Aerobiology of Artemisia airborne pollen in Murcia (SE Spain) and its relationship with weather variables: Annual and intradiurnal variations for three different species. Wind vect...

Article *in* International Journal of Biometeorology · November 1999

DOI: 10.1007/s004840050116 · Source: PubMed

Manuel Munuera
Universidad Politécnica de Cartagena - UPCT
87 PUBLICATIONS **2,633** CITATIONS

José Carrión
University of Murcia
324 PUBLICATIONS **13,155** CITATIONS

Int J Biometeorol (1999) 43:51–63

ORIGINAL ARTICLE

Manuel Munuera Giner · José S. Carrión García
Javier García Sellés

Aerobiology of Artemisia airborne pollen in Murcia (SE Spain) and its relationship with weather variables: annual and intradiurnal variations for three different species. Wind vectors as a tool in determining pollen origin

Received: 6 May 1998 / Revised: 24 February 1999 / Accepted: 12 March 1999

Abstract Detailed results from a 2-year survey of airborne pollen concentrations of *Artemisia* in Murcia are presented. Three consecutive pollen seasons of *Artemisia* occurring each year, related to three different species (*A. campestris*, *A. herba-alba* and *A. barrelieri*), were observed. A winter blooming of *Artemisia* could explain the incidence of subsequent pollinosis in the Murcia area. With regard to meteorological parameters, mathematical analyses showed relationships between daily pollen concentrations of *Artemisia* in summer–autumn and precipitations that occurred 6–8 weeks before. The cumulative percentage of insolation from 1 March seemed to be related to blooming onsets. Once pollination has begun, meteorological factors do not seem to influence pollen concentrations significantly. Intradiurnal patterns of pollen concentrations were similar for late summer and winter species (*A. campestris* and *A. barrelieri*). During autumn blooming (*A. herba-alba*), the intradiurnal pattern was particularly erratic. Theoretical values of wind run were obtained for each pollen season by the graphical sum of hourly wind vectors. When theoretical wind run was mapped onto the vegetation pattern, supposed pollen source locations were obtained for each hour. By comparing supposed hourly pollen origins with the intradiurnal patterns of pollen concentrations, it can be seen that this simple model explains variations in mean pollen concentrations throughout the day.

Key words *Artemisia* pollen · Annual and intradiurnal variations · Meteorological relationships · Pollen origin · Wind transport

M. Munuera Giner (✉) · J.S. Carrión García
Departamento de Biología Vegetal (Botánica),
Facultad de Biología, E-30100 Espinardo, Murcia, Spain
e-mail: mmunuera@fcu.um.es
Fax: +34 968 363 963

J. García Sellés
Sección de Alergia (R. General). H.U. "Virgen de la Arrixaca",
El Palmar, Murcia, Spain

Introduction

Murcia is a province located in southeastern Spain (Fig. 1). The main city is Murcia (population 156 000) and about 50 towns and villages, with a total population close to 400 000 people, are found within a radius of 15 km around the sampling site (4 km from Murcia city). Because of the particular type of climate, there are many plants flowering throughout the year. *Artemisia* is an important allergenic genus, with a prevalence of 23.5% and represents approximately 90% of the total count of the atmospheric Asteraceae in Murcia (García Sellés and Munuera 1996).

In an inital report based on 1-year's data on airborne pollen in the Murcia area (Munuera et al. 1995), an interesting pattern of pollen production from *Artemisia* was noticed, showing two different pollen seasons in the

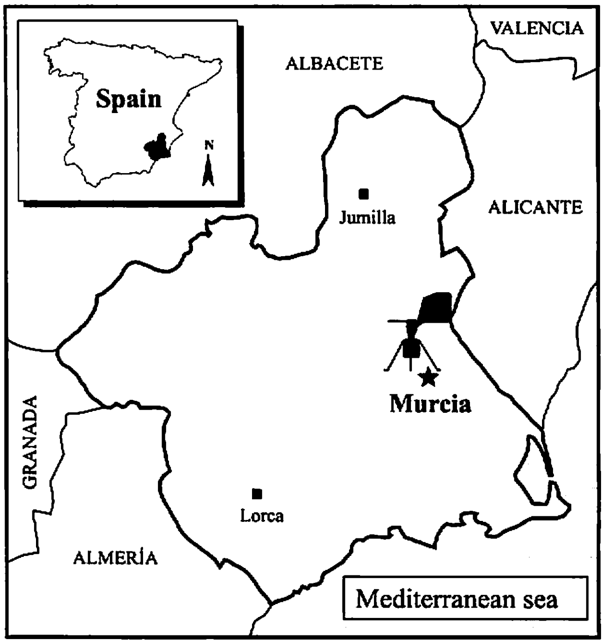


Fig. 1 Sampling site

year, occurring in late summer and winter. Such pattern had not been reported hitherto in Europe. Further studies (Munuera et al. 1996) reported a third blooming during autumn. These pollen seasons (late summer, autumn and winter) were related to three different species of *Artemisia* (*A. campestris*, *A. herba-alba* and *A. barrelieri*). The aims of this paper are to present the results obtained from a fuller analysis of the relationship between weather variables and pollen production, investigated on the basis of a 2-year study. This aimed to establish intradiurnal variations of pollen production for these three species (as well as the possible relationship with hourly meteorological factors) and to provide a simple graphical method to determine the location of pollen sources.

Materials and methods

By using a Burkard spore-trap located on the exposed flat roof of the Veterinary Faculty, Murcia University (19 m above ground level, 110 m above sea level, 38° 01' N, 1° 10' W, 4 km NW of Murcia city), airborne pollen was monitored from 1 March 1993 to 28 February 1995. There are no taller buildings in the immediate vicinity of the faculty. Daily slides were prepared from weekly ribbon strips following standard methods and were examined by light microscopy.

Daily pollen data were obtained by counting all pollen grains on four longitudinal transects. Missing and rainy days (those with rainfall above 0.1 l/m^2) were not taken into consideration in the calculations.

In order to determine the onset and length of the main pollen seasons, several methods were initially tried (Mullenders et al. 1972; Pathirane 1975; Nilsson and Persson 1981; Andersen 1991). We finally chose the method of Nilsson and Persson (1981): the pollen season is the period from when the sum of daily mean concentrations reaches 5% of the annual sum, until the time when it reaches 95% of the annual sum. For the winter blooming, the Pathirane method (1975) appeared to fit better.

As expected, *Artemisia* pollen counts did not follow a Normal distribution, even after logarithmic or square-root transformations; the same was true for meteorological data. For this reason pollen concentrations were measured and non-parametric tests used. Mathematical analyses were carried out by using the computer program SPSS 5.0 (SPSS, Chicago).

For annual comparisons, in order to allow for annual variations in total pollen production (Fig. 2A), daily pollen counts (grains/m^3) were standardised to percentages of the annual amount and transformed into 7-day running means, centred on the 4th day (Fig. 2B). In this figure all days were included.

For intradiurnal variations, only days with above average concentration have been considered (Table 1) and in graphical representations, hourly pollen counts (Spanish official time, UT+2 in spring–summer and UT+1 in autumn–winter) have been standardised to percentages and then transformed into 3 h running means (centred in the 2nd h). Annual models are also shown as a mean for the two years involved.

The Centro Meteorológico Territorial of the Instituto Nacional de Meteorología (3.6 km from the sampling site) provided the meteorological data (Fig. 3). The variables and abbreviations used in annual studies are shown in Table 2. The hourly meteorological data used for intradiurnal analyses were mean temperature (T) and relative humidity (RH) at peak hours, wind run in the last hour (WR), and maximum wind speed (WS) and its direction (WD) over 10 min previous to peak hours.

Finally, in order to determine sources for *Artemisia* airborne pollen in the Murcia area, graphical representations of the hypothetical wind routes throughout the day were constructed. For each hour between the onset and the end of the pollen curves, wind vectors have been designed. These vectors have WR as size and WD as direction (were 0°=N and 180°=S). Afterwards, the sum of the wind vectors was sketched on a map, showing theoretical routes of the pollen recovered in the Burkard trap.

