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PAPER

Platanus pollen season in Andalusia (southern Spain): trends and modeling

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Platanus is a major cause of pollen allergy in many Spanish cities. The present paper reports an analysis of *Platanus* pollen season throughout the Andalusia region (southern Spain), which has among the highest pollen counts and the highest incidence of *Platanus*-related allergies in Europe. The main aim was to analyze pollen season trends from 1992 to 2010 in Andalusia; models were also constructed to forecast the start of the season. Daily pollen counts were recorded using Hirst-type volumetric spore-traps. Pollen season start-dates were very similar at all sites, usually occurring in March. The pollen season was delayed over the study period. The Pollen-season duration and Pollen index generally increased throughout the study period. The starting date for temperature accumulation was around the 10th February, although the threshold temperatures varied by site. The regional model for Andalusia failed to provide sufficiently accurate results compared with sub-regional or local models. For modeling purposes, three sub-regions are recommended: Inland, East Coast and West Coast.

Introduction

Awareness of the impact of climate change on ecosystems has, over the last few years, prompted growing research into the effect of climate on plant phenology; studies have focused on analyzing possible trends and on modelling the response of plants to the climate.[1] Many diseases are caused or aggravated by pollen and other biological particles that display a marked seasonality, and change with weather conditions.[2] *Platanus* is a common pollen type, with high airborne counts over much of southern Europe, including many Spanish cities. *Platanus* sp. is widely used for ornamental purposes: in Andalusia, the most commonly-cultivated species is *Platanus hispanica* Miller ex Münchh (*Platanus hybrida* Brot). High airborne pollen counts in Andalusia reflect not only the abundance of *Platanus* but also the considerable pollen production of these species, which can exceed one hundred thousand million pollen grains per tree.[3] Clinical studies have identified *Platanus* as a major cause of pollen allergy in many Spanish cities. In Madrid (central Spain), where these trees are numerous, the prevalence of positive skin prick tests is around 52–56%.[4,5] In Galicia (north-western Spain), sensitization-rates range between 8% and 9%.[6] Research in Andalusia has confirmed high local airborne *Platanus* pollen counts,[7,8,9] as well as marked local sensitivity: in the city of Córdoba (south-western Spain), for example, 17% of the population is sensitive to *Platanus*.[7]

Earlier research in Spain has shown that the *Platanus* pollen season is short and intense, occurring between March and April. Pollen appears abruptly in the air, and peak counts are usually recorded only a week after the start of the pollen season. The

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Environmental impact

Monitoring biological particles in the air is important, especially if they have an impact on public health. This is the case of *Platanus* pollen with implications for pollen allergy suffers. Long-term studies of a wide area are useful to study changes in pollen season over time due to different weather conditions. Moreover, data from a high number of years and cities allows the construction of models to forecast the start of the pollen season. Regional models are useful to promote prevention in a wide area, avoiding the need to calculate the pollen count at a high number of monitoring sites.

season lasts an average of 36 days in Córdoba,[7] 40 days in Galicia[6] and 67 days in Madrid.[10] In Spain, the annual *Platanus* Pollen Index (PI), defined as the annual sum of daily values, ranges from below 50 in parts of Galicia to over than 20 000 in Barcelona, Madrid, Seville and Córdoba. On the peak day, usually occurring in March, counts vary from less than one hundred to several thousand pollen grains m^{-3} day^{-1}, depending on their abundance as ornamentals.[9] Annual airborne counts vary as a function of weather conditions but also as a function of human activity, especially pruning, since *Platanus* is mostly used for ornamental purposes. Pruning, often intense, is carried out before flowering, prompting a decline in recorded pollen counts. A number of studies confirm that temperature is the weather parameter with the greatest influence on the *Platanus* pollen season, affecting both start-date and daily pollen counts.[6,11,12] Rainfall, although presenting pronounced variations in Andalusia, does not affect the *Platanus* pollen season as it is an ornamental tree artificially watered. The present paper reports on an analysis of the *Platanus* pollen season throughout the whole Andalusia region (southern Spain), which has among the highest pollen counts and the highest incidence of *Platanus*-related allergies in Europe.[7,9]

The main aim of this study was to analyze *Platanus* pollen season trends from 1992 to 2010, at 8 sites in Andalusia, noting variations in the start-date, end-date, duration and intensity of the season; models were also constructed to forecast the start of the season in the region.

