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PREDICTION OF AIRBORNE *ALNUS* POLLEN CONCENTRATION BY USING ARIMA MODELS

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Abstract: To take preventative measures to protect allergic people from the severity of the pollen season, one of aerobiology's objectives is to develop statistical models enabling the short- and long-term prediction of atmospheric pollen concentrations. During recent years some attempts have been made to apply Time Series analysis, frequently used in biomedical studies and atmospheric contamination to pollen series. The aim of this study is to understand the behaviour of atmospheric alder pollen concentrations in northwest Spain in order to develop predictive models of pollen concentrations by using Time Series analysis. The prediction line proposed for Oviedo and Ponferrada are similar (Arima 2,0,1) while in Vigo a more accurate model founded by Arima (3,0,1) and in León (1,0,1) was used. The results suggest that Ponferrada and Oviedo are the cities in northwest Spain where *Alnus* pollen allergic individuals should to take preventive measures to protect themselves from the severity of the pollen season. *Alnus* pollen values higher than 30 grains/m^3, a quantity considered sufficient to trigger severe allergy symptoms of other trees of the Betulaceae family, could be reached during 25 days in some years. The predicted lines conformed with the observed values overall in the case of León and Ponferrada. Time Series regression models are especially suitable in allergology for evaluating short-term effects of time-varying pollen appearance in the atmosphere.

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Key words: ***Alnus*, airborne pollen, ARIMA, predictive models, Spain, time series.**

INTRODUCTION

Airborne pollen in the outdoor environment is the main cause of asthma and rhinoconjuntivitis in pollen allergic individuals in Europe [14]. Atmospheric contamination reinforces this effect, being the main contributor to the remarkable increase of environmental and health problems during recent decades [10, 41]. One of aerobiology's objectives is to develop statistical models enabling the short- and long-term prediction of atmospheric pollen concentrations. This enables allergic individuals to take preventive measures to protect themselves from the severity of the pollen season. During flowering, meteorological factors such as hours of sunshine, temperature, rainfall and relative humidity determine the opening of the anthers, while wind finally determines the dispersion of pollen and other particles of the aerosol into the atmosphere [8, 22]. Pollen concentration predictions are usually made short-term, e.g. 1–2 days in advance. The prediction based in statistical tools such as the

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Table 1. Sampling sites characteristics.

Localities	Vigo	Oviedo	Ponferrada	León
Position	42º14' N, 8º43' W	43º21' N, 5º52' W	42º33' N, 6º35' W	42º34' N, 5º35' W
Environment	Urban	Rural/Urban	Rural/Urban	Rural/Urban
Altitude (m)	50	285	541	830
Annual total rainfall (mm)	1412	963	640	550
Annual mean temperature (ºC)	14,9	12,5	10,3	10
Bioclimate Type	Temperate hyperoceanic submediterranean	Temperate oceanic submediterranean	Mediterranean pluviseasonal oceanic	Mediterranean pluviseasonal oceanic
Phytogeographical Region	Eurosiberian	Eurosiberian	Mediterranean	Mediterranean

correlation of pollen levels with meteorological variables is usually made by means of uni-dimensional non-linear equations using variables with the greatest prediction capacity [37, 41]. During recent years, some attempts have been made to apply Time Series analysis, frequently used in biomedical studies [24, 45] and atmospheric contamination [5] to pollen series [6, 9, 12, 34,]. A temporary series is the collection of orderly observations periodically recorded at the time [45]. The analysis of Time Series by using probabilistic models started with the Box and Jenkins works (Box-Jenkins type) on the stochastic treatment of series. It is considered that each value of a variable has been extracted randomly of a distribution of probability, that is to say, the values of the temporary series are supposed samples with a certain function of probability. We attempt to estimate this function of probability starting from the construction of models. The difficulty of modeling by using Time Series is due to the very nature of the series, since it consists of pollen values with zero value throughout the entire year, interrupted by one or several random intervals, of short duration, of high values with very fast fluctuations [13].