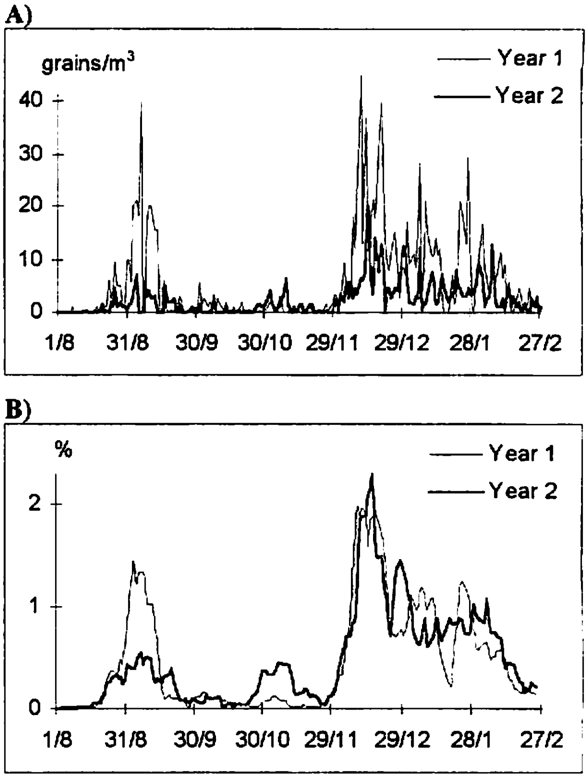


Fig. 2(A) Daily pollen concentrations; **(B)** 7-day running mean of standardised values (percentages of annual pollen concentration)

Table 1 Main pollen data

	Number of days			*Artemisia* pollen (grains/m^3)		
	Total	Rainless	Above average[a]	Total	Rainless days	Above average[a]
Summer 1	24	20	9	494	452	374
Summer 2	40	35	10	125	120	81
Autumn 1	17	12	4	27	20	18
Autumn 2	28	24	6	79	63	42
Winter 1	75	71	26	1762	1585	1131
Winter 2	76	73	29	778	743	511

[a] For days when pollen concentrations were greater than average

Results and discussion

Annual tendencies in meteorological factors were very similar between the two 12-month periods, but differences were observed in the graphical and mathematical (Mann–Whitney U-test) comparisons of data. The second period was warmer and drier than the first (Fig. 3), but less windy.

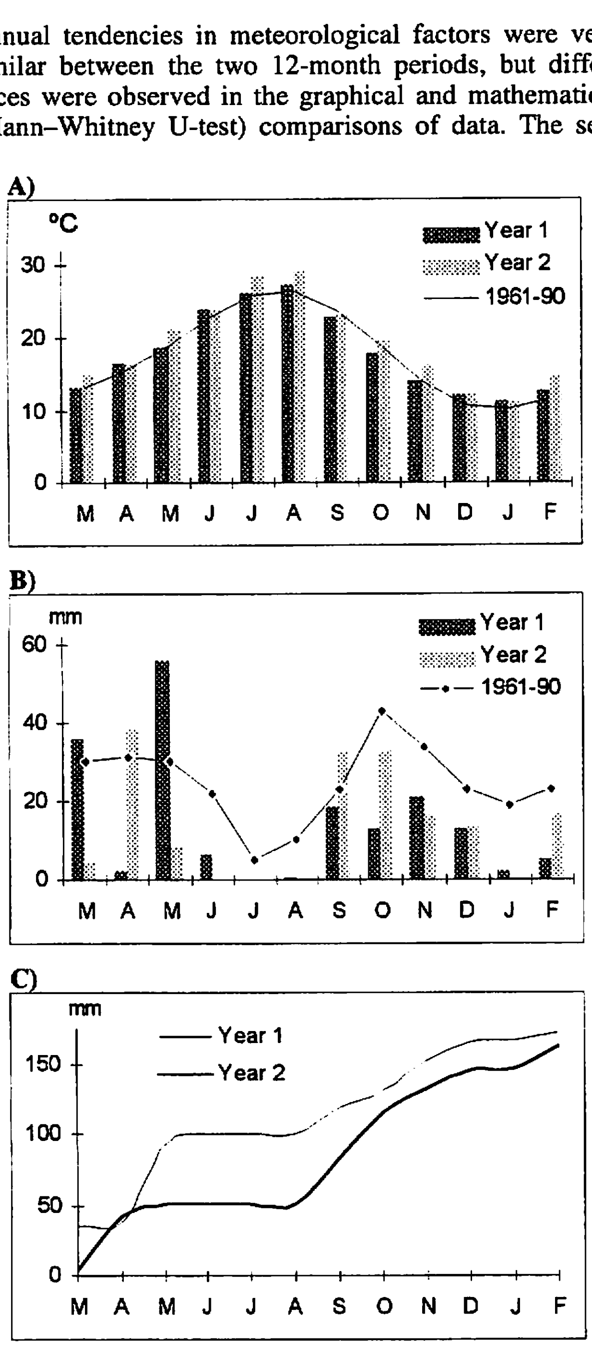


Fig. 3 Monthly meterorological data: (**A**) mean temperatures; (**B**) rainfall; (**C**) cumulative rainfall

Figure 2 shows the whole pollination period for *Artemisia* (90% of the annual amount), including three different pollen seasons: a late-summer pollen season (*A. campestris*), a brief flowering about November (*A. herba-alba*) and a third pollen season starting in late autumn and lasting for most of the winter (*A. barrelieri*). Each will be described separately later. Finally, results about determining the origin of the pollen will be included.

For the 12-month periods considered, both the length and starting date of the whole pollination period (Table 3A) were very similar, with a 7-day advancement of the second period that could correspond to a 1.2°C higher spring temperature, similarly reported by Fitter et al. (1995) in England. The beginning of the pollination period appeared to correlate with the cumulative temperatures from 1 March (Table 3B), particularly with T_{min}_0.15_cum. Further results from later years are needed to test this hypothesis.

Whole 12-month periods showed large differences in pollen amounts (Table 3A, Fig. 2A) but no disparity was found in the annual distribution patterns of pollen concentrations, particularly considering the running mean of standardised values (Fig. 2B).

Several atmospheric factors showed good correlation with daily pollen concentrations (Table 3C) during the pollination period, and its onset seemed to be related to days when certain cumulative temperatures were reached (Table 3B). However, it would be unsafe to extrapolate these results, bearing in mind the considerable length of the period studied, including flowering periods (summer, autumn and winter) that were related to three different species. In other words, airborne pollen concentrations and meteorological parameters might show different relationships for each season. Therefore, it would be more realistic to study these relationships independently by season.

Late summer season: *A. campestris*

Interannual variation

In spite of differences in the onsets of the whole pollination periods, the beginning of the late summer blooming coincided for both years (Table 4A). The percentage of cumulative insolation from 1 March seemed to be related with the beginning and maximum dates (Table 4D).