Numerous studies have highlighted the close relationship between temperature and plant phenology especially in woody plants. The reproductive phenology of trees, especially in temperate climates, is commonly assumed to be strongly related to temperature, but also locally adapted to different climate ranges. However, recent research suggests that this local adaptation may not been as great as expected.[13,14] Although phenological models have traditionally been constructed using only local data in order to obtain more precise results, recent studies indicate that phenological models for tree populations can be established over wider regional areas. Here, the influence of temperature on the start of the *Platanus* pollen season was analyzed, and various temperature-based models were constructed. The results of local models for each of the eight study sites were compared with a regional model for the whole of Andalusia, and with sub-regional models for different areas of Andalusia, in order to assess the efficiency of wider regional models and measure the influence of local adaptation to climate on the phenological response, with a view to minimizing the number of models required to predict *Platanus* reproductive phenology in Andalusia and to optimizing their practical application.

Material and methods

Study area

Airborne pollen data were recorded in the capital cities of the eight provinces of Andalusia, in southern Spain. The coordinates, altitude, mean temperature during the pollen season, average cumulative annual rainfall, distance from meteorological stations and pollen samplers, and study years, are shown in Table 1. *Platanus* is most frequently observed in the inland cities of Seville and Córdoba, followed by Granada and Jaén, and less frequently observed in the coastal cities of Almería, Cádiz, Huelva and Málaga.

Andalusia has a Mediterranean climate. Cádiz, Huelva, Málaga and Almería are coastal cities with mild temperatures due to a strong maritime influence. Córdoba, Seville, Granada and Jaén are inland cities with a greater temperature range; colder winters and hotter summers. Mean daily temperatures for each site were obtained from the regional weather station network run by the Spanish Meteorological Agency (AEMET) and from the Regional Government Department of Agriculture.[15]

Pollen counts

Daily pollen counts were recorded using Hirst-type spore traps[16] (Burkard Manufacturing Co. Ltd., UK or VPPS 2000 Lanzoni s.r.l., Italy, 7-day volumetric pollen traps in both cases) for a period from 11 to 19 years depending on the site (1992–2010) (Table 1); following the standardized methodology proposed by Galán *et al.*[17] for the Spanish Aerobiology Network (REA) as the reliability of data is the prerequisite for successful monitoring.[18] In the 8 sampling sites belonging to REA, samplers function continuously providing daily records. The drum inside the sampler can work continuously for one week. In the 8 provinces, every Monday the used drum with the sampling tape was taken to the laboratory. The same adhesive (LANZONI s.r.l. silicon fluid) and mounting media (fuchsin-stained glycerin gelatin) was used. All points followed the same counting method (4 continuous horizontal sweeps over the slide with a 40 × 10 lens). Once the daily number of pollen grains per cubic meter was ascertained for the whole 7-day week, the data was sent for analysis to the REA

Table 1 Characteristics of study sites. Distance from meteorological station to pollen sampler (DMS). Average pollen season duration (PSD) and start-dates (from January 1st)

City	Sampling period	Coordinates	Altitude m. a.s.l.	Mean Temp. Pollen season (°C)	Annual rainfall (mm)	DMS (Km)	PSD (days)	Start (days)
Almería	1998–2010	36°50′N, 2°28′W	23	16	345	15	27	72
Cádiz	2000–2010	36°32′N, 6°18′W	7	15	463	9.5	37	66
Córdoba	1992–2010	37°50′N, 4°45′W	123	15	674	4.5	46	67
Granada	1992–2010	37°11′N, 3°35′W	685	13	462	10	47	69
Huelva	1993–2010	37°16′N, 6°75′W	20	16	719	12	38	67
Jaén	1993–2010	37°46′N, 3°47′W	550	14	582	2.5	35	69
Málaga	1992–2010	36°47′N, 4°19′W	5	17	575	5	46	65
Seville	1993–2010	37°25′N, 5°54′W	10	16	737	10	55	61

Center for Coordination at the University of Córdoba. The start of the pollen season was defined as the first day on which a daily average of at least 1 pollen grains m^{-3} was detected, followed by five subsequent days with 1 or more pollen grains m^{-3}. The end of the pollen season was defined as the last day on which a daily average of at least 1 pollen grain m^{-3} was recorded, when counts for the five following days were below this level.[19] The peak date was defined as the day on which maximum pollen counts were recorded. PI was defined as the annual sum of daily values.