Alnus glutinosa (L.) Gaertner, is a monospecific tree broadly represented in northwest Spain, where it mainly forms part of riverside forests. There are a great number of papers centred on the study of its pollen grains [18, 26, 42] as in northwest Spain between 9–20% of hay fever sufferers are allergic to *Alnus* pollen [3, 7, 17, 21]. The *Alnus* pollen cause annual early hay fever symptoms, but its epidemiology is not very important since this pollen type appears in the atmosphere in periods of the year in which, because of the climate, exposure to its allergens is not carried out during a long period of time [43]. It has a high degree of crossed reactivity with pollen grains of other genus of the Betulaceae family, some food of vegetal source and even with some of the Fagaceae family [28].

The aim of this study is to understand the behaviour of atmospheric alder pollen concentrations in northwest Spain in order to develop predictive models of pollen concentrations by using Time Series analysis.

MATERIAL AND METHODS

The studied zones are located in northwestern of Spain: Vigo, Ponferrada, León and Oviedo. Biogeographical, climatological and environment details of the four areas are shown in Table 1. Hirst-type pollen traps [27] were used in each locality, placed 15-25 m above ground level in areas close to meteorological stations. Sampling was carried out continuously from 1 January 1996 (Vigo, León and Ponferrada) and 1 January 1998 (Oviedo) to 31 December 2003. The Lanzoni sampler is calibrated to handle a flow of 10 l of air per minute, thus matching the human breathing rate. Pollen grains are impacted on a cylindrical drum covered by a melinex film coated with a 2% silicon solution as trapping surface. The drum was changed weekly and the exposed tape was cut into seven pieces, which were mounted on separate glass slides. Pollen identification was performed using optical microscopes equipped with a 40×/0.95 lens. Pollen counts were made using the model proposed by the R.E.A., consisting in four continuous longitudinal traverses along the 24-hr slide [16]. We used the 2.5% method [46] in order to calculate the main flowering period, which includes 95% of the annual total pollen collected, eliminating the initial period until 2.5% is attained and the final period once 97.5% has been attained.

Spearman's correlation test was used to find a possible relationship between *Alnus* pollen concentrations and the main meteorological factors. The following group of variables was available for the construction of the models: the number of pollen grains (X_1) and meteorological variables: rainfall (mm), relative humidity (%), hours of sunshine (hours), maximum, minimum and mean temperatures (ºC), wind direction (%) and wind speed (m/s). Weather data were supplied by the National Institute of Meteorology.

In order to predict the pollen concentrations ARIMA models have been applied (Autoregresive Integrated Model of Running Mean) univariated seasonal and non-seasonal (also knows as "Box-Jenkins" models). The Time Series are a mixture of several components: T_t or the long trend value, E_t or the fluctuations of the series in periods smaller than one year, C_t or fluctuations of the series in periods longer than one year, and finally the I_t or random or sporadic factors [45]. The equation followed by a Time Series is an additive model: $Y_t = T_t + C_t + E_t + I_t$.

A model is considered as autorregresive if the values of the series depend on or are related with previous values of the variable. In this way, it is possible to establish a multiple lineal regression function in which the dependent variable is the observation in the "$_t$" period and the

Table 2. Characteristics of *Alnus* pollen season calculated according 2.5% method [46]: starting and ending date, length, mean concentration during pollen season, value of peak day in pollen/m^3 and its date, total annual pollen and number of days with values above pollen/m^3 threshold (e.g. Days>30, Days>80).