Table 2 Meteorological variables and their abbreviations

Evapo	Evaporation	T_{max}	Maximum temperature
Insol	Percentage of insolation	T_{max}_cum	Cumulative T_{max} from 1 March
Insol_cum	Cumulative Insol from 1 March	T_{min}	Minimum temperature
P_cum	Cumulative precipitation from 1 March	T_{min}-n	T_{min} n days before
P_cum-n	P_cum n days before	T_{min}_0.15	T_{min} at 15 cm above floor level
RH00	Relative humidity at midnight	T_{min}_0.15_cum	Cumulative T_{min}_0.15 from 1 March
RH07	Relative humidity at 7 a.m.	T_{min}_cum	Cumulative T_{min} from 1 March
RH13	Relative humidity at 1 p.m.	WR	Wind run per day
RH18	Relative humidity at 6 p.m.	WS	Wind speed

Table 3 Whole pollination period: **A** main characteristics; **B** relationships with cumulative temperature from 1 March; **C** day-to-day correlations with meteorological factors

A

	Whole pollination period			Total pollen (grains/m^3)	
	Onset	End	Days	Pollen season	Annual amount
1st period	31-08-93	09-02-94	163	1132	1248
2nd period	24-08-94	11-02-95	172	489	541

B

	1st period	2nd period
Onset	31-08-93	24-08-94
T_{max}_cum >5100°C	01-09-93	23-08-94
T_{min}_cum >2700°C	03-09-93	23-08-94
T_{min}_0.15_cum >2300°C	30-08-93	25-08-94

C

	1st period	2nd period
	Whole period	Whole period
Evapo	0.0782	0.0499
Insol	0.2750**	0.1936*
P_cum	0.3795**	0.4852**
RH00	–0.1797*	–0.2470**
RH07	–0.1107	–0.1108
RH13	–0.2659**	0.0614
RH18	–0.2250**	–0.0564
T_{max}	–0.0550	–0.3462**
T_{min}	–0.2804**	–0.4833**
T_{min}_0.15	–0.2934**	–0.4910**
WR	0.0836	0.0160
WS	0.0482	–0.0386

*$P<0.05$ **$P<0.01$

Late summer blooming for the second period was lesser than in the first (Fig. 2A, Table 4A). This could be due to the rainfall recorded up to that time being merely half that of the first year (Fig. 3C), and undoubtedly, seriously affecting the plant development in the locality. In addition, the vegetative growth might have been favoured instead of blooming, due to the higher summer temperatures during the second year (Fig. 3A).

By means of the Spearman method, day-to-day correlations between *Artemisia* pollen concentrations and atmospheric variables have been studied for the whole summer period and for the time until the maximum concentration (Table 4C). A negative sign for P_cum during the second summer was a consequence of a gradual increase in P_cum at the end, when pollen concentrations were falling. Particularly interesting were correlations with the rainfall recorded over the previous few weeks for the 1st year, being noticeable for a period of 6–8 weeks (Table 4B).

For the second summer, quadratic regression showed values of nightly RH (RH00 and RH07) greater than 60%, which could be related to the lowest *Artemisia* pollen concentrations, but when RH07 surpassed 80%, concentrations increased again. Other factors such as T, WR and evaporation, which influence RH, were correlated with the atmospheric pollen concentrations of *Artemisia* (Table 4C).

Intradiurnal variations

During both summers studied, the daily patterns of *T*, RH, WR and WS were almost coincident and their values similar (Fig. 4). Furthermore, those patterns correlated well with pollen concentrations (Table 5). WD showed different nightly behaviour between years, with a southern tendency in 1994 and mainly southwestern during 1993 (Fig. 5A). For both years, it was clear that there was a prevalent southeastern component between 1 p.m. and 11 p.m. Likewise, there was an evident coincidence between the pollen count curves (Fig. 4), increasing in parallel with the recovery of *T*, WR and WS, just when RH began to fall. The main features of the graphs are summarized in Table 6.

The midday pollen reduction coincided with a southern WD, when Murcia city and nearby Huerta (where *Artemisia* is certainly not common) were the theoretical pollen source areas (Fig. 8A). This drop was more noticeable during 1994, probably due to the smaller seasonal amount of pollen (approximately a quarter of the amount in 1993). The second peak and the subsequent fall in *Artemisia* concentrations were paralleled by falls in *T*, WR and WS, and the beginning of the rise in RH. All of these facts favour redeposition of pollen grains

Table 4 Late summer season: **A** main characteristics; **B** correlation with cumulative precipitations a given number of days earlier; **C** day-to-day correlation with meteorological factors; **D** relation with cumulative insolation from 1 March

A

	Late summer season				**Total pollen**
	Onset	Maximum	End	Days	grains/m^3
Summer 1	24-08-93	06-09-93	16-09-93	24	494
Summer 2	24-08-94	04-08-94	02-10-94	40	125

B

	Summer 1	**Summer 2**
*P*_cum-41	0.8001**	0.8082**
*P*_cum-42	0.8253**	0.8667**
*P*_cum-43	0.8063**	0.7921**
*P*_cum-44	0.8265**	0.7591**
*P*_cum-45	0.7845**	0.7484**
*P*_cum-46	0.6921**	0.5850*
*P*_cum-47	0.6927**	0.6264*
*P*_cum-48	0.6106**	0.5590
*P*_cum-49	0.5212*	0.3900
*P*_cum-50	0.5404*	0.3916
*P*_cum-51	0.5557*	0.4111
*P*_cum-52	0.6120**	0.6634*
*P*_cum-53	0.6595**	0.8721**
*P*_cum-54	0.6319**	0.7862**
*P*_cum-55	0.6579**	0.7194**
*P*_cum-56	0.7472**	0.7553**

*$P<0.05$ **$P<0.01$

C

	Summer 1		**Summer 2**	
	Whole period	Before maximum	Whole period	Before maximum
Evapo	0.0529	–0.3286	0.4915**	–0.2955
Insol	–0.2124	–0.3404	0.2684	0.2072
*P*_cum	0.7801**	0.7408**	–0.5439**	–
RH00	–0.0960	0.0458	–0.4817**	–0.1954
RH07	0.0202	0.4638	–0.4135*	0.2058
RH13	–0.2461	–0.0510	–0.3485	0.2219
RH18	0.0669	0.4183	–0.3145	0.2358
$T_{\max}$	0.2621	0.3922	0.4351*	–0.1643
$T_{\min}$	–0.1560	0.2566	0.3064	0.0251
$T_{\min}$_0.15	–0.1587	0.2531	0.2904	0.2111
WR	–0.5912**	–0.5290	0.4640**	0.2022
WS	–0.1625	–0.3150	0.1452	–0.0679

*$P<0.05$ **$P<0.01$

D

	Summer 1	**Summer 2**
Onset	24-08-93	24-08-94
Insol_cum >12 500%	25-08-93	24-08-94
Maximum	06-09-93	04-09-94
Insol_cum >13 300%	06-09-93	03-09-94

and spores in high levels and, therefore, the second peak may be due to the pollen released during the very early hours and coming from the more distant *A. campestris* populations. This hypothesis agrees with results of Käpylä (1981) in Finland and of Wahl and Puls (1989, 1991) in Germany, with pollen concentration curves which are broader and lower, and delayed peaks when pollen sources are remote and/or when pollen traps are installed at roof level.

Autumn season: *A. herba-alba*

Interannual variation

For both years, the autumn blooming began on almost the same date (Table 7A). Again, coincidences were observed between onset, maximum dates and dates when certain percentage cumulative insolation from 1 March was reached (Table 7E).

The interpretation of the late autumn blooming was difficult for the second year. Field observations suggested that the more prominent autumn *Artemisia* blooming observed during the 2nd year (Fig. 2) may have been due to: 1) an unexpected late blooming of *A. campestris* (owing to poor pollen dispersal in summer, when high temperatures could have favoured vegetative growth instead), and 2) an expected *A. herba-alba* blooming (but still higher than in the first year), owing to a slight increase in minimum temperatures in early October, together with the late September/early October rainfall. During the first year, the late autumn blooming was not well defined (Fig. 2B) but a slight increase in *Artemisia* concentrations during the first few days of November was certainly noticed. Therefore, for the first year, late autumn blooming probably related only to *A. herba-alba*.

Day-to-day correlations between *Artemisia* pollen counts and weather variables were explored (Table 7C). For the second year, the existence of a positive correlation with RH and negative correlations with evaporation, WR and WS are noteworthy.

Quadratic regressions showed that the autumn atmospheric content of *Artemisia* increased when RH13 was higher than 50%, RH18 higher than 65% and, particularly, when nightly RH (RH00 and RH07) was higher than 80%.

