Polish Allergology Standards [21] seems to be a cause of lower model accuracy for this taxon.

CONCLUSIONS

The obtained results indicated that the days classified among the lowest category of pollen concentration (0–10 PG/m^3) dominated for all the studied taxa (*Alnus*, *Corylus*, *Betula* and Poaceae). The application of the recommended threshold values during the predictive models construction seems to be really useful to estimate the real threat of allergen exposure. It was found the statistically significant relationship between the probability of the correct or incorrect classification of daily pollen concentration with the meteorological conditions in a given day before the pollen season. The influence of the mean running values were conformed in case of some daily pollen concentration, not in case of the meteorological elements. It was indicated that the multinomial logistic regression models could be a practical tool for effective forecasting in biological monitoring of pollen exposure. In spite of the highest percentage of obtained predictions for the category of the lowest concentrations, the proposed models confirm acceptable efficiency of prediction except *Corylus*. In authors opinion, the proposed methodology of model preparation could be used by other allergological centres co-operating with aerobiological sites.

The study was supported by the statute project of the Ministry of Science and Higher Education No. K/ZDS/002432.

The author would like to thank the management of the Department of Climatology, Jagiellonian University for providing me with the meteorological data.

REFERENCES

1. Ring J, Krämer U, Schäfer T, Behrendt H. Why are allergies increasing? Current Opinion in Immunology 2001; 13: 701–708.
2. D'Amato D, Cecchi L, Bonini S, Nunes C, Annesi-Maesano I, Behrendt H, Liccardi G, Popov T, van Cauwenberge P. Allergenic pollen and pollen allergy in Europe. Allergy 2007; 62: 976–990.
3. Samoliński B, Sybilski AJ, Raciborski F, Tomaszewska A, Samel-Kowalik P, Walkiewicz A, Lusawa A, Borowicz J, Gutowska-Ślesik J, Trzpil L, et al. Prevalence of rhinitis in Polish population according to the ECAP (Epidemiology of Allergic Disorders in Poland) study. Otolaryngol Pol. 2009; 63: 324–330.
4. Myszkowska D, Stępalska D, Obtułowicz K, Porębski G. The relationship between airborne pollen and fungal spore concentration and seasonal pollen allergy symptoms in Cracow in 1997–1999. Aerobiologia 2002; 18: 153–161.
5. Frenz DA. Interpreting atmospheric pollen counts for use in clinical allergy: allergic symptomology. Ann Allergy Asthma Immunol. 2001; 86: 150–158.
6. Canonica GW, Baena-Cagnani CE, Bousquet J, Bousquet PJ, Lockey RF, Malling HJ, Passalacqua G, Potter P, Valovirta E. Recommendations for standardization of clinical trials with Allergen Specific Immunotherapy for respiratory allergy. A statements of a World Allergy Organization (WAO) taskforce. Allergy 2007; 62: 317–324.
7. Myszkowska D, Jenner B, Puc M, Stach A, Nowak M, Malkiewicz M, Chłopek K, Uruska A, Rapiejko P, Majkowska-Wojciechowska B,