	1996	1997	1998	1999	2000	2001	2002	2003	Average
VIGO									
Start date	Jan 14	Jan 12	Jan 10	Jan 20	Jan 17	Dec 19	Jan 20	Jan 18	Jan 12
Final date	Mar 12	Feb 27	Mar 03	Feb 25	Mar 03	Feb 19	Feb 22	Mar 03	Feb 28
Length (Days)	59	47	53	37	47	63	34	45	48
Mean (pollen/m^3)	12	29	13	41	10	5	16	21	18
Peak value	93	245	56	165	53	66	115	184	122
Peak day	Feb 14	Jan 28	Feb 06	Jan 28	Jan 31	Jan 08	Jan 29	Feb 08	Jan 30
Total pollen	730	1424	695	1580	478	345	577	971	850
Days >30 pollen/m^3	6	15	8	15	4	3	4	9	8
Days >80 pollen/m^3	2	4	0	6	0	0	1	4	2
OVIEDO									
Start date			Jan 26	Jan 18	Jan 25	Dec31	Jan 20	Jan 18	Jan 17
Final date			Mar 7	Mar 2	Feb 24	Feb 28	Feb 23	Mar 15	Mar 2
Length (Days)			41	44	31	60	35	57	45
Mean (pollen/m^3)			16	47	58	19	67	4	35
Peak value			65	257	209	79	260	25	149
Peak day			Feb 11	Feb 8	Feb 1	Feb 3	Jan 30	Feb 9	Feb 5
Total pollen			574	2187	1865	1171	2473	245	1419
Days >30 pollen/m^3			6	23	18	10	20	0	13
Days >80 pollen/m^3			0	8	9	0	11	0	5
PONFERRADA									
Start date	Dec 31	Dec 25	Jan 4	Jan 17	Jan 17	Dec19	Jan 25	Dec 23	Jan 4
Final date	Mar 6	Feb 21	Feb 23	Feb 27	Feb 22	Feb 12	Feb 23	Feb 20	Feb 22
Length (Days)	67	59	51	42	37	56	30	60	50
Mean (pollen/m^3)	10	14	6	47	58	24	64	18	30
Peak value	51	84	36	236	473	106	273	130	165
Peak day	Jan 27	Feb 1	Jan 18	Feb 7	Feb 6	Jan 4	Jan 30	Jan 29	Jan 26
Total pollen	693	850	320	2654	2251	1404	2016	1110	1340
Days >30 pollen/m^3	4	9	1	25	14	14	18	10	12
Days >80 pollen/m^3	0	2	0	7	8	1	7	2	3
LEÓN									
Start date	Jan 11	Jan 27	Jan 7	Jan 23	Feb 1	Jan 4	Jan 26	Dec 28	Jan 15
Final date	Mar11	Feb 27	Mar 4	Mar15	Mar 9	Feb 27	Feb 26	Mar 14	Mar 6
Length (Days)	61	32	57	52	38	55	32	71	50
Mean (pollen/m^3)	4	9	2	3	6	5	10	2	5
Peak value	47	86	19	18	56	36	48	12	40
Peak day	Feb 18	Feb 4	Feb 2	Feb 20	Feb 13	Feb 3	Feb 13	Feb 9	Feb 10
Total pollen	251	326	117	146	244	271	343	161	232
Days >30 pollen/m^3	1	1	0	0	2	1	2	0	1
Days >80 pollen/m^3	0	1	0	0	0	0	0	0	0

independent ones are those variables of the previous periods that keep relationship with the dependent variable. In the model the three parameters of the ARIMA model has been proved, Autoregresive (p), Differentiation (d) and Running mean (q).

p = Number of autoregresive parameters of the model. Each parameter measures the independent effect of the values with a specified retard. An order 2 autoregresive means that each value of the series is affected by the two precedents values (independently the one of the other).

d = Number of times that a time series was transformed calculating the differences between the values of the series and its predecessors.

q = The order of the running mean of the process.

The values of the year 2003 were used to check the validity and prediction capacity of the proposed model.

RESULTS

As would be expected from the differences in bioclimate there is low variations in the start date of the *Alnus* pollen season in northwestern Spain, flowering earlier at western localities (Tab. 2). Alder tree flowers at the start of winter during the second half on December, and is one of the first to appear in the annual spectrum. The pollen of *Alnus* is mainly recorded in the atmosphere in January and February with a length of pollen season of 45-50 days. Generally, the end of the pollen season takes place during the last week of February in the western locations while in the first week of March in the eastern locations.