It is also worth mentioning that, for both years, there were very significant and positive correlations between *Artemisia* pollen counts (from the onset until the time the maximum count was reached) and minimum temperatures 28–30 days before (Table 7B), and with cumulative precipitation during the previous few days (Table 7D). In the 2nd year, correlations with precipitation extended back continuously to the last days of September (41 days before), when the rainfall was frequent. In the first year, correlations with precipitation were intermittently significant about 26, 33 and 40 days before. The interpretation of these correlations must be viewed with caution since they might be merely a statistical conse-

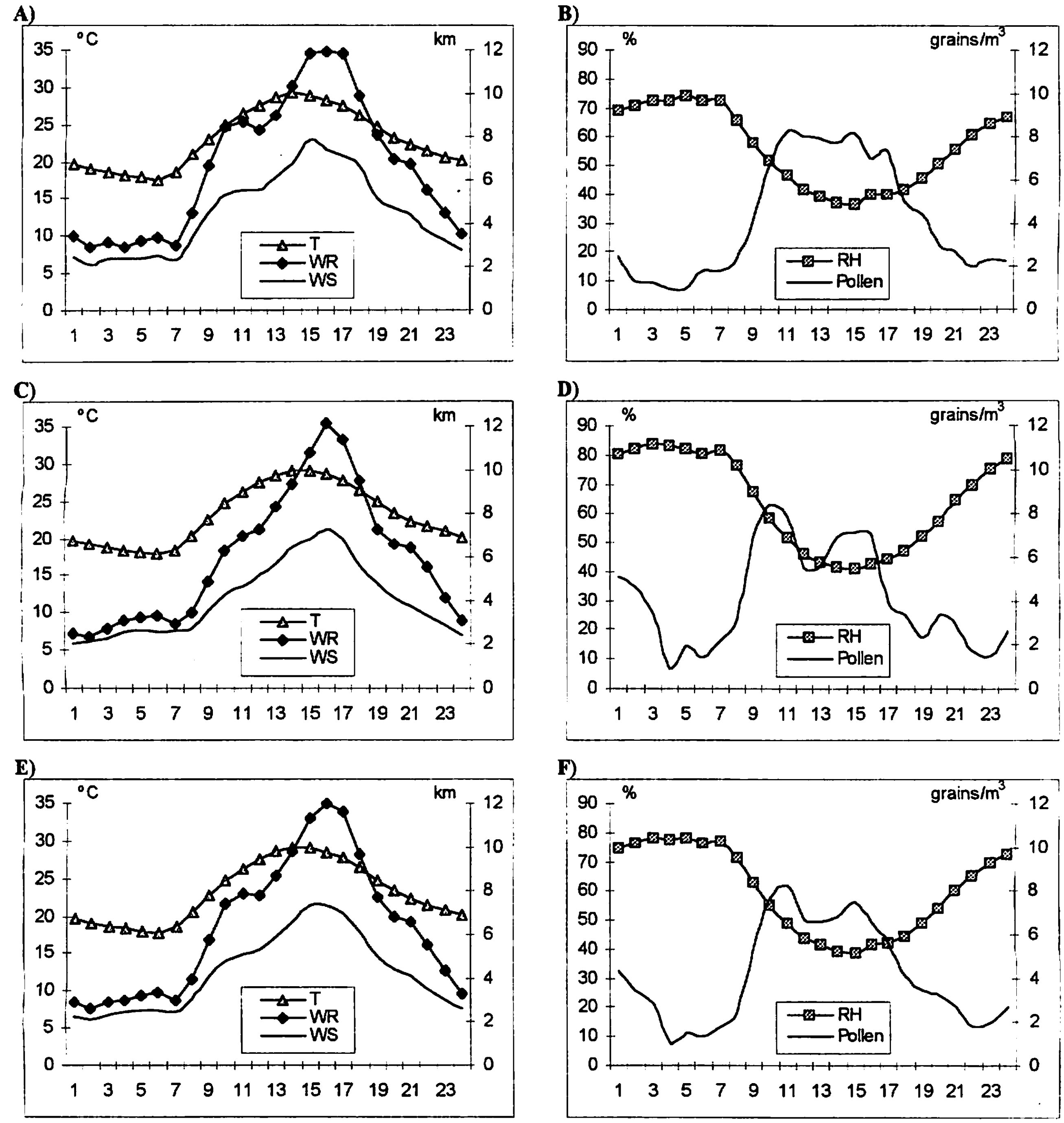


Fig. 4 Mean hourly meterological data and pollen counts in Murcia: (A, B) Summer 1; (C, D) Summer 2; (E, F) 2-year mean

quence of the progressive increases in the two variables involved (*P*_cum and pollen concentration until maximum). However, correlations with the rainfall 30–40 days earlier seem to be realistic because this is when the stamens of *A. herba-alba* was starting to develop in the area.

Intradiurnal variation

During both autumns, the daily patterns for *T*, RH, WR and WS were extremely similar (Fig. 6A–D) and no correlation could be established with pollen counts (Table 5). WD was quite irregular during autumn 1993 (Fig. 5B) and it appeared not to correspond with variations in *Artemisia* concentrations. In contrast to the homogeneous patterns showed by meteorological factors, pollen distributions were particularly variable during autumn, particularly in 1993 (Fig. 6B, D). This could be a consequence of several factors:

Table 5 Correlations between hourly pollen counts and meteorological parameters

	Summer		Autumn		Winter	
	1	2	1	2	1	2
WS	0.2284***	0.1200**	–0.0163	0.0030	0.0314	0.1278***
WD	0.1101*	0.0089	0.1189	–0.1273**	–0.0743**	0.0277
WR	0.2138***	0.0733	–0.0255	–0.0023	0.0294	0.1352***
RH	–0.3767***	–0.1992***	–0.0732	–0.0213	–0.1201***	–0.1675***
T	0.3921***	0.2016***	0.0784	0.0756	0.2402***	0.2230***

**P*<0.05, ***P*<0.01, ****P*<0.001

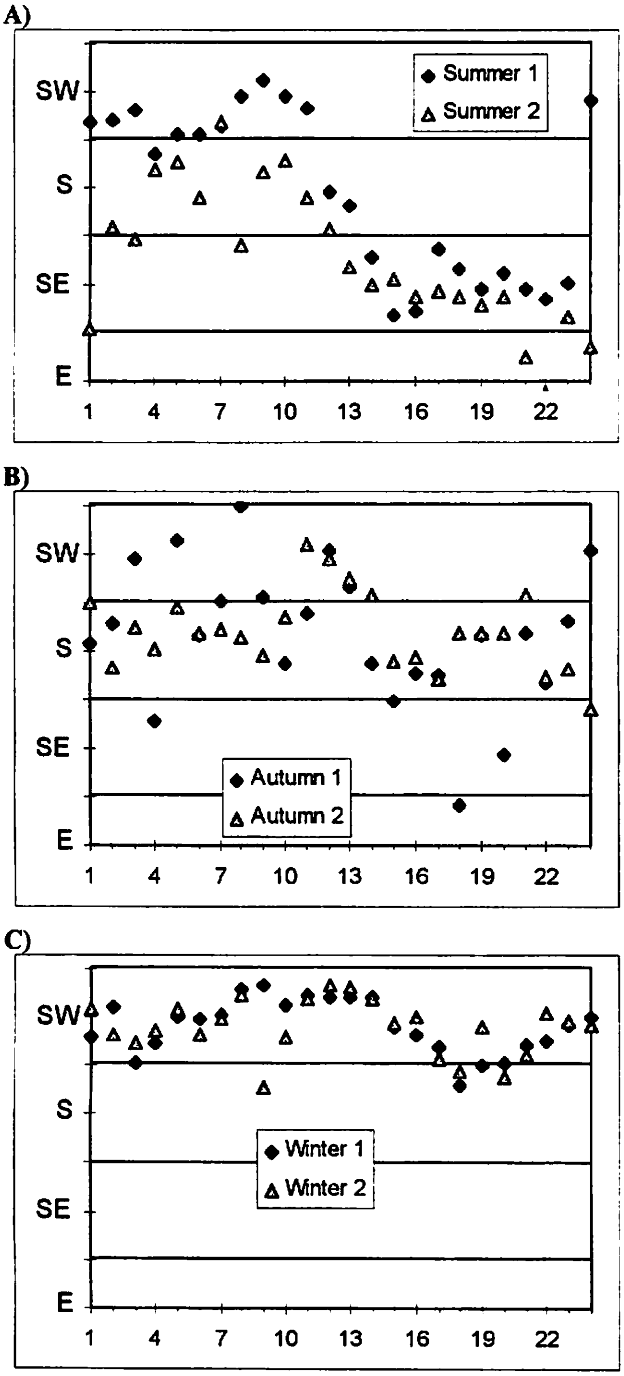


Fig. 5 Mean hourly wind direction for the three pollen seasons

Table 6 Intradiurnal variations in *A. campestris* pollen concentrations (Spanish official time)

