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# Influence of wind direction on pollen concentration in the atmosphere

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**Abstract** The daily pollen concentration in the atmosphere of Badajoz (SW Spain) was analysed over a 6-year period (1993–1998) using a volumetric aerobiological trap. The results for the main pollination period are compared with the number of hours of wind each day in the four quadrants: 1 (NE), 2 (SE), 3 (SW) and 4 (NW). The pollen source distribution allowed 16 pollen types to be analysed as a function of their distribution in the four quadrants with respect to the location of the trap. Four of them correspond to species growing in an irrigated farmland environment (Amaranthaceae-Chenopodiaceae, *Plantago*, *Scirpus*, and *Typha*), five to riparian and woodland species (*Salix*, *Fraxinus*, *Alnus*, *Populus*, and *Eucalyptus*), four to urban ornamentals (*Ulmus*, Arecaceae, Cupressaceae, and *Casuarina*), and three which include the most frequent pollen grains of widely distributed species (Poaceae, *Quercus*, and *Olea*). The results show that the distribution of the sources and the wind direction play a very major role in determining the pollen concentration in the atmosphere when these sources are located in certain quadrants, and that the widely distributed pollen sources show no relationship with wind direction. In some years the values of the correlations were not maintained, which leads one to presume that, in order to draw significant conclusions and establish clear patterns of the influence of wind direction, a continuous and more prolonged study will be required.

**Key words** Aerobiology · Wind influence · Pollen · Pollination

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## Introduction

The suspension of pollen grains in the atmosphere is a phenomenon that is inherent to the biological function of these particles, since the wind is the mode of transport of the pollen of many flowering plants. It carries the grains from the anthers of the flower, the masculine organ, to the pistil, the feminine organ, thereby facilitating fecundation. This is most frequent in plants with unisexual flowers (Charlesworth 1993), and often involves major modifications even to the pollen grains themselves (Crane 1986). One indirect consequence of this airborne transport is the appearance of allergic reactions in humans when the pollen is inhaled and its proteins are released, thereby forming antigens to which the immune system reacts, provoking allergic symptoms.

As in many other biological processes, pollen dispersal is influenced by meteorological parameters. These may determine the timing of the flowering season by way of the photoperiod, the rate of development and vernalization, by acting on flower organ activity via their physiology or development etc., or by affecting the dynamics of the air as a fluid in which the pollen grains travel as passive elements (Lighthart et al. 1979; Benninghoff 1987).

The effects of some of these parameters have been widely studied. For instance, the physiological effects of humidity and temperature are well known (Norris-Hill 1997; Frenguelli 1991). The importance of others is diminished, however, by their varying according to local conditioning factors.

The wind is known to be capable of transporting pollen grains over long distances (Gregory 1978; Bourgeois et al. 1985). While its importance in dispersing the pollen of anemophilous plants is clearly recognized, it is more complicated to separate its influence from that of other meteorological variables (Emberlin and Norris-Hill 1996). Wind speed is recognized as being one of the most important factors in some cases (Ljunkuist et al. 1977; McDonald 1980). The effect of wind direction is known in coastal areas, where pollen concentrations in-

**Fig. 1** Location of the trap and the surrounding vegetation


crease when the wind is from the interior and decline when it blows from the sea (McDonald 1979, 1980; González Minero et al. 1993). This parameter is rarely used, however, since one often finds contradictory results from one year to another (Recio et al. 1996).

The aim of the present work is to clarify the role of wind direction in the variation of pollen grain concentrations. Over 6 consecutive years in the city of Badajoz (SW Spain), the daily pollen concentrations corresponding to some plants from well localized sources in the surrounding area were studied, and correlated with the dominant wind direction for each day.

## Materials and methods

The pollen concentrations were monitored using a Burkard model volumetric trap. This separates-out the small-sized solid particles contained in the air, since they are carried to an adhesive surface by an air flow of 10 l/min according to the method described by Hirst (1952). The samples analysed allow us to estimate the daily pollen concentrations in grains per cubic metre of air. The trap was located in the Agrarian Engineering School of the University of Extremadura in Badajoz (SW Spain) at a height of 6 m above ground level. There were no obstacles impeding the free circulation of air in its surroundings. The sampling period was from 13 May 1993 to 31 December 1998, including a break caused by a technical problem from 6 November 1995 to 13 February 1996.