In spite of February being the month in which the higher levels were recorded (Fig. 1), daily maximum concentration was usually registered in January or February, depending on the year and site. A difference of more than 30 days between the days of maximum daily concentration was observed in the same station and in different years (Tab. 2). Although this pollen type only includes a single species, the curve of daily mean values is characterized by several concentration peaks throughout the pollen season (Fig. 1). The number of days on which *Alnus* was present in the atmosphere in high concentrations was greater in northwest Spain, with the exception of León values. Between 8–12 days concentrations are higher than 30 grains/m^3 as a mean, attaining in Ponferrada a number of 25 during 1999. In the case of León these concentration was reached only on 1 or 2 days during the pollen season (Tab. 2).

The quantity of total pollen was highly variable, between a mean of 2473 pollen grains in Oviedo and 232 pollen grains in León (Tab. 2). There were also fluctuations in the maximum values during the years under study (Fig. 2).

Relationships between daily *Alnus* pollen counts and meteorological parameters were investigated at each site for individual alder pollen seasons and all localities combined. The whole pollen season and the prepeak period were considered and summarizing (Tab. 3), and the Spearman correlation coefficients obtained. Correlations were significant in a large number of cases, especially in

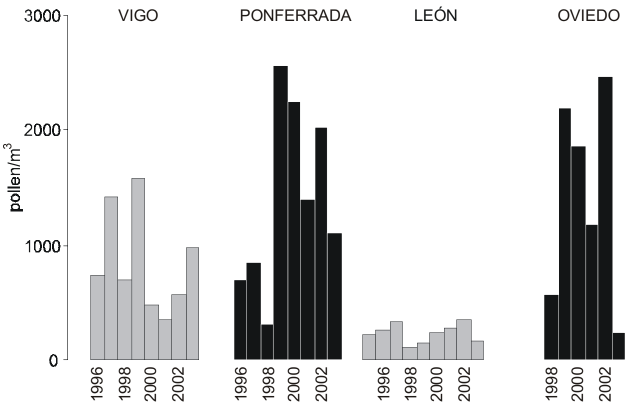

Figure 2. Total annual values.

Vigo and Oviedo. Results of pollen season and prepeak analysis shows that daily alder pollen counts are more highly related to temperatures and sun hours in a positive way (mainly maximum temperature), and rainfall or relative humidity in negative one. Positive high correlations with a minor p value <0.05 were founded with wind calms.

ARIMA analysis was performed to predict *Alnus* pollen concentrations (Tab. 4), using as independent variables weather parameters with a high correlation coefficient: maximum temperature in all cases. Figure 3 shows the corresponding graph with data from 2003; the values predicted fit in most cases the pollen concentrations registered.