	Onset	Peak	Drop	Second peak	Nightly maximum
Summer 1	05	11	12–13	15	23–00
Summer 2	04–06	10	12–13	15	00–01
2-year mean	05	11	12–13	15	00

1. In 1994 there was a greater number of higher than average pollen days, and the pollen amount during 1994 was more than twice as high as in 1993 (Table 1).
2. Autumn is palynologically complex, because it includes *A. campestris* pollen grains delayed from the summer station and advanced *A. barrelieri* pollen grains (winter season), in addition to the expected *A. herba-alba* pollination. Apparently, there is an interaction of three different patterns.
3. Populations of the different species involved are at different locations, varying distances from the Burkard trap.
4. The autumn in 1993 was very dry while in 1994 normal values of precipitation were recorded. The pollen concentration graph during 1994 (Fig. 6D) may therefore be considered more realistic.

Winter season: *A. barrelieri*

Interannual variation

For the winter season, it is difficult and somewhat subjective to fix upon limits because they are influenced by those previously established for the autumn blooming. Autumn and winter seasons are too close, and this is why the Nilsson and Persson's (1981) method displays two main limitations for winter season: 1) the first blooming days (particularly for the second year) could have been considered as the final days of the autumn season and, consequently, the beginning of winter season could be artificially delayed, and 2) the end of the winter season is arbitrary because we lack data for the whole season (until June) in the second year and, therefore, the calculations have been made up to the last day registered (28 February) in both years. Furthermore, if we include up to 30 June 1994 in order to calculate the limits of the first winter by means of Nilsson and Pearson's method, the winter blooming termination date would be 17 Feb-

Table 7 Autumn season: **A** main characteristics; **B** correlations with temperatures a given number of days earlier; **C** day-to-day correlations with meteorological factors; **D** correlations with cumulative precipitations a given number of days earlier; **E** relationships with cumulative insolation from 1 March

A

	Autumn season			**Total pollen**	
	Onset	Maximum	End	Days	grains/m³
Autumn 1	25-10-93	06-11-93	10-11-93	17	27
Autumn 2	23-10-94	09-11-94	19-11-94	28	79

B

	Autumn 1	**Autumn 2**
T_{min} –26	0.2546	0.1173
T_{min} –27	0.0364	0.4694
T_{min} –28	0.1576	0.6769**
T_{min} –29	0.2303	0.6358**
T_{min} –30	0.7395*	0.3887
T_{min} –31	0.2788	0.3406

*$P<0.05$ **$P<0.01$

C

	Autumn 1		**Autumn 2**	
	Whole period	Before maximum	Whole period	Before maximum
Evapo	0.0870	0.0242	–0.6447**	–0.6903**
Insol	–0.0434	0.0485	–0.2480	–0.4081
P_cum	0.5563	0.8395**	0.0715	0.7216**
RH00	–0.4026	–0.3152	0.5933**	0.5782*
RH07	0.0248	0.1576	0.5233**	0.5116*
RH13	–0.2330	–0.0488	0.5557**	0.5838*
RH18	–0.1714	–0.0183	0.6054**	0.5802*
T_{max}	0.4642	0.6074	–0.2541	–0.3565
T_{min}	0.1858	0.5577	0.1232	0.0977
T_{min}_0.15	–0.0681	0.1455	0.1863	0.2364
WR	0.0528	0.0364	–0.5549**	–0.4710
WS	0.1429	0.0727	–0.5343**	–0.4054

*$P<0.05$ **$P<0.01$

D

	Autumn 1	**Autumn 2**
P_cum –11	0.8908**	0.7866**
P_cum –12	0.9296**	0.8074**
P cum-26	0.9031**	0.6772**
P_cum-33	0.9031**	0.7129**
P_cum-40	0.8438**	0.6736**
P_cum-41	0.8778**	0.5390*

* $P<0.05$ ** $P<0.01$

E

	Autumn 1	**Autumn 2**
Onset	25-10-93	23-10-94
Insol_cum >16 600%	24-10-93	24-10-94
Maximum	06-11-93	09-11-94
Insol_cum >17 200%	08-11-93	06-11-94

ruary, which is only one day different to that obtained by Pathirane's method. Consequently, using Pathirane's limits for the winter season appears to be more appropriate. The main characteristics of the winter pollen season are shown in Table 8A.

As in the summer and autumn pollen seasons, the correspondence between the dates when certain percentages of cumulative insolation from 1 March were reached and the beginning of blooming date were again exceptional (Table 8B).

Day-to-day relationships between *A. barrelieri* pollen counts and atmospheric variables were explored for three different periods: the whole winter season and the time before and after the maximum count (Table 8C). The positive correlation with T_{max} during the first year for the whole season and for the period after the maximum count was clearly noticeable. This was probably due to mean T_{max}, being lower than 19°C in both cases (18.6°C and 18.4°C, respectively), because during the second winter this value was greatly exceeded by mean T_{max}. Therefore, 19°C probably is near to the lowest level for optimal *A. barrelieri* pollination. In the second winter, *Artemisia* pollen counts showed negative correlations with T_{min} and T_{min}_0.15 from the onset to the time of the maximum count, perhaps because temperatures were largely above 5.5°C and 3°C, respectively, values much greater than those reached in the first winter. These temperatures could be near to the uppermost level for optimal *Artemisia* pollination.

In short, our data suggest that *A. barrelieri* is a heavy pollen producer during the winter with an optimum about 19°C T_{max}, 5.5°C T_{min} and 3°C T_{min} _0.15. The results of the quadratic regression with such variables agreed with this hypothesis and the resulting mean T (about 12°C) is similar to the threshold value for the emission of *A. vulgaris* pollen (13–14°C) reported by Wahl and Puls (1989) in Germany. However, further years of data on pollen counts are needed to confirm this positively.

No correlations were found with precipitations or temperatures during the preceding months.

Intradiurnal variation

T, WS and WR display similar daily distributions, for both years, although the 1994 values for T were slightly higher and those for WR and WS slightly lower. For both years interesting coincidences are noticeable in the pollen curves (Fig. 7) which are summarized in Table 9. WD was constantly SW throughout the day (Fig. 5C).