The meteorological data were collected by the staff of the Extremadura Meteorological Centre at their Station in Talavera la Real, situated 10 km from the trap. For the present work, we used the number of hours each day (24 h) that the wind direction was in each of the four quadrants: 1 (NE), 2 (SE), 3 (SW), and 4 (NW), or the number of hours of still air.

The pollen types chosen for the study were those in which the sources were perfectly situated in one of the aforementioned quadrants and the pollen had a major representation in the atmosphere. We rejected those types that, while satisfying the second criterion, appeared too evenly distributed, as was the case with species of *Rumex*, Urticaceae, Asteraceae, and *Pinus*. Taking the location of the trap as the origin, the distribution of the vegetation units is as follows (Fig. 1): quadrant 1 is almost totally occupied by irrigated cropland; quadrant 2 contains a small portion of irrigated farmland, and a noteworthy presence of zones of riparian vegetation and eucalyptus stands, although the greater part of the area is given to dryland farming; quadrant 3 contains most of the urban area; and lastly quadrant 4 is devoted to grazing and dryland farming.

Two pollen types were chosen that correspond to weeds that are characteristic of the irrigated lands of the zone: Amaranthaceae-Chenopodiaceae (goosefoot and amaranths) and *Plantago* species (plantains); two types covering wetland perennials associated with streams and irrigation canals: *Scirpus* (rush) and *Typha* (reedmace); three types of riparian species of trees or shrubs: *Salix* (willows), *Fraxinus* (ash), and *Alnus* (alder); two types corresponding to riparian plantations: *Populus* (poplar) and *Eucalyptus* (eucalyptus); and four types representing urban ornamentals: *Ulmus* (elms), Arecaceae (palms), Cupressaceae (cypresses and cedars), and *Casuarina* (casuarina). As controls, we also studied three types representing species that are broadly distributed in the zone: Poaceae (gramineae), *Quercus* (holm and cork oaks), and *Olea* (olive).

The study consisted in analysing the annual correlations that might exist between the wind direction data and the daily variations in pollen concentration corresponding to these pollen types. For this purpose we used the Pearson correlation coefficient calculated with the program NCSS (Number Cruncher Statistical System). For the winter types (*Fraxinus*, *Alnus*, *Cupressus*), 4 years were included in the study, for *Salix* 5 years, and for the rest 6 years. We did not use all the data of any given year, but calculated the main pollination period following Mäkinen (1977). In this method, the mean day and standard deviation are calculated and only those days are taken that lie within one standard deviation of the mean. This, therefore, includes 68.3% of the data, the beginning and end of the whole pollination period being rejected because one considers that they would include many pollen grains coming from distant sources.

## Results

The predominant winds in Badajoz are westerly, although their frequency varies somewhat over the course of the year (Fig. 2). From October to March, the winds are in quadrants 1 and 2 for 4–6 h/day and the rest of the year for 2–4 h/day. There were winds in quadrants 3 and 4 for 8–11 h/day from April to September and the rest of the year for around 4 h in quadrant 4 and some 8 h in

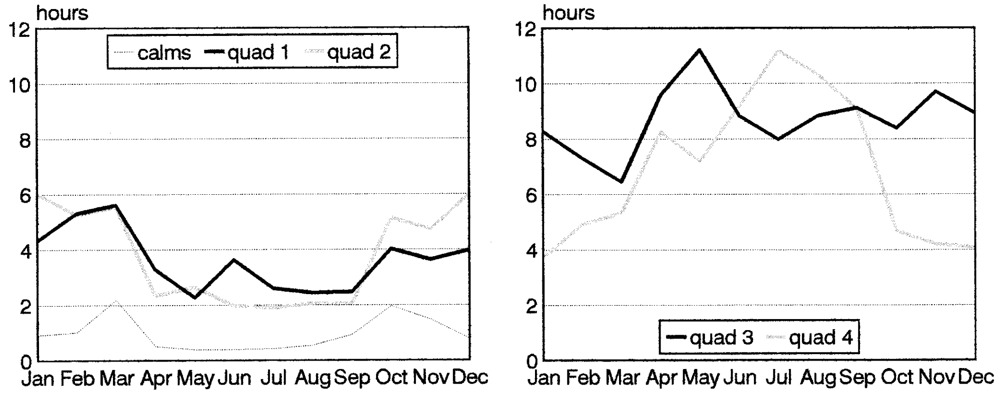


**Fig. 2** Average monthly values, during the period 1993–1998 in Badajoz, for the duration of the periods when the wind was blowing in each of the four quadrants and of the still-air periods