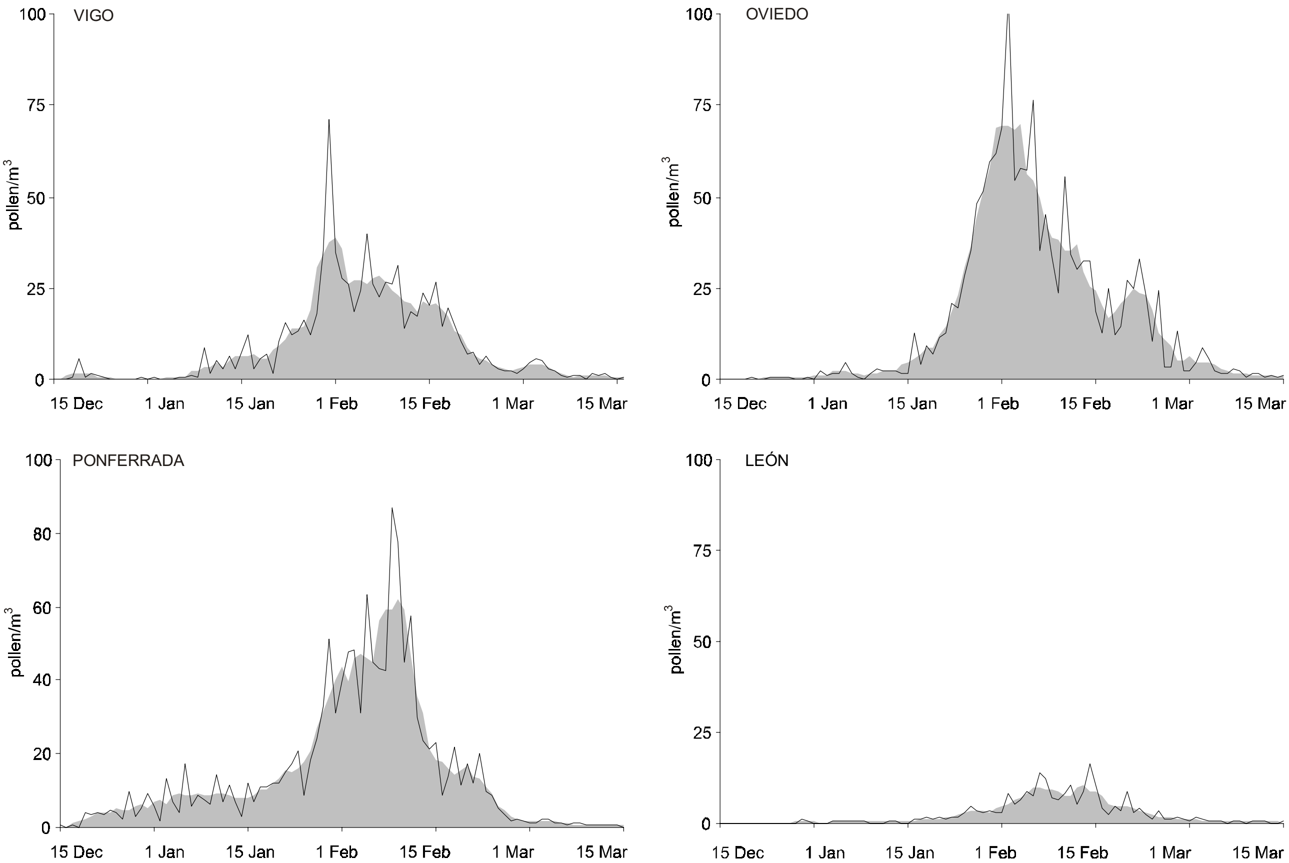

Figure 1. Daily pollen concentrations (line) for *Alnus*, along with the three days running mean values (area).

Table 3. Correlation coefficients between *Alnus* pollen concentrations and meteorological parameters during pollen season and prepeak period considering the years together (Spearman's coefficient *95%, **99.9% significance). Also correlation coefficients values are presented considering only northwest locations.

	Vigo	Oviedo	Ponferrada	León	Northwest
Pollen season					
Rainfall	-0.405**	-0.434**	-0.137*	-0.079	-0.199**
Humidity	-0.441**	-0.450**	-0.067	0.023	-0.175**
T maximum	0.295**	0.511**	0.294**	0.198**	0.359**
T minimum	0.039	0.173*	0.148*	0.106*	0.266**
T mean	0.181**	0.398**	0.248**	0.190**	0.342**
Sun hours	0.330**	0.269**		0.120*	0.147**
Wind calm	0.192**	-0.065	-0.027	0.135*	0.195**
Wind N-NE	0.286**	-0.056	-0.061	-0.177**	-0.231**
Wind NE-S	0.087	0.296**	0.222**	-0.151**	0.170**
Wind S-SW	-0.371**	0.186*	0.215**	0.166**	0.058*
Wind SW-N	-0.187**	-0.143*	0.017	-0.031	0.071*
Wind Path	-0.250**	0.029	0.156*	0.110*	0.290**
Prepeak period					
Rainfall	-0.460**	-0.386**	-0.166*	-0.150	-0.219**
Humidity	-0.452**	-0.357**	-0.258**	-0.181	-0.346**
T maximum	0.304**	0.474**	0.602**	0.443**	0.528**
T minimum	0.064	0.060	0.142	0.132*	0.262**
T mean	0.197*	0.317**	0.387**	0.379**	0.428**
Sun hours	0.355**	0.284*		0.212*	0.223**
Wind calm	0.240*	-0.058	-0.021	0.163*	0.213**
Wind N-NE	0.181*	0.045	-0.006	-0.200**	-0.225**
Wind NE-S	0.234*	0.204*	0.254**	-0.193**	0.242**
Wind S-SW	-0.381**	0.246*	0.139	0.214**	0.068
Wind SW-N	-0.203*	-0.168	0.026	-0.086	0.096*
Wind Path	-0.301**	-0.068	0.198*	0.146*	0.282**