The model for each year is coincident with that for considering both years together (Fig. 7). The slight dip around 3–4 p.m. was probably related to the beginning of a fall in T. On the other hand, similarly to that reported in Finland (Käpylä 1981) and Germany (Wahl and Puls 1989, 1991) and our own summer season data, the midday peak could be due to the nearby *A. barrelieri* populations whereas the second peak could be linked to

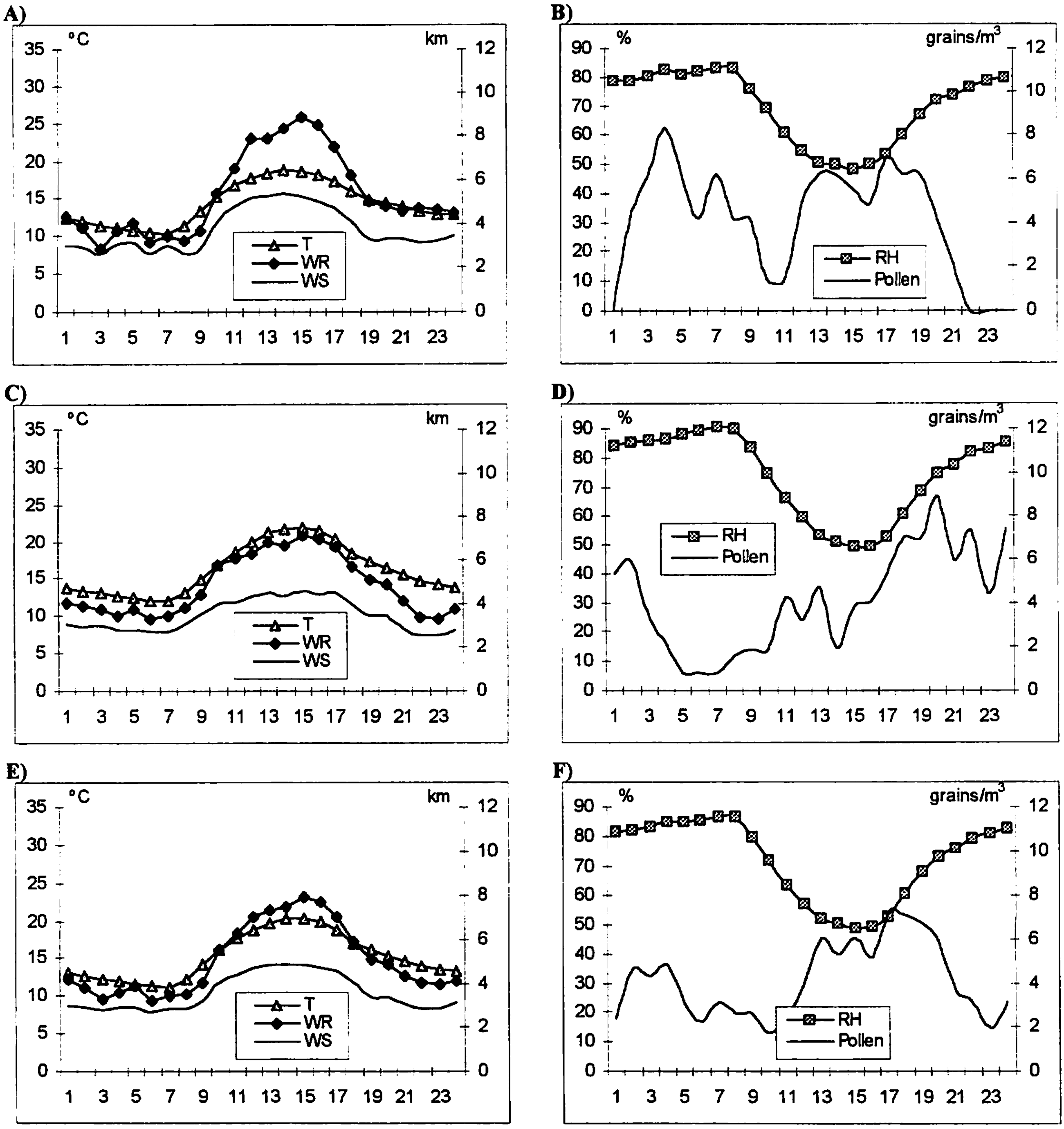


Fig. 6 Mean hourly meteorological data and pollen counts in Murcia: **(A, B)** Autumn 1; **(C, D)** Autumn 2; **(E, F)** 2-year mean

A. barrelieri populations from the Guadalentín Basin, 35–40 km away. It must be taken into account that WD remains constant all the time (Fig. 5C).

Pollen origin: wind vectors

For each pollen season, a simple graphical method has been used in order to determine the theoretical pollen movement of the *Artemisia* pollen grains from the producer populations to the trap. The method consist in creating wind vectors (having WR as size and WD as direction) for all hours between the onset and the end of the pollen curves. The vectors obtained are then successively added (by ordinary graphical sum of vectors) and superimposed in a vegetation map. Thus, the theoretical location of pollen sources can be found for each hour of the day (Fig. 8).

While recognizing the pitfalls of the method, we think that proposed model is still useful if we assume the following:

1. WD is the direction of the maximum gust of wind in the 10 min prior to the peak hours. This assumes that,

Table 8 Winter season: **A** main characteristics; **B** relationship with cumulative insolation from 1 March; **C** day-to-day correlations with meteorological factors

A

	Winter season				Total pollen
	Onset	Maximum	End	Days	grains/m^3
Winter 1	03-12-93	11-12-93	16-02-94	75	1762
Winter 2	02-12-94	14-12-94	16-02-95	76	778

B

	Winter 1	Winter 2
Onset	03-12-93	02-12-94
Insol_cum >18 800%	06-12-93	02-12-94

C

	Winter 1			Winter 2		
	Whole period	Before maximum	After maximum	Whole period	Before maximum	After maximum
Evapo	–0.0392	0.0669	–0.1334	0.0539	0.0740	0.0822
Insol	0.1981	0.8158**	0.2126	–0.0362	0.6072*	–0.0924
P_cum	–0.3437**	–	–0.4984**	–0.2855*	–	–0.4105**
RH00	0.1799	0.0596	0.2571*	0.0176	–0.4159	0.0558
RH07	0.1703	0.0084	0.2732*	0.0964	0.2137	0.0720
RH13	0.0020	–0.4167	0.0846	0.0828	–0.5781*	0.1563
RH18	0.0610	–0.0667	0.1039	0.1365	–0.4327	0.1995
T_{max}	0.3379**	0.6051	0.3541**	0.1102	0.0041	0.1471
T_{min}	–0.0067	0.0168	–0.0032	–0.0233	–0.7476**	0.0733
T_{min}_0.15	0.0656	–0.1333	0.0986	–0.0011	–0.8702**	0.1004
WR	–0.2318	–0.2167	–0.2847*	–0.0458	–0.3503	0.0254
WS	–0.2604*	–0.0667	–0.3264*	–0.0831	–0.4214	–0.0151

*$P<0.05$ ** $P<0.01$

during all the preceding hours, that was the constant wind direction or, at least, its mean value over a 50-km radius around the Burkard trap. In any case, a possible WD fluctuation of ± 15°–22.5° should be borne in mind.

2. WR is assumed to be constant, at least approximately 50 km around the sample site.
3. The influence of the Sierra del Puerto (S), Sierra de Carrascoy (SW) and Sierra Espuña (W) mountains on WR and WD is considered not to be significant.
4. Convection air movements and pollen release were considered to occur homogeneously over the area.
5. In order to establish the onset of daily pollen dispersal, the relationship between T and pollen concentrations is considered to be meaningful.
6. The influence of WS in diluting pollen in the air is not taken into account. In any case, for the periods studied, WS never displays high values and its effects can be confidently minimised.

Despite these considerations, the graphical representations shown here allow general inferences about the origin of *Artemisia* pollen in our Burkard trap. In summer, there was a dominant south-southeastern origin (Fig. 8A). Clearly south was the dominant origin in autumn (Fig. 8B), while the winter pollen origin was mainly southwestern (Fig. 8C).

