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Bioclimatic factors affecting daily Cupressaceae flowering in southwest Spain

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Abstract Daily variations in Cupressaceae pollen counts were analysed, together with climatic variables in the southwest of Spain, in order to understand the bioclimatic variables affecting Cupressaceae flowering in a Mediterranean climate. The study was carried out using the Spanish Aerobiology Network recommendations, using a Burkard Hirst-type spore trap. Regression analyses were applied to the pollen counts of the winter months of 13 consecutive years. The regression analysis applied to each year indicated that temperature is the most important variable to include in the model. Temperature affected the pollen counts differently according to the yearly climatic trend. During the coldest years, pollen counts depended on the minimum temperature, while in the warmest ones they were affected by higher temperatures. However, during the driest years, pollen counts depended more on the humidity level, while in the wettest years they depended more on the hours of sunshine.

Key words Cupressaceae airborne pollen · Biometeorology · Allergenic pollen · Pollen forecast

Introduction

The Cupressaceae family produces stenopalynous pollen grains, characterized as spheroidal, intectate and monoporate, with a distinct annulus. The pollen has remained largely unnoticed due to its small size and its tendency to fracture. Its structure is uniform and consists of round to polygonal scabrate microverrucae or microgemmae, which may be covered with microechinae (Bortenschlager 1990).

Although species of three genera (*Cupressus*, *Thuja* and *Juniperus*) are relatively common in the province of Córdoba, only those of *Cupressus* are sufficiently common to produce enough airborne pollen during air sampling. *Juniperus* species are found in the mountains, north and south of the province, far from urban areas. *Thuja* species are used throughout the city as hedges, but their pruning does not usually allow them to blossom into flower. The different species of *Cupressus* are not native to southern Spain but are adaptable enough to grow in the area. During the past 40 years, trees of this genus have been planted profusely for reforesting the mountains around Córdoba. This provides a good example of how environmental change can produce an important epidemiological effect, similar to what occurred in Bari, Italy (Caiaffa et al. 1993).

Airborne pollen counts do not usually separate Cupressaceae pollen from that of Taxaceae and Taxodiaceae, because of their similar morphology. However, species from Taxaceae and Taxodiaceae are not common in urban areas.

Cupressaceae pollen plays an important role as an airborne allergen in the Mediterranean area, particularly in Italy, France and Israel. Moreover, the diagnosis of allergy to *Cupressus* is usually unequivocal in Mediterranean countries since this genus has its pollination season in the winter, when no other plant is flowering (D'Amato and Liccardi 1994). This type of pollen is most commonly found in the atmosphere of the city of Córdoba, accounting for at least 30% of the total pollen count during the winter season (Ruiz de Clavijo et al. 1988). However, it was only in the 1990s that the Allergy Unit of the Reina Sofía Hospital gave importance to Cupressaceae pollen as an allergen. A positive skin test reaction was observed in 35% of allergic patients (Guerra et al. 1996).

It is well known that the atmospheric pollen concentration fluctuates with weather changes. Conifer pollen is produced in two or more pollen sacs on the lower side of the male cone scales. Some Cupressaceae species have hygroscopic mechanisms protecting their pollen from rain. Cone scales interlock closely in damp weather and

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allow pollen release only in dry weather, when cone scales become separated (Gregory 1973). Once pollen grains have been released, other variables will control their dispersal and transport.

Because of the prevalence of this type of pollen in our region, the influence of the most important meteorological variables on daily pollen counts was investigated in order to achieve a better understanding of the bioclimatic conditions governing Cupressaceae flowering phenology in a Mediterranean climate.

Past studies on pollen count forecasts have generally tried to predict only the most significant parts of the annual pollen time series, such as the date of onset of the pollen season or the dates of peak pollen counts. Less attention has been paid to models giving forecasts for each day of the main pollen season. Pollen forecast models can be divided into two groups: those centred on multiple regression analyses (Emberlin and Norris-Hill 1991a; Galán et al. 1995) and those centred on time series analysis (Moseholm et al. 1987). Because the latter method incorporates, as a variable, the previous pollen counts up to the date for which a forecast is needed, it generally gives more precise forecasts. However, the models have only been applied to herbaceous taxa, such as grasses or ragweed, which show a clear and recurrent pollen profile year after year (Comtois and Sherknies 1992), i.e. a trend that is easy to extract directly from the cumulative pollen counts. This is not the case for most tree species and certainly not for Cupressaceae. This family is the first to flower, at the end of winter, at a time when variable temperature trends make it unlikely that a particular pattern will recur over the years. Our study was therefore built on the application of regression analysis.