**Table 1** Analysis of correlations and their significance levels between pollen concentration of plants from an irrigated farmland environment (origin in quadrants 1 and 2) and wind direction or period of calm

| | | | | | |
|---|---|---|---|---|---|
| Amaranthaceae-Chenopodiaceae | | | | | |
| Year (days) | Calm | Quad. 1 | Quad. 2 | Quad. 3 | Quad. 4 |
| 1993 (79) | **0.2287**** | **0.7005***** | **0.5839***** | **–0.4970***** | **–0.4177***** |
| 1994 (102) | **0.2873***** | **0.3232***** | **0.5242***** | **–0.1771*** | **–0.3135***** |
| 1995 (103) | 0.0786 | 0.1276 | **0.3212***** | 0.1090 | **–0.3228***** |
| 1996 (102) | **0.3477***** | **0.3804***** | **0.5025***** | **–0.3062***** | **–0.4037***** |
| 1997 (108) | **0.2897***** | **0.4271***** | **0.5264***** | **–0.1629*** | **–0.4421***** |
| 1998 (101) | –0.1018 | –0.0334 | 0.0457 | **–0.2174**** | **0.2263**** |
| *Plantago* | | | | | |
| Year (days) | Calm | Quad. 1 | Quad. 2 | Quad. 3 | Quad. 4 |
| 1993 (48) | **0.3562**** | 0.2324 | –0.0639 | **–0.2458*** | 0.1275 |
| 1994 (66) | 0.1638 | **0.6334***** | 0.0851 | **–0.5622***** | –0.0227 |
| 1995 (44) | 0.1201 | **0.3694***** | 0.1192 | –0.1431 | **–0.2749**** |
| 1996 (52) | **0.2594*** | 0.2126 | 0.1844 | **–0.2794**** | –0.0624 |
| 1997 (77) | 0.0446 | **0.3000***** | 0.1251 | **–0.2610**** | 0.0246 |
| 1998 (64) | 0.1344 | **0.4486***** | **0.2224*** | **–0.3674***** | –0.0733 |
| *Scirpus* | | | | | |
| Year (days) | Calm | Quad. 1 | Quad. 2 | Quad. 3 | Quad. 4 |
| 1993 (41) | 0.2342 | **0.4686***** | **0.4308***** | **–0.3244**** | **–0.3280**** |
| 1994 (54) | **0.2337*** | **0.4945***** | **0.4127***** | **–0.2850**** | **–0.4232***** |
| 1995 (56) | –0.0304 | 0.1453 | 0.0232 | –0.0472 | –0.0752 |
| 1996 (48) | 0.2393 | **0.3860***** | **0.2913**** | 0.0060 | **–0.4633***** |
| 1997 (85) | 0.0128 | 0.0964 | –0.0983 | –0.0915 | 0.0846 |
| 1998 (57) | –0.1510 | **0.2446*** | **0.4496***** | **–0.3898***** | –0.0125 |
| *Typha* | | | | | |
| Year (days) | Calm | Quad. 1 | Quad. 2 | Quad. 3 | Quad. 4 |
| 1993 (41) | –0.1080 | 0.2548 | **0.4314***** | 0.2588 | 0.2365 |
| 1994 (46) | 0.0172 | **0.3090**** | **0.4179***** | **–0.3232**** | –0.2130 |
| 1995 (28) | –0.2480 | 0.1404 | 0.0643 | –0.1584 | 0.0247 |
| 1996 (48) | –0.1118 | **0.2630*** | –0.0914 | –0.1443 | –0.0833 |
| 1997 (39) | 0.0757 | –0.0263 | –0.1137 | –0.0727 | 0.1105 |
| 1998 (42) | –0.1167 | –0.0803 | 0.0009 | –0.2193 | **0.2594*** |

*$P<0.1$; **$P<0.05$; ***$P<0.01$

quadrant 3. Still air was maintained for approximately 1 h/day, on average, throughout the year, except for March and October in which it lasted up to 2 h/day.