The model provides explanations for some phenomena observed in the intradiurnal and annual pollen concentration curves previously described for *Artemisia*:

1. In summer 1993, the early morning pollen was probably coming from the Guadalentín Basin (SW), where *Artemisia* populations are abundant, while in 1994 that input was dominated by a more southerly component (Murcia and nearby Huerta, where no significant *Artemisia* populations can be found; Fig. 8A). This may partially explain (in addition to the influence of meteorological factors in the preceding months) the higher quantities of pollen reported in 1993 than in 1994.
2. During summer, the drop in pollen concentrations about 12–1 p.m. corresponds to Sierras del Puerto (1994) and Carrascoy (1993) inputs (Fig. 8A), rich in pine- and oak-dominated communities where *Artemisia* is rare.
3. It seems logical to record low *Artemisia* pollen concentrations in the city of Murcia during summer, when the input is mainly southern (Fig. 8A) and have in mind that *A. campestris* (the summer blooming species) is only abundant in the north.
4. Falls in *Artemisia* pollen concentrations during winter (4 p.m. in 1993 and 3 p.m. in 1994; Fig. 7B, C) could be due to a probable pollen origin around Librilla (1994) and Alhama (1993) (Fig. 8C).

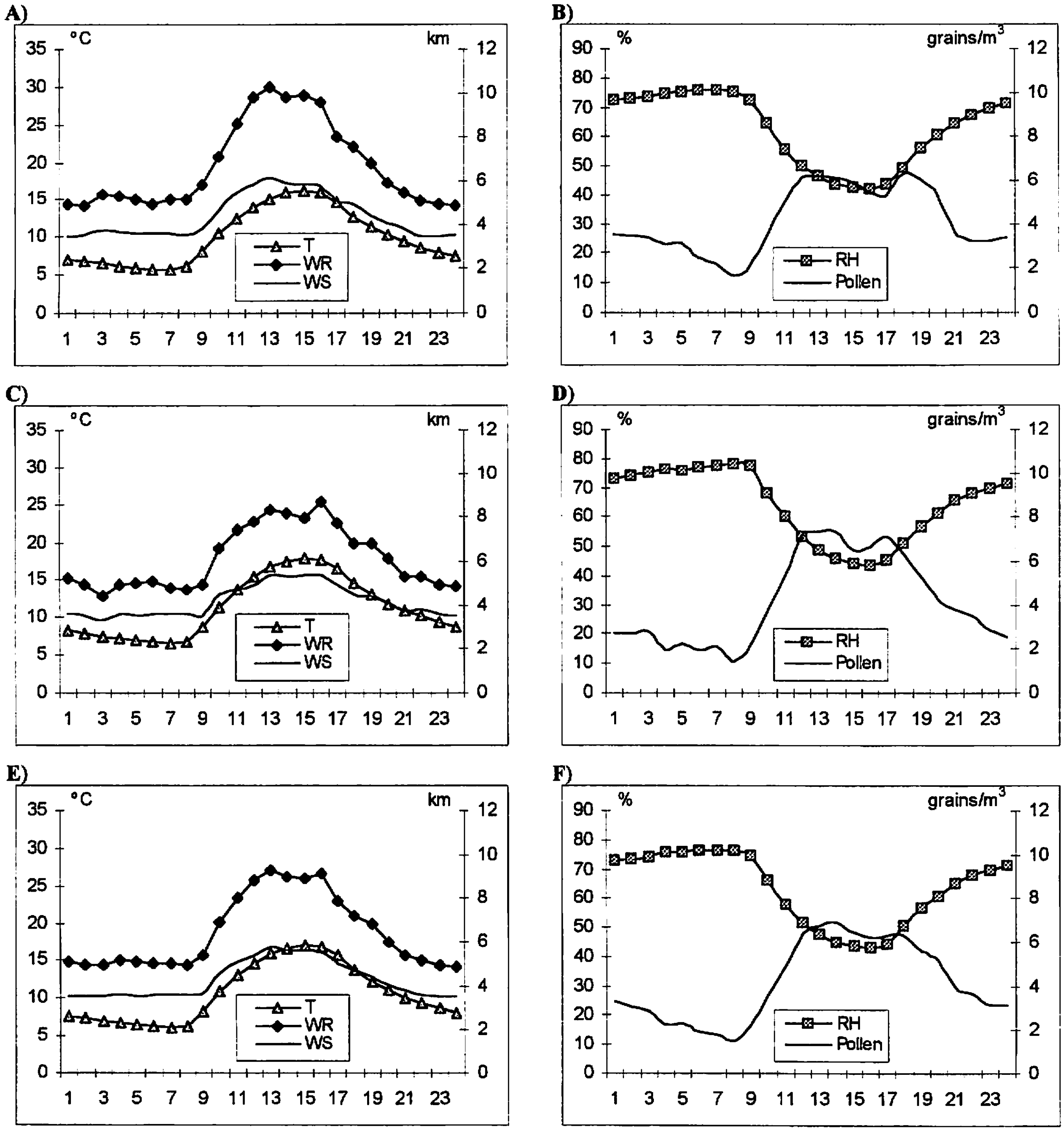


Fig. 7 Mean hourly meteorological data and pollen counts in Murcia: (**A, B**) Winter 1; (**C, D**) Winter 2; (**E, F**) 2-year mean

5. The very important winter pollen concentrations seem to have their origin in the Guadalentín Basin area (Fig. 8C) where *A. barrelieri* is abundant.

Theoretical WR curves were almost coincident for both autumn seasons (Fig. 8B) and do not provide any useful information to explain the erratic behaviour of daily pollen concentrations. Further studies focused on other taxa, and including several years data, are needed in order to validate or reject the proposed model.

Table 9 Intradiurnal variations in *A. barrelieri* pollen concentrations (Spanish official time)

	Onset	Peak	Trough	2nd peak	Nightly maximum
Winter 1	08	12–13	16	18	02
Winter 2	08	12–13	15	17	01
2-year mean	08	12–13	15–16	18	01

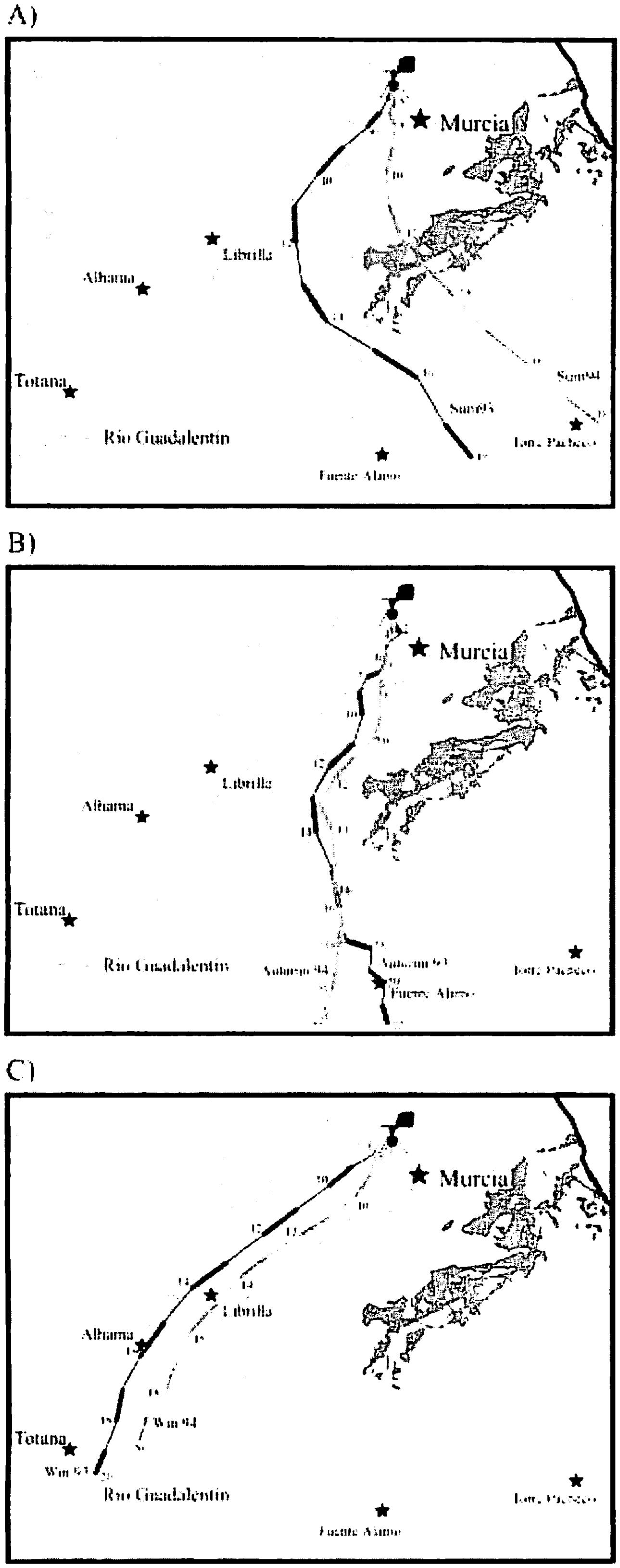
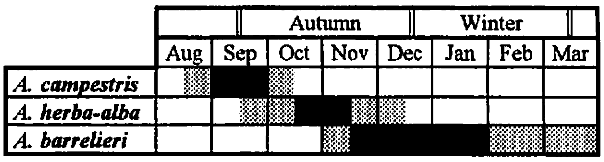