DISCUSSION

The *Alnus glutinosa* pollination period started during the first half of January. Previous works conducted in the same areas [42] point out the overall trend the displayed by start date of the pollen season displayed: a delay of the onset for western cities and a negative slope for eastern cities. Temperature is the factor exerting the clearest influence on the onset of *Alnus* flowering, since the timing of pollination is due to major and successive temperature requirements [22, 31, 42]. Preceding studies report the most important effect in the start of flowering was exerted by temperatures over the previous 30-40 days [42]. At a particular level, and inside each area, the differences in the start of the flowering throughout the years can be explained by temperature during the period prior to flowering [32]. Different authors consider that high chilling temperatures accelerate the renewal of growth once dormancy is broken; the more chilling units are cumulated, the less forcing units are subsequently needed for budburst [11, 35] and the start date of the pollen takes place earlier. This behaviour has been demonstrated in this study as, for instance, the early 2003 flowering in Ponferrada and León coincide with very lower temperatures during the end of November.

The highest concentrations of *Alnus* pollen in Spain are recorded in the northwest Iberian Peninsula [30], being the concentrations of this pollen type higher in the north of Europe [4, 44]. During the study period, the annual sum of *Alnus* pollen fluctuated from year to year, and three behaviour patterns have been found. Vigo described a biennial behaviour with an alternation of years in which the tree gives priority to reproduction and others in which it focuses on vegetative growth [2, 19, 20, 29, 33, 36, 40, 44]. This behaviour is also influenced by the meteorological conditions prevailing during the pollination period, since the lower flowering during 2001 coincided with high precipitation in January and February. The second was followed by Oviedo and Ponferrada in which two years of high concentrations were followed by one of low concentrations. Studies conducted by Aira *et al.* [1] in the city of Santiago de Compostela point out the opposite behaviour. Finally, in León pollen concentrations rose successively during four years and droped drastically the following year, to start the cycle again.

Alnus pollen values higher than 30 grains/m^3 a quantity considered sufficient to trigger severe allergy symptoms of other trees of the Betulaceae family, were attained during 25 days as a maximum, showing high variability as consequence of the presence of years with high and low concentrations. For its part, it is difficult to surpass more than 8 days on which concentrations are higher than 80 grains/m^3; this is the value cited as sufficient to produce symptoms in 90% of patients in other Betulaceae such as *Betula* genus [15, 48]. These results indicate that Ponferrada and Oviedo are the cities of the northwest