Weryszko-Chmielewska E, Piotrowska K, Kasprzyk I. Spatial variations in dynamics of *Alnus* and *Corylus* pollen seasons in Poland. Aerobiologia 2010; 26: 209–221.
8. Laadi M. Predicting days of high allergenic risk during *Betula* pollination using weather types. Int J Biometeorol. 2001; 45: 124–132.
9. Norris-Hill J. The modeling of daily Poaceae pollen concentrations. Grana 1995; 34: 182–188.
10. Smith M, Emberlin J. Constructing a 7-dayahead forecast model for grass pollen at north London, United Kingdom. Clin Exp Allergy. 2005; 35: 1400–1406.
11. Stach A, Smith M, Prieto Buena JC, Emberlin J. Long-term and short-term forecast model for Poaceae (grass) pollen in Poznań, Poland, constructed using regression analysis. Environ Exp Bot. 2008; 62: 323–332.
12. Piotrowska K, Kubik-Komar A. The effect of meteorological factors on air borne *Betula* pollen concentrations in Lublin (Poland). Aerobiologia 2012. doi: 10.1007/s10453–012–9249-z.
13. Rodriguez-Rajo FJ, Valencia-Barrea RM, Vega-Maray AM, Suarez FJ, Fernandez-Gonzales D, Jato V. Prediction of airborne *Alnus* pollen concentration by using Arima models. Ann Agric Environ Med. 2006; 13: 25–32.
14. Puc M. Artificial neural networks model of the relationship between *Betula* pollen and meteorological factors in Szczecin (Poland). Int J Biometeorol. 2012; 56: 396–401.
15. DellaValle CT, Triche EW, Bell ML. Spatial and temporal modeling of daily pollen concentrations, In J Biometeorol. 2012; 56: 183–194.
16. Jantunen J, Saarinen K, Rantio-Lehtimäki A. Allergy symptoms in relation to alder and birch pollen concentrations in Finland. Aerobiologia. 2012; 28: 169–176.
17. Viander M, Koivikko A. The seasonal symptoms of hyposensitized and untreated hay fever patients in relations to birch pollen counts: Correlations with nasal sensitivity, prick tests and RAST. Clinical Allergy. 1987; 8: 387–396.
18. De Weger L, Bergmann K-Ch, Rantio-Lehtimäki A, Dahl A, Buters J, Déchamp Ch, Belmonte J, Galán C, Waisel Y. Impact of pollen. In: Sofiev M, Bergmann K-Ch. Allergenic pollen. Springer, Dordrecht, 2013.p.161–215.
19. Frei T, Gassner E. Trends in prevalence of allergic rhinitis and correlation with pollen counts in Switzerland. Int J Biometeorol. 2008; 43: 191–195.
20. Burr ML, Emberlin J, Treu R, Cheng S, Pearce NE. Pollen counts in relations to the prevalence of allergic rhinoconjunctivitis, asthma and atopic eczema in the International Study of asthmna and allergies in Childhood (ISAAC). Clin Exp Allergy. 2003; 33: 1675–1680.
21. Samoliński B, Rapiejko P, Lipiec A, Kurzawa R. Metody ograniczenia narażenia na alergen. In: Kruszewski J, Kowalski ML. Standardy w alergologii. Część I. Medycyna praktyczna, Kraków 2010.p.143–149 (in Polish).
22. Woś A. Klimat Polski. Państwowe Wydawnictwo Naukowe PWN, Warszawa, 1999 (in Polish).
23. Stach A, Kasprzyk I. Metodyka badań zawartości pyłku roślin i zarodników grzybów w powietrzu z zastosowaniem aparatu Hirsta. Bogucki Wydawnictwo Naukowe, Poznań, 2005 (in Polish).
24. Myszkowska D. Prediction of the birch pollen season characteristics in Cracow, Poland using an 18-year data series. Aerobiologia 2013; 29: 31–44.
25. Hosmer DW, Lemeshow S. Applied logistic regression. Wiley-Interscience, 2000.
26. Jones AM, Harrison RM. The effect of meteorological factors on atmospheric bioaerosol concentrations – a review. Science of the Total Environment. 2004; 326: 151–180.
27. Matyasovszky I, Makra L, Guba Z, Pátkai Z, Páldy A, Sümeghy Z. Estimating the daily Poaceae pollen concentration in Hungary by linear regression conditioning on weather types. Grana 2011; 50: 208–216.
28. Norris-Hill J. The influence of ambient temperature on the abundance of Poaceae pollen. Aerobiologia 1997; 13: 91–97.
29. Schäppi GF, Taylor PE, Kenrick J, Staff IA, Suphioglu C. Predicting the grass pollen count from meteorological data with regard to estimating the severity of hayfever symptoms in Melbourne (Australia). Aerobiologia 1998; 14: 29–37.
30. Green BJ, Dettmann M, Yli-Panula E, Rutherford S, Simpson R. Atmospheric Poaceae pollen frequencies and associations with meteorological parameters in Brisbane, Australia: a 5-year record, 1994–1999. Int J Biometeorol. 2004; 48: 172–178.
31. Aboulaich N, Achmakh L, Bouziane H, Mar Trigo M, Recio M, Kadiri M, Cabezudo B, Riadi H, Kazzaz M. Effect of meteorological parameters on Poaceae pollen in the atmosphere of Tetouan (NW Morocco). Int J Biometeorol. 2013; 57: 197–205.
32. Mendez J, Comtois P, Iglesias I. *Betula* pollen: One of the most important aeroallergens in Ourense, Spain. Aerobiological studies from1993 to 2000. Aerobiologia. 2005; 21: 115–123.
33. Rantio-Lehtimaki A, Koivikko A, Kupias R, Makinen Y, Pohjola A. Significance of sapling height of airborne particles for aerobiological information. Allergy 1991; 46: 68–76.
34. Thibaudon M. Allergy risk associated with pollens in France. Eur Ann Allergy and Clinical Immunology. 2003; 35: 170–172.