Tables 1–4 list the correlations found for the 6 years of the study. All four types chosen for their origins in the irrigated lands of quadrants 1 and 2 showed significant positive correlations with those quadrants, and negative correlations with quadrants 3 and 4, except for Amaranthaceae-Chenopodiaceae in quadrant 4 in 1998 (Table 1). The type that presented least constancy in the significance of the interannual correlations was *Typha*.

The pollen concentrations of the riparian trees and shrubs, as well as of the eucalyptus and poplars in the repopulation plantations along the river banks, showed significant positive correlations with winds from quadrants 1 and 2 and negative correlations with 3 and 4 (Table 2). For Alnus, the values were negative for quadrant 2 and positive for quadrant 4. The pollen concentrations of *Salix*, *Fraxinus*, and *Eucalyptus* seem to increase under the influence of winds from quadrants 1 and 2 and diminish in winds from 3 and 4. With respect to *Populus*, the correlations are of low significance, but one observes

**Table 2** Analysis of correlations and their significance levels between pollen concentration of plants from riparian and forested environments (origin in quadrants 1 and 2) and wind direction or period of calm

| *Salix* | | | | | |
|---|---|---|---|---|---|
| Year (days) | Calms | Quad. 1 | Quad. 2 | Quad. 3 | Quad. 4 |
| 1994 (18) | 0.3717 | 0.3859 | **0.6725*** ** | **–0.4391*** | –0.3926 |
| 1995 (28) | 0.0833 | **0.5303** ** | **0.5235*** ** | **–0.5213*** ** | **–0.4953*** ** |
| 1996 (33) | –0.1112 | 0.1610 | **0.4818*** ** | –0.2280 | **–0.3030*** |
| 1997 (19) | –0.0287 | 0.3116 | 0.2978 | –0.3420 | –0.3881 |
| 1998 (28) | –0.2295 | 0.1779 | **0.6692*** ** | **–0.4275** ** | **–0.3918*** |
| *Fraxinus* | | | | | |
| Year (days) | Calms | Quad. 1 | Quad. 2 | Quad. 3 | Quad. 4 |
| 1993–94 (66) | 0.0410 | **0.3450*** ** | **0.3521*** ** | **–0.3004** ** | **–0.2086*** |
| 1994–95 (84) | 0.0707 | **0.3786*** ** | **0.3750*** ** | **–0.3630*** ** | **–0.1939*** |
| 1996–97 (80) | 0.1340 | 0.0188 | **0.3392*** ** | **–0.2655** ** | **–0.2539** ** |
| 1997–98 (57) | –0.1726 | 0.1697 | **0.3512*** ** | **–0.3195** ** | –0.2106 |
| *Alnus* | | | | | |
| Year (days) | Calms | Quad. 1 | Quad. 2 | Quad. 3 | Quad. 4 |
| 1993–1994 (48) | –0.0323 | **0.4573*** ** | –0.0302 | **–0.3636** ** | 0.1466 |
| 1994–1995 (34) | –0.1742 | **0.4825*** ** | –0.1464 | **–0.2885*** | 0.1167 |
| 1996–1997 (38) | –0.0602 | –0.0322 | 0.0717 | –0.0498 | 0.0590 |
| 1997–1998 (32) | –0.1867 | 0.2202 | –0.0524 | –0.2679 | **0.3662** ** |
| *Populus* | | | | | |
| Year (days) | Calms | Quad. 1 | Quad. 2 | Quad. 3 | Quad. 4 |
| 1994 (17) | **0.6344*** ** | 0.3344 | 0.0319 | **–0.4279*** | 0.1338 |
| 1995 (13) | –0.1778 | 0.4498 | 0.0157 | –0.3391 | –0.0916 |
| 1996 (38) | –0.1547 | 0.0655 | **0.3007*** | –0.0508 | –0.1782 |
| 1997 (16) | **0.5782** ** | 0.2078 | –0.1822 | –0.3196 | –0.3719 |
| 1998 (20) | –0.3350 | 0.1180 | –0.3439 | **0.3965*** | 0.1071 |
| *Eucalyptus* | | | | | |
| Year (days) | Calms | Quad. 1 | Quad. 2 | Quad. 3 | Quad. 4 |
| 1993 (43) | 0.1366 | **0.2753*** | **0.6118*** ** | –0.2214 | **–0.4337** ** |
| 1994 (61) | 0.1699 | 0.1222 | **0.2867*** | –0.1906 | –0.0767 |
| 1995 (52) | **0.5709*** ** | 0.1970 | **0.3134** ** | **0.2885** ** | **–0.5870*** ** |
| 1996 (85) | 0.0882 | 0.1385 | **0.2104*** | 0.0779 | **–0.2888*** ** |
| 1997 (84) | 0.0955 | 0.0445 | **0.3352*** ** | 0.0714 | **–0.2672** ** |
| 1998 (94) | –0.0996 | 0.0642 | 0.1689 | 0.0785 | **–0.1817*** |