Fig. 8 Wind vectors showing theoretical location of *Artemisia* pollen sources at each hour throughout the day: (**A**) Summer, (**B**) Autumn, (**C**) Winter. *Grey* zones show areas where *Artemisia* is frequent, *black* zones represent sparse *Artemisia* populations and *spotted* zones denote the Guadalentin Basin, largely populated by *A. barrelieri* and, to a lesser extent, *A. herba-alba*



			Autumn			Winter		
	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
A. campestris	□▨	■■	▨□					
A. herba-alba		□▨	▨■	■▨	▨□			
A. barrelieri				▨■	■■	■■	▨▨	▨▨

Fig. 9 *Artemisia* pollen calendar

Conclusions

In conclusion, *Artemisia* begins to bloom in late summer, when temperatures fall. There are three blooming stages in Murcia (summer, autumn and winter), which appear to correspond with three different species, *A. campestris*, *A. herba-alba* and *A. barrelieri*, respectively (Figs. 2, 9).

We surmise that there must be an important phenological factor affecting flowering, because only small differences between the start and end dates of the pollen periods could be observed, despite different meteorological conditions. Pollen abundance seems to be influenced by the meteorological features of the weeks before flowering (particularly in summer and autumn blooming) but once the pollination has begun, they do not seem to have a significant influence (except, perhaps, RH in summer and autumn and *T* during winter). In the different pollen seasons, peaks in daily pollen concentrations were usually recorded 11–13 days from the beginning.

For the second year, total pollen count was lower because of high temperatures and less precipitation. The arid period suffered in Spain from 1991 had, in all probability, an additive effect. No significant differences in the pollen distribution patterns throughout the 2 years were found.

The onset dates of blooming in the summer, autumn and winter pollen seasons appear to be related to the cumulative percentage insolation from 1 March, being when values of 12 500%, 16 600% and 18 800%, respectively are exceeded. The same applies to the time when maximum counts are reached in summer and autumn (13 300% and 17 200%, respectively).

In the summer blooming, nightly RH (RH00 and RH07) in excess of 60% appeared to influence negatively the atmospheric pollen concentrations during the day but, when RH was higher than 80% at 7 a.m., pollen concentrations increased again. Likewise, summer pollen production increased when it rained about 6–8 weeks (40–56 days) before blooming and decreased when *T* was high for weeks prior to flowering.

Summer *A. campestris* pollen in Murcia has a mainly southern origin. Intradiurnal patterns for both 1993 and 1994 were very similar and agree well with *T*, WS and RH. According to the model described here, pollen dispersal begins around 5 a.m., reaching a peak about 11 a.m. Around 3 p.m., a second maximum is registered, which could be related to high atmosphere pollen falling. A dip in pollen counts about 12–1 p.m. could be because pollen come mainly from the mountains situated to the south of Murcia city, where *Artemisia* is rare (Fig. 8A).

During autumn, pollen production seem to be strongly dependent on the rainfall recorded weeks earlier. Rainfall during late September (about 30–40 days before blooming) could be particularly important. On the other hand, increases in the T_{min} during October (one month before blooming) may have also played a part in increasing the *Artemisia* pollen concentrations during autumn. Daily pollen concentrations of *Artemisia* were further increased when the nightly RH (RH00 and RH07) was higher than 80%.

The autumn pollen concentration of *Artemisia* in Murcia is likely to be produced by several species, among which *A. herba-alba* is prevalent. No correlations have been found between the erratic intradiurnal pollen variations and atmospheric variables, including wind origin.

The most important *Artemisia* pollen season in Murcia occurs in winter. During this season, the greatest pollen concentrations seem to be related to T_{max} over 19°C, and T_{min} and $T_{min-}15$ lower than 5.5°C and 3°C, respectively. Pollen concentrations do not appear to correlate with the meteorological factors considered during the days and weeks prior to blooming.

In winter, west winds bring the *A. barrelieri* pollen to Murcia from the Guadalentín Basin area. The model suggests that pollen dispersal begins around 8 a.m., reaching a peak about 12 p.m. A second peak was detected at 6 p.m., possibly due to the deposition of high atmosphere pollen that could have been released several hours earlier from saltmarsh populations in the Alhama area.

A. campestris and *A. barrelieri* show a similar intradiurnal behaviour, although the latter species exhibits a less pronounced curve of intradiurnal variation.

We have shown that a simple graphical representation of hourly vectors (having WR as size and WD as direction) is a valuable method for establishing the sources of and explaining the intradiurnal and interannual airborne variations in pollen concentrations.

Acknowledgements The authors would like to thank Fundación Séneca (Comunidad Autónoma de Murcia), FEDER (Fondo Europeo de Desarrollo Regional) and CICYT (Comision Interministerial de Ciencia y Tecnología) for financial support throughout projects PLP/3/FS/97, IFD97-0898 and CLI97-0445-C02, respectively. M. M. G. thanks Fundación Séneca for a grant to study airborne pollen in the city of Murcia (00266/CV/97).

References

Andersen TB (1991) A model to predict the beginning of the pollen season. Grana 30: 269–275

Fitter AH, Fitter RSR, Harris ITB, Williamson MH (1995) Relationships between first flowering date and temperature in the flora of a locality in central England. Funct Ecol 9: 55–60

García Sellés J, Munuera M (1996) Alergenos: pólenes. In: Negro JM (ed) Rinitis alérgica. Mecanismos y tratamiento. Edika Med, Barcelona, pp 148–166

Käpylä M (1981) Diurnal variation of non-arboreal pollen in the air in Finland. Grana 20: 55–59

Mullenders M, Dirickx M, Van der Haegen D, Bastin-Servais Y, Desair Coremans M (1972) La pluie pollinique à Louvain. Louvain Med 91: 159–176

Munuera M, Carrión JS, García Sellés J (1996) Winter blooming of *Artemisia*. Two years survey in Murcia (Spain). Proceedings of the 1st European Symposium on Aerobiology. Aira MJ, Iato MV, Iglesias I, Galán C (eds.) Santiago de Compostela (España). pp 59–60

Munuera M, Carrión JS, Guerra J (1995) Approaches to airborne pollen in SE Spain. First survey in Murcia: one year of pollen monitoring (1993–94). Aerobiologia 11: 189–194

Nilsson S, Persson S (1981) Tree pollen spectra in the Stockholm region (Sweden), 1973–1980. Grana 20: 179–182

Pathirane L (1975) Graphical determination of the main pollen season. Pollen Spores 17: 609–610

Walh PGv, Puls KE (1989) The emission of mugwort pollen (*Artemisia* vulgaris L.) and its flight in the air. Aerobiologia 5:55–63

Wahl PGv, Puls KE (1991) Pollenemission und pollenflug von kräuterpollen (*Artemisia vulgaris*, *Plantago lanceolata* und *Rumex* ssp). Grana 30: 260–264