Materials and methods

Córdoba is a semi-rural city of 300,000 inhabitants located in the southwestern part of the Iberian Peninsula, at an altitude of 123 m above sea level, in the Guadalquivir valley (37° 50' N and 4°

45' W). The climate of Córdoba is typically Mediterranean with a weak continental influence. The average annual precipitation is 670 mm and the average yearly temperature is 18°C.

The present study was undertaken using the Spanish Aerobiology Network (REA) recommendations, using a Burkard Hirst-type spore trap. Daily pollen counts were obtained by means of four continuous horizontal scans, at a magnification of 400×. Counts were multiplied by a factor of 0.54 in order to give a daily mean pollen concentration per cubic metre of air.

Pollen counts for the winter months (from 21 December to 21 March) of 13 consecutive years (1982–1994) were collected. The main pollen season has been defined as the period of the year which accounts for 95% of the total annual catch (Nilsson and Persson 1981). Acknowledging that the frequency distribution approximates to a bell-shaped curve, this procedure eliminates the long tails of low values at the start and the end of the season which may not accord with local phenology and may introduce an error in the statistical analysis. In order to decrease the daily stochastic sampling error, the 5-day moving average of each annual Cupressaceae pollen profile was calculated before submitting the data to any statistical analysis.

Cupressaceae pollen seasonal data for 13 consecutive years are presented in Table 1. Due to technical problems related to the sampler motor, the pollen counts for the years 1982, 1985, 1988 and 1989 are incomplete. In order to understand the influence of meteorological variables on daily pollen counts, the maximum, average and minimum air temperatures, average relative humidity, total daily rainfall and hours of sunshine have been studied. Meteorological data was supplied by the Meteorological Station of Córdoba Airport (National Institute of Meteorology). Linear, polynomial or multiple regression analyses have been applied to the daily meteorological and palynological data for each year to obtain the best possible predictive equation.

Results

During the period studied, the main Cupressaceae pollen season was found between the months of January and March (Table 1). The start of the season varied between 3 January and 26 January. The length of the pollen season varied between 39 and 71 days, and the highest concentrations of pollen were recorded between 11 February and 7 March. The maximum daily average was recorded in 1991 and accounted for 1002 grains per cubic metre of

Table 1 Descriptive parameters of each Cupressaceae pollen season (1982–1994)

Years	Total annual pollen (grains/m ³)	Start of season	End of season	Season length (days)	Maximum daily value of pollen (grains/m ³)	Date maximum value recorded
1982*	1460	26 Feb	22 Mar	25	174.72	7 Mar
1983	2428	25 Jan	4 Mar	39	752.22	22 Feb
1984	1621	14 Jan	17 Mar	64	341.67	2 Mar
1985*	895	27 Jan	16 Mar	49	100.28	23 Feb
1986	1269	19 Jan	20 Mar	61	333.26	28 Feb
1987	1833	3 Jan	12 Mar	69	244.68	28 Feb
1988*	2462	18 Feb	13 Mar	25	606.02	19 Feb
1989*	464	8 Jan	4 Feb	28	96.14	23 Jan
1990	1979	15 Jan	15 Mar	60	252.78	3 Mar
1991	4035	13 Jan	11 Mar	58	1001.9	23 Feb
1992	4025	26 Jan	10 Mar	45	413.19	23 Feb
1993	4026	17 Jan	18 Mar	61	373.56	14 Feb
1994	1528	13 Jan	25 Mar	71	126.72	11 Feb

* Incomplete season

Table 2 Average yearly climatic conditions (1982–1994). Mean values for average temperature (T_{ave}), maximum temperature (T_{max}), in minimum temperature (T_{min}), rainfall and humidity for the three winter months of each year are shown