*$P$<0.1; **$P$<0.05; ***$P$<0.01

a major reduction of the pollen concentration when the winds are from quadrant 3.

For the ornamental species of Arecaceae and Cupressaceae, which include a wide variety of species grown in the city, one finds a strongly positive action from quadrant 3 and an almost negative effect of the winds from the other three quadrants, this always being negative for quadrants 1 and 2 (Table 3). For each of the other types, there was only one species involved and the number of significant correlations was low. In the case of *Casuarina*, there were only three significant correlations: two negative for quadrant 1, and one positive for quadrant 2. In *Ulmus*, there were three significant positive correlations: two for quadrant 3 and one for quadrant 2.

The last group of pollen types, representing plants that may be situated in all four quadrants because of their abundance in the zone or their cultivation, showed no clear tendencies with respect to any quadrant (Table 4). There was either a notable lack of significant correlations (Poaceae) or there were variations in the sign of the correlation in the different periods for the same pollen type (*Quercus* and *Olea*).

## Discussion

Although all the pollen types studied appear frequently in the neighbourhood of the trap (some metres), their preponderant location in one or another quadrant is determined by the dominant vegetation there. The action of the wind in concentrating greater or lesser amounts of pollen from these sources is manifest in the results expressed in Tables 1–4. It can be seen that the wind not only is able to carry pollen from sources far from the sampling point, as has been demonstrated by different workers (Hjelmroos 1991; Comtois 1997), but may also modify pollen concentrations from sources closer by.

In the three groups of vegetation analysed, it was found that, when the wind was from the quadrant in which the sources were located, the pollen concentrations rose, and naturally when it was from the opposite quadrant they fell. The degree of significance of the correlations seems to be related to the precision with which the pollen sources are localized in the quadrants. Thus, for instance, in the case of the *Fraxinus* type there were significant correlations with the four quadrants during the four flowerings studied, while in no case were there

**Table 3** Analysis of correlations and their significance levels between pollen concentration of urban ornamental plants (quadrant 3) and wind direction or period of calm

| *Ulmus* | | | | | |
|---|---|---|---|---|---|
| Year (days) | Calms | Quad. 1 | Quad. 2 | Quad. 3 | Quad. 4 |
| 1994 (34) | 0.1618 | –0.1837 | –0.1743 | **0.3250*** | –0.2284 |
| 1995 (17) | –0.1276 | –0.1815 | –0.1301 | **0.4285*** | –0.3915 |
| 1996 (19) | 0.0704 | 0.2330 | –0.1766 | 0.1628 | –0.1524 |
| 1997 (21) | –0.2239 | 0.0350 | 0.2039 | –0.1288 | 0.1180 |
| 1998 (15) | –0.2967 | –0.3286 | **0.6605***** | –0.2596 | –0.1826 |
| *Arecaceae* | | | | | |
| Year (days) | Calms | Quad. 1 | Quad. 2 | Quad. 3 | Quad. 4 |
| 1993 (65) | **–0.2438**** | **–0.3988***** | **–0.2776**** | **0.3883***** | 0.1692 |
| 1994 (120) | –0.1381 | **–0.2712***** | –0.0179 | **0.2842***** | 0.0062 |
| 1995 (53) | –0.1587 | 0.0875 | 0.2084 | **0.3874**** | **–0.3837**** |
| 1996 (84) | 0.0134 | –0.1435 | –0.0153 | **0.2043*** | –0.0901 |
| 1997 (90) | **–0.2799**** | **–0.3440***** | **–0.3081***** | **0.5317***** | 0.0070 |
| 1998 (109) | –0.1213 | **–0.2169**** | –0.1343 | **0.2948***** | –0.0261 |
| *Cupressaceae* | | | | | |
| Year (days) | Calms | Quad. 1 | Quad. 2 | Quad. 3 | Quad. 4 |
| 1993–94 (47) | –0.0104 | –0.2105 | –0.2008 | **0.2972**** | –0.0418 |
| 1994–95 (47) | **–0.2636*** | **–0.3387**** | **–0.2502*** | **0.4868***** | –0.2188 |
| 1996–97 (77) | –0.1804 | **–0.3493**** | **–0.2705**** | **0.4280***** | **0.3084**** |
| 1997–98 (68) | 0.1947 | **–0.3288***** | 0.1084 | 0.1323 | –0.0904 |
| *Casuarina* | | | | | |
| Year (days) | Calms | Quad. 1 | Quad. 2 | Quad. 3 | Quad. 4 |
| 1993 (62) | –0.0976 | **–0.2439*** | –0.1102 | 0.1753 | 0.0410 |
| 1994 (79) | 0.0300 | –0.0654 | 0.0159 | 0.1226 | –0.0728 |
| 1995 (22) | –0.2215 | –0.1437 | –0.0607 | 0.2369 | –0.0289 |
| 1996 (34) | 0.1882 | 0.0168 | **0.4574***** | –0.1568 | –0.1807 |
| 1997 (64) | –0.0116 | **–0.2318*** | –0.0240 | 0.1621 | –0.0009 |
| 1998 (36) | 0.0900 | –0.1097 | –0.1072 | 0.1605 | –0.0760 |