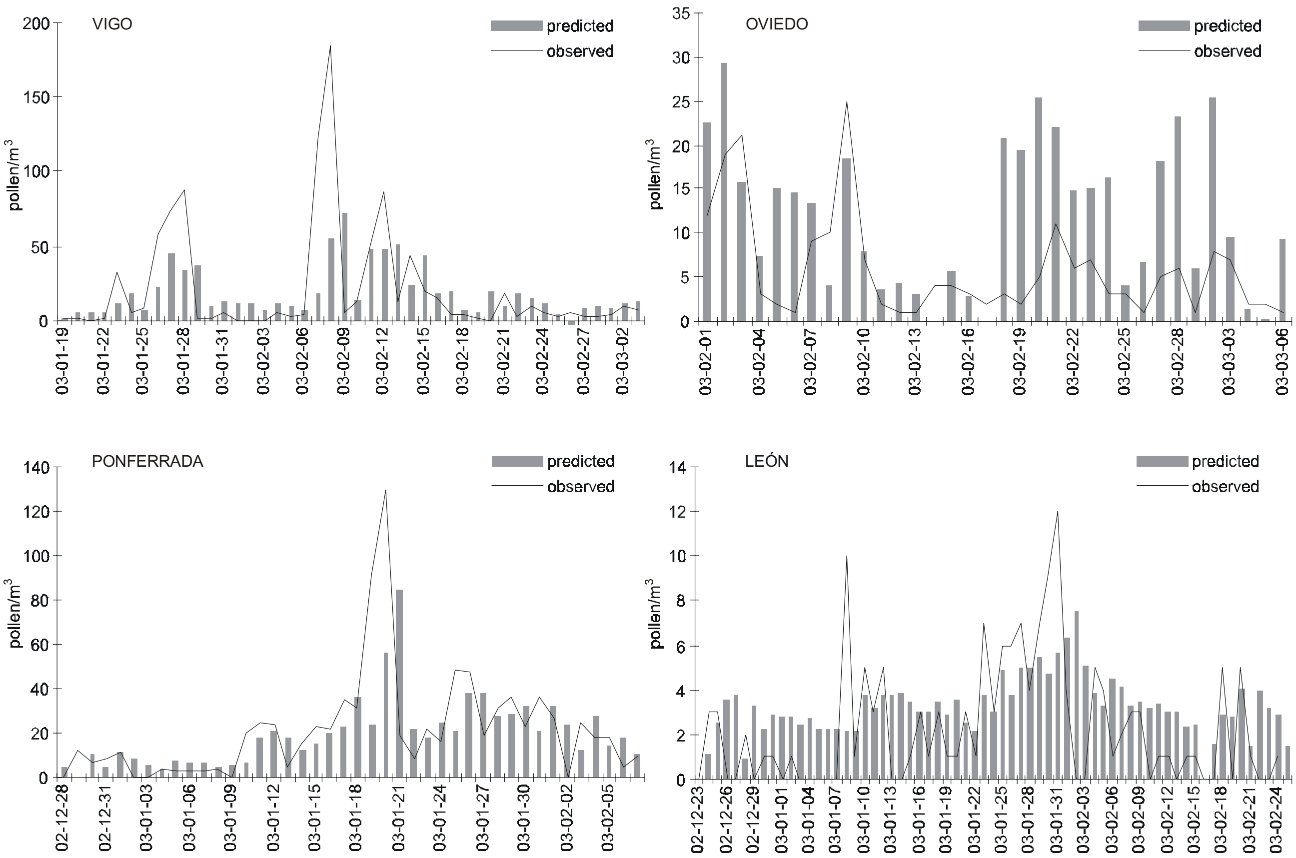

Figure 3. Predicted values (bars) and observed values (line) of *Alnus* pollen concentrations during 2003.

Spain where *Alnus* pollen allergic individuals should to take preventive measures to protect themselves from the severity of the pollen season.

In spite of the biennial concentration rhythms that make it difficult to find strong coefficient correlations with meteorological parameters, Spearman coefficients presents a p value <0.01 in a high number of cases. As a general rule, the positive higher and constant correlations coefficients during the years of study were founded with maximum temperatures and sun hours, as pointed out by different authors who have highlight the importance of these parameters during the pollination period [38] and during the period prior to flowering [23]. The negative influence of rainfall on airborne pollen grains is a global finding in aeropalynological studies. This is explained on the basis of the sedimentation of the grains and the corresponding increase of the relative humidity [47], and was also significantly manifested in the present study. Wind also highly influences *Alnus* pollen concentrations. The negative sign or no significant correlation with wind speed, and positive one with wind calms, may indicate that the captured pollen is from sources of pollen centred in the immediate vicinity of the sampling sites. Transport and dilution is caused by the air movement, so that the wind dilutes and carries off the pollen accumulated in the zone [47]. These results reveal the effect of temperature on *Alnus* pollen levels. Therefore, maximum temperature was used in both localities to establish models for both the onset of the pollen season and the pollen concentrations that may be attained during such seasons. Numerous authors have highlighted this parameter's influence on pollination [25, 39, 41].