	T_{ave} (°C)	T_{max} (°C)	T_{min} (°C)	$T_{max}-T_{min}$ (°C)	Rainfall (mm)	Humidity (%)
1982	12.0	17.9	6.1	11.8	255	75
1983	10.8	18.1	3.5	14.6	127	71
1984	9.5	15.2	3.9	11.3	145	74
1985	10.7	16.5	5.0	11.5	222	73
1986	10.3	15.4	5.2	10.2	185	81
1987	11.3	17.1	5.5	11.6	231	78
1988	11.6	17.6	5.6	12.0	128	79
1989	11.9	18.3	5.3	13.0	119	74
1990	12.4	19.0	5.9	13.1	94	73
1991	10.4	15.7	5.0	10.7	511	80
1992	10.2	17.5	3.0	14.5	104	67
1993	10.8	18.4	3.3	14.1	9	65
1994	11.2	18.0	4.6	13.7	106	71

Table 3 Polynomial regression equations used to forecast the daily pollen catch (5-day moving average, y) using the different meteorological variables (x) of the hours of sunshine, humidity, maximum temperature (T_{max}), minimum temperature (T_{min}) and average temperature (T_{ave})

Years	Variable (x)	R^2
1982	Sunshine $y = -861.8 + 332.2x - 42.8x^2 + 1.85x^3$	73%
1983	T_{min} $y = -4.18 + 0.69x + 0.95x^2$	77%
1984	T_{min} $y = 392.4 - 552.8x + 265.4x^2 - 36.14x^3$	87%
1985	T_{max} $y = 624.4 - 63.4x + 1.64x^2$	40%
1986	T_{max} $y = -9.08 + 2.28x - 0.52x^2 + 0.03x^3$	44%
1987	T_{max} $y = -3.05 + 0.382x + 0.00753x^2 - 0.00021x^3$	43%
1988	T_{ave} $y = 2.94 - 1.02x + 0.46x^2$	85%
1989	Humidity $y = -77.8 + 2.39x - 0.018x^2$	61%
1990	Humidity $y = -23.79 + 0.753x - 0.00577x^2$	67%
1991	T_{max} $y = 241.5 - 37.90x + 1.44x^2$	73%
1992	T_{max} $y = -1.18 + 1.68x - 0.06x^2$	15%
1993	T_{max} $y = -26.59 + 1.90x$	9%
1994	Humidity $y = -39.279 + 0.865x$	24%

Table 4 Multiple regression equations used to forecast the daily pollen catch (5-day moving average, y) using the different meteorological variables of the hours of sunshine (SH), rainfall (R), humidity (H), maximum temperature (T_{max}), minimum temperature (T_{min}) and average temperature (T_{ave})

Year	r^2
1982	$y = 91.094 - 4.607T_{max} + 8.795SH$ 36%
1983	$y = 195.93 - 11.9T_{max} + 36.86T_{min} - 31.67R$ 64%
1984	$y = 82.049 + 3.401T_{max} - 477SH - 1.077H$ 13%
1985	$y = 70.11 - 2.818T_{max} - 0.656R$ 23%
1986	$y = -31.27 + 41.803T_{ave} - 18.39T_{max} - 18.69MIN T$ 38%
1987	$y = -46.12 + 3.72T_{max} + 2.09SH$ 39%
1988	$y = -49.906 + 16.89T_{min} + 12.258SH$ 24%
1989	$y = 125.95 - 3.66T_{max} + 2.086SH - 0.78H$ 70%
1990	$y = 92.036 + 3.676T_{ave} - 1.28H$ 23%
1991	$y = -165.109 + 22.128T_{ave} + 6156SH$ 38%
1992	$y = 126.31 - 5.87T_{max} + 9.53T_{min} + 7.97SH$ 28%
1993	$y = -42.01 + 3.376T_{max} + 3.83SH$ 13%
1994	$y = -40.351 + 0.674T_{max} + 0.697H$ 11%

air. The end of the season was found between 4 March and 25 March.