*$P<0.1$; **$P<0.05$; ***$P<0.01$

**Table 4** Analysis of correlations and their significance levels between pollen concentration of plants of multiple origin and wind direction or period of calm

| *Poaceae* | | | | | |
|---|---|---|---|---|---|
| Year (days) | Calms | Quad. 1 | Quad. 2 | Quad. 3 | Quad. 4 |
| 1993 (62) | 0.0861 | –0.1771 | –0.1186 | 0.0613 | 0.1615 |
| 1994 (68) | –0.0940 | 0.1846 | –0.1868 | –0.2168* | 0.1587 |
| 1995 (44) | –0.1815 | –0.0506 | –0.0584 | –0.1107 | 0.1760 |
| 1996 (56) | –0.1286 | –0.0820 | –0.2327 | –0.0367 | **0.3139**** |
| 1997 (85) | **–0.1818*** | –0.0651 | –0.1553 | –0.0526 | 0.1919 |
| 1998 (68) | 0.0441 | 0.0161 | 0.1203 | –0.1911 | 0.0963 |
| *Quercus* | | | | | |
| Year (days) | Calms | Quad. 1 | Quad. 2 | Quad. 3 | Quad. 4 |
| 1993 (56) | –0.0056 | **–0.2256*** | 0.1045 | **–0.2770**** | –0.0706 |
| 1994 (54) | –0.0716 | **0.2791**** | 0.1941 | –0.1532 | –0.1549 |
| 1995 (34) | –0.1547 | **0.5575***** | 0.1403 | –0.1749 | **–0.4275**** |
| 1996 (69) | **0.4750***** | 0.1962 | –0.1030 | **–0.2209**** | 0.0566 |
| 1997 (42) | **0.3047**** | 0.1828 | **–0.2689*** | –0.0593 | 0.0575 |
| 1998 (59) | **0.5650***** | 0.1073 | **0.2763**** | –0.1555 | **–0.3018**** |
| *Olea* | | | | | |
| Year (days) | Calms | Quad. 1 | Quad. 2 | Quad. 3 | Quad. 4 |
| 1993 (34) | 0.1095 | –0.2770 | **–0.3157*** | 0.1199 | 0.2543 |
| 1994 (40) | –0.0232 | 0.0663 | –0.0914 | **–0.3663**** | **0.3873**** |
| 1995 (24) | 0.3536 | 0.3298 | **0.6124***** | –0.2013 | **–0.5224**** |
| 1996 (40) | 0.1080 | 0.1554 | 0.2629 | –0.1589 | –0.0805 |
| 1997 (27) | 0.2899 | 0.1322 | 0.1890 | –0.2413 | 0.0006 |
| 1998 (37) | 0.0510 | 0.0210 | **0.5584***** | –0.1942 | –0.2260 |

*$P<0.1$; **$P<0.05$; ***$P<0.01$

any with the *Populus* type, possibly because of the localization of trees of this genus grown as ornamentals in other quadrants. We could adduce the same explanation for the types *Ulmus* and *Casuarina*. In the case of irrigated lands of quadrant 3 there must be an effect of filtering caused by the city buildings.