Linear logistic models are usually used in aerobiological studies aimed at predicting pollen concentrations. Regression lines of these models, using only meteorological variables as prediction variables, produce results with a low prediction level, which shows that the former do not explain such behaviour on their own. Other variables that reflect better the series of factors affecting the plant, and on which its pollen production and release depends, should be taken into account. In this regard, the pollen concentrations of previous days reflect this series of factors substantially improving the prediction capacity of the models and are often included as a predictor variable. In this way, the proposed Time Series Arima models are more accurate for predicting *Alnus* pollen concentrations. In spite of the lower concentrations registered during 2003, the estimated curve accurately describe the *Alnus* pollen grains' behaviour, founding in some cases a decalage in the series of the same longitude as the prediction horizon. The prediction line proposed for Oviedo (Arima 2,0,1) takes into account values of the three previous days, 1 day running mean and maximum temperature. The values registered during the third week of February were overestimated as a consequence that during this period the *Alnus* flowering in Oviedo

Table 4. Values of Arima test coefficients.

		B	SEB	T-ratio	p value
VIGO	AR1	1.051	0.118	8.947	0.000
Analysis of variance:	AR2	-0.313	0.078	-4.025	0.000
Sum of Squares 227747.40	AR3	0.164	0.055	2.975	0.003
Residual Variance 537.5883	MA1	0.659	0.113	5.824	0.000
Residuals 423	T max.	2.519	0.504	5.003	0.000
	constant	-19.413	7.851	-2.473	0.014
OVIEDO	AR1	0.651	0.133	4.888	0.000
Analysis of Variance:	AR2	0.218	0.099	2.186	0.029
Sum of Squares 308766.32	MA1	0.376	0.131	2.865	0.004
Residual Variance 1202.71	T max.	3.663	0.740	4.952	0.040
Residuals 255	constant	-19.321	13.924	-1.388	0.096
PONFERRADA	AR1	1.268	0.242	5.230	0.000
Analysis of variance:	AR2	-0.351	0.174	-2.013	0.045
Sum of squares 202569.47	MA1	0.690	0.224	3.076	0.002
Residual variance 525.43544	T max.	1.468	0.480	3.057	0.001
Residuals 384	constant	1.933	6.680	0.289	0.172
LEÓN					
Analysis of variance:	AR1	0.688	0.082	8.405	0.000
Sum of squares 23291.194	MA1	0.372	0.105	3.550	0.000
Residual variance 53.15230	T max.	0.199	0.032	6.119	0.000
Residuals 438	constant	2.438	0.772	3.157	0.002

coincides with the presence of strong precipitations rainfall producing atmospheric cleansing.

A similar model was proposed for Ponferrada, while in Vigo the more accurate model founded was Arima (3,0,1) and in León (1,0,1). The predicted lines fitted the observed values, overall in the case of León and Ponferrada.

CONCLUSIONS

In northwestern Spain alder tree flowers at the start of winter during the first half on January, and there is low variations in the start date of the *Alnus* pollen season. In spite of February being the month in which the higher levels were recorded, daily maximum concentration was usually registered in January or February. The results suggest that Ponferrada and Oviedo are the cities of northwest Spain where *Alnus* pollen allergic individuals should take preventive measures to protect themselves from the severity of the pollen season. *Alnus* pollen values higher than 30 grains/m^3, a quantity considered sufficient to trigger severe allergy symptoms of other trees of the Betulaceae family, could be reached during 25 days in some years. The quantity of total pollen was highly variable, making it difficult to found strong correlation coefficients with meteorological parameters and confident prediction models. Maximum temperature, sun hours and rainfall are the meteorological parameters that most influence the levels of *Alnus* pollen in the atmosphere. In spite of the lower concentrations registered during 2003, the estimated curve calculated with the proposed Arima models fitted the observed values. As previously expressed, this situation suggests that the currently available meteorological variables are not sufficiently explicative. Time Series regression models are especially suitable in allergology for evaluating short-term effects of time-varying pollen appearance in the atmosphere.

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