Table 2 represents the average climatic conditions for the three winter months of each year. Data from this table suggest that some winters were clearly colder with an average minimum temperature below 4°C (1983, 1984, 1992 and 1993). The warmest winters were 1982 and 1990. The winters experiencing the highest degree of precipitation (total rainfall over 119 mm) were 1982, 1985, 1989 and 1991 while the driest winters (total rainfall below 100 mm) were 1990 and 1993. During the latter year, only 9 mm of rain was recorded.

Figure 1 represents daily pollen counts, temperature and rainfall for each year. Their analysis reveals that, after an initial priming of decreasing temperature, and in the absence of subsequent rainy days, pollen counts increase together with an increase in temperature. We can therefore observe a pollen curve characterized by one or several peaks.

The best results using meteorological data as independent variables influencing the daily Cupressaceae pollen counts were obtained with polynomial regression. The explained percentage variation in pollen count ranged from 9% to 87% (Table 3). The most important factor is

temperature, followed by humidity. Only once (in 1982), was the length of sunshine predominant. Since the polynomial order changes yearly, it was not considered practical to use these equations for real-time forecasting. Therefore, analyses were repeated for each year using only multiple linear regressions (Table 4).

Because variations in pollen counts for the consecutive years 1983 and 1984; 1985, 1986 and 1987; 1989 and 1990; and 1991, 1992 and 1993 are best explained by respectively, minimum temperature (1983 and 1984), maximum temperature (1985, 1986 and 1987; and then 1991, 1992 and 1993), and humidity (1989 and 1990) (Table 3), we can combine these yearly equations into equations for multiple years as follows:

1983 and 1984:

$$y = 10.07 + 6.74x \pm 1.98x^2; r^2 = 39\%$$

1985, 1986 and 1987:

$$y = -98.3 + 23.08x - 1.53x^2; r^2 = 15\%$$

1989 and 1990:

$$y = -1000.18 + 43.63x - 0.58x^2; r^2 = 3\%$$

1991, 1992 and 1993:

$$y = 194.95 - 44.72x \pm 3.66x^2 - 0.08x^3; r^2 = 8\%$$

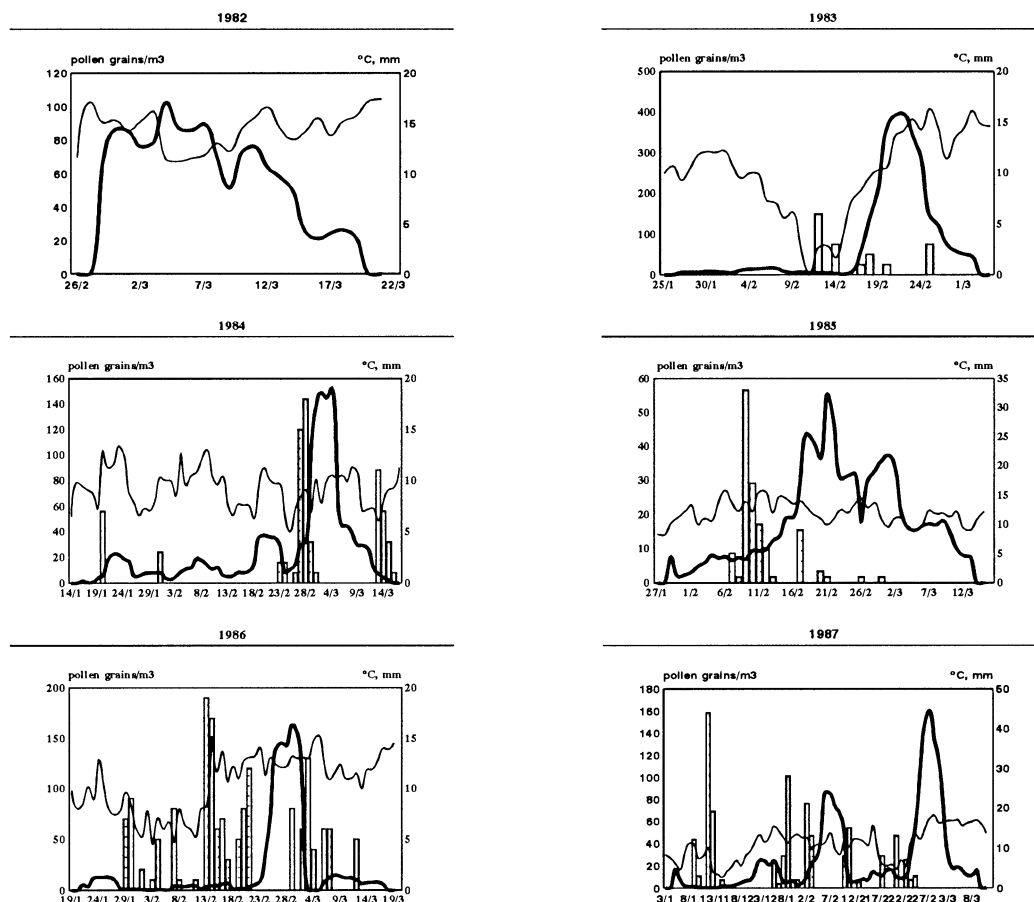


Fig. 1 Daily Cupressaceae pollen variation (5-day moving average), average temperature and total rainfall (1982–1994). The time series on the horizontal axis does not cover the same period in every year because of variations in the starting date of the pollen season

These regressions consistently explain less of the variation in daily pollen counts than those established for individual years. As Table 3 suggests, there is always a change in the regression coefficients for consecutive years. Even when the regression equations used the same regression variables, we often see a change in the direction of their effect on a yearly basis (for example, the coefficient applied to the same variable can be negative for one year and positive for the subsequent year). Only relative humidity seems to be associated with more constant regression coefficients. Therefore, the mean regression coefficients are not really meaningful when applied to the “joint consecutive years” data set. Indeed, the Spearman’s correlation coefficient (ρ) found between the mean Pearson’s coefficient for consecutive years and the one found for the cumulative data set is 0.80 (P 0.06).

Discussion

Our results agree with the findings of previous papers. The main variables with a positive effect on Cupressac-

ae pollen variation are temperature and the hours of sunshine, while relative humidity has the highest negative effect. Under the influence of these variables the scales of male cones in some conifers will open or close (Gregory 1973). Higher temperatures provoke air convection and as the air becomes turbulent pollen is dispersed (Norris-Hill and Emberlin 1991).

The usual effect of rainfall is to wash out particles in the atmosphere, at least when heavy showers occur. Light rainfall, for its part, can bring clouds of particles from the highest layer of the atmosphere to the ground. This is due to the coalescent effect of water drops on pollen grains, which then act as condensation nuclei. Moreover, light rainfall, together with a turbulent situation, may provoke a re-suspension of the particles that have previously been deposited on the ground or on any obstacle (Emberlin and Norris-Hill 1991b). Finally, the harmomegate characteristic of the Cupressaceae pollen grains permits them to inflate when humidity is high, and they fall down as they become heavier.

The daily pattern of Cupressaceae pollen counts was quite different every year (Fig. 1). This is because we have a different meteorological situation each year. Some winters are colder and drier, while others are warmer or present significantly higher levels of precipitation (Table 2). In climatically different years, it is to be expected that the important meteorological variables will differ, and this is reflected in our predictive formulas. Similar con-