With respect to the periods of still air, our understanding is that when there appear to be significant correlations with this state as well as with the wind from any one of the four quadrants, this indicates that there are sources of this pollen type in the proximity of the trap, and that the increases in pollen concentration are very probably due to convection currents. This phenomenon appeared in at least 2 years for Amaranthaceae-Chenopodiaceae, *Plantago*, *Populus*, and *Quercus*, and only for Arecaceae did the pollen concentrations decline in the absence of wind.

There seems to be no doubt that the wind direction must be taken into account to explain part of the daily variation in pollen concentrations in the atmosphere. In view of the results, and in particular of the fact that rarely was any constancy observed over all the years for the significant correlations, it seems evident that a significant number of years of study are required to test the influence of wind direction on pollen concentration in the atmosphere. Obviously to establish predictive models one will not only have to take into account the wind direction but also analyse in detail the distribution of pollen sources over the surrounding terrain.

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## References

Benninghoff WS (1987) Environmental influences on deposition of airborne particles. In: Boehm G, Leusner RM (eds) Advances in aerobiology. Proceding of the 3rd International Conference on Aerobiology. Birkhäuser, Basel, pp 11–18

Bourgeois J C, Koerner R M, Alt B T (1985) Airborne pollen: a unique mass tracer, its influx to the Canadian high arctic. Ann Glaciol 7:109–116

Charlesworth D (1993) Why are unisexual flowers associated with wind pollination and unspecialized pollinators? Am Nat 141:481–490

Comtois P (1997) Pollen dispersal and long distance transport: the case of thermophilic pollen in subarctic Canada. Grana 13:37–42

Crane PR (1986) Form and function in wind dispersed pollen. In: Blackmore S, Ferguson IK (eds) Pollen and spores, form and function. Academic Press, London, pp 179–202

Emberlin J, Norris-Hill J (1996) The influence of wind speed on the ambient concentrations of pollen from Gramineae, *Platanus*, and *Betula* in the air of London, England. In: Muilenberg M, Burge H (eds) Aerobiology. Lewis, Boca Raton, Fla., pp 27–48

Frenguelli GF, Spieksma SFT, Bricchi E, Romano B, Mincigrucci G, Nikkels AH, Dankaart W, Ferranti F (1991) The influence of air temperature on the starting dates of the pollen season of *Alnus* and *Populus*. Grana 30:196–200

González Minero F J, Candau P, Marroquín A (1993) Relaciones entre aerobiología y meteorología. Calendario Meteorol 1993:229–234

Gregory PH (1978) Distribution of airborne pollen and spores and their long distance transport. Pure Appl Geophys 116:309–315

Hjelmroos M (1991) Evidence of long-distance transport of *Betula* pollen. Grana 30:215–228

Hirst J M (1952) An automatic volumetric spore trap. Ann Appl Biol 39:257–265

Lighthart B, Spendlove J C, Akers T G (1979) Sources and characteristics of airborne materials. Factors in the production, release, and viability of biological particles. In: Edmonds RL (ed) Aerobiology. The ecological systems approach. Dowden, Hutchinson % Ross, Stroudsburg, pp 11–84

Ljunkuist S, Bringfelt B, Fredriksson U (1977) Correlation between the pollen content of the Stockholm air and meteorological data. Grana 16:145

Mäkinen Y (1977) Correlation of atmospheric spore frequencies with meteorological data. Grana 16:149–153

McDonald MS (1979) The effects of meteorological conditions on the concentration of air-borne pollen over an estuarine area on the west coast of Ireland. Pollen Spores 21:233–238

McDonald M S (1980) Correlation of airborne grass pollen levels with meteorological data. Grana 19:53–56

Norris-Hill J (1997) The influence of ambiental temperature on the abundance of Poaceae pollen. Aerobiologia 13:91–98

Recio M, Cabezudo B,.Trigo MM, Toro FJ (1996) *Olea europaea* pollen in the atmosphere of Málaga (S. Spain) and its relationship with meteorological parameters. Grana 35:308–313