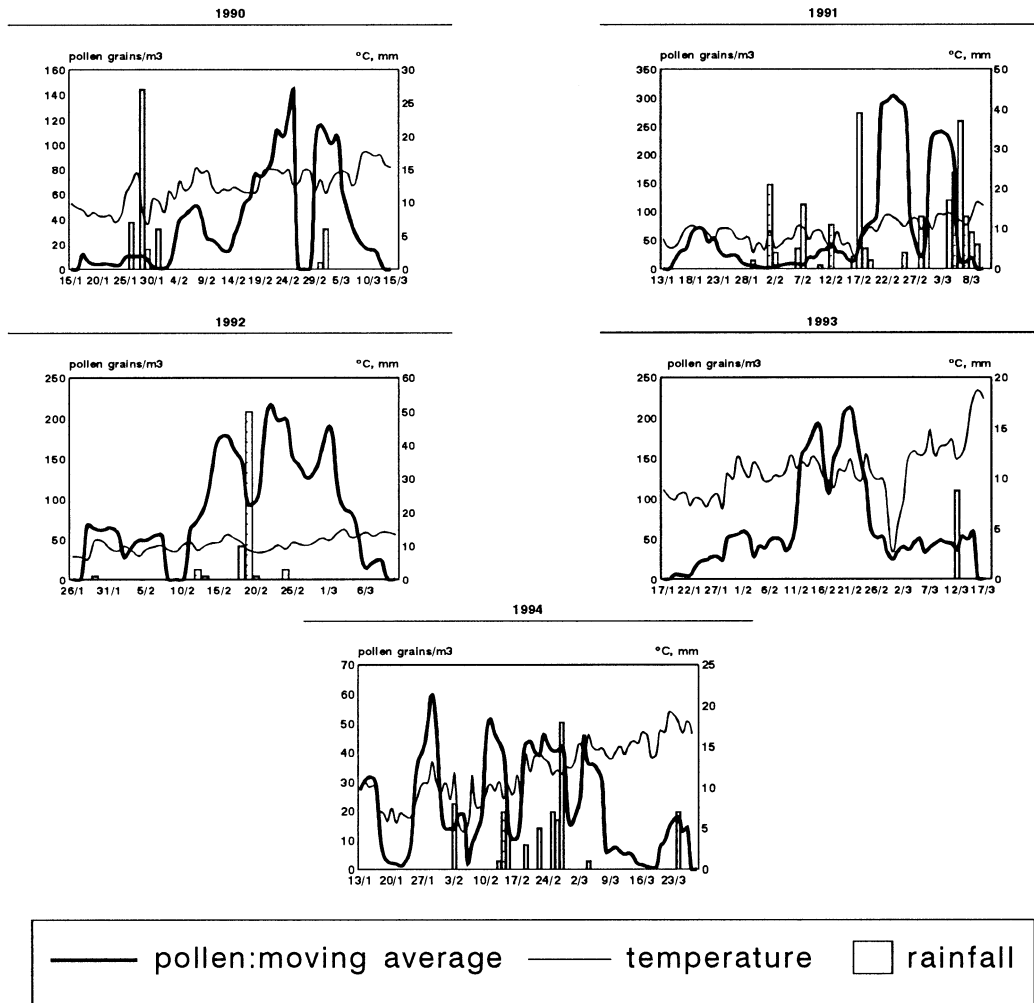


Fig. 1

clusions were reached by Emberlin and Norris-Hill (1991a) in London for Urticaceae pollen.

The regression results show that temperature is the most important parameter to be included in any model. However, in the driest years (e.g. 1989 and 1990), pollen counts are linked more to the humidity level, while in years with heavy rainfall (e.g. 1982, 1987 and 1991), pollen counts are linked more to the hours of sunshine. It was also shown that different threshold temperatures will affect pollen counts in different years. In the coldest years (e.g. 1983, 1992 and 1993), pollen counts could be linked to minimum temperatures, while in other years pollen counts were governed by maximum temperatures.

From 1991, a 3-year drought made it difficult to find a dominant meteorological variable that significantly affected the Cupressaceae daily pollen curve. It can be seen that in years with minimum temperatures below 4°C (1992 and 1993) more airborne pollen was registered than in 1994, when minimum temperatures were higher. For this reason, temperature, and sometimes relative humidity and the hours of sunshine, directly influence Cupressaceae daily pollen variation, but their relative effect will be felt differently each year. With long-term weather forecasting, it should be possible to choose the meteorological

variable that will produce the most reliable pollen forecast.

If multiple regression analysis is used for all the years taken together, temperature and the hours of sunshine explain most of the variation in the daily Cupressaceae pollen counts, and are therefore the most efficient coefficients to use in unknown situations (i.e. when meteorological characteristics of the whole winter are unknown). However, these variables only explain, on average, 8% of the total variation in Cupressaceae day-to-day pollen concentrations. The average predictive formula is as follows:

$$y = -23.11 + 5.552 T_{\text{ave}} + 2.38(\text{SH})$$

where T_{ave} = average temperature and SH = hours of sunshine

We have only presented here only results related to statistical analyses. With more field data, particularly phenological data, it should be possible to produce biological models, i.e. models that could reproduce the whole pollination cycle of Cupressaceae.

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