Phenological models

The phenological patterns reported here were based on a 1-phase Growing Degree Days (GDD°) model for budburst.

$$GDD = \frac{T_{\max} + T_{\min}}{2} - T_b$$

The pattern considers temperature conditions after the quiescence phase, only after dormancy break. The GDD model

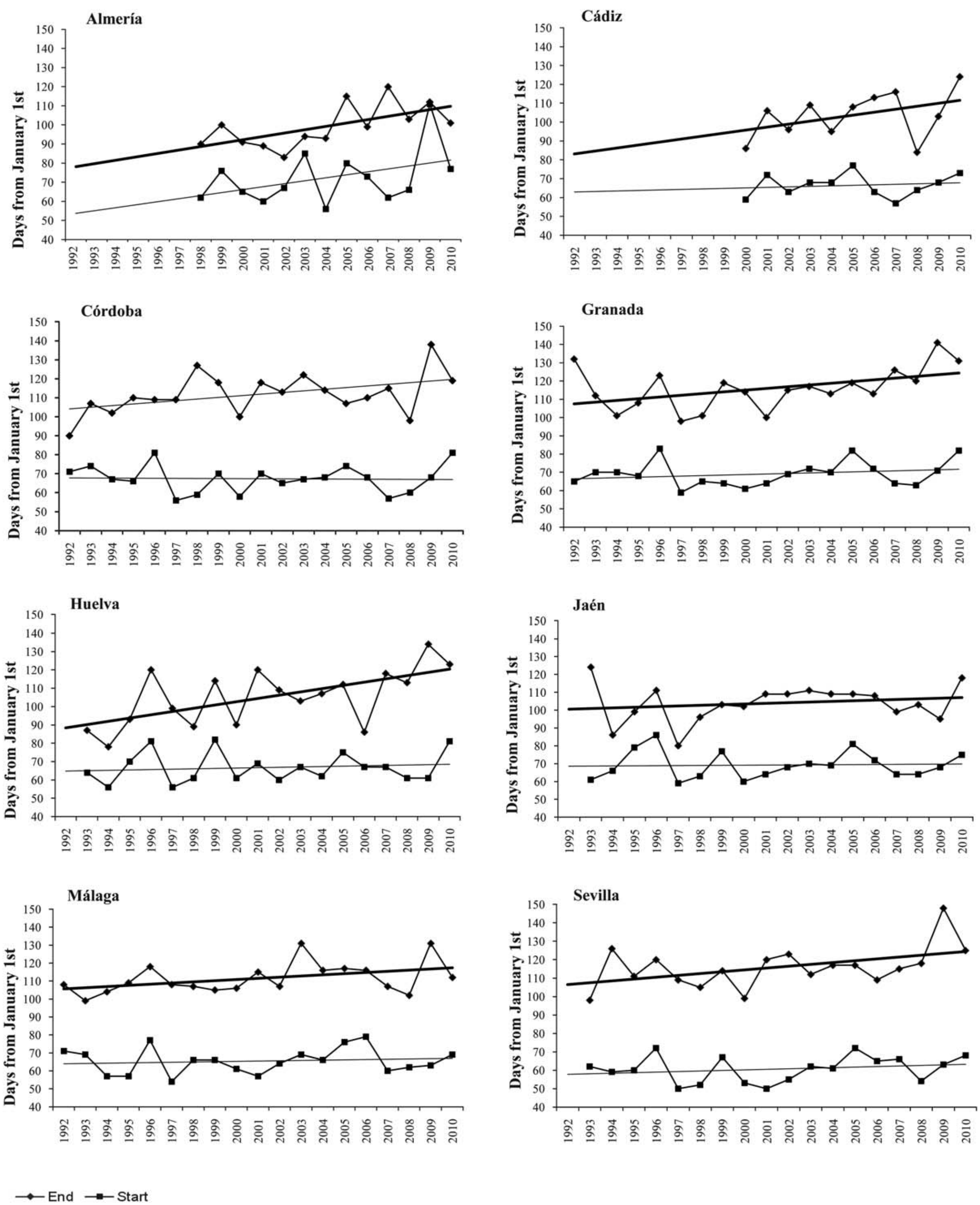

Fig. 1 Number of days from January 1st to the start and end dates of the pollen season during the study years.

Table 2 Slope values, R^2 and significance (p) for the trend equation of the start dates, end dates, Pollen Season Duration (PSD) and Pollen Index (PI), during the study period in Andalusia

	Start			End			PSD			PI		
	Slope	R^2	p	Slope	R^2	p	Slope	R^2	p	Slope	R^2	p
Almería	1.55	0.17	0.10	1.76	0.39	0.00	0.24	0.00	0.44	3.26	0.04	0.32
Cádiz	0.27	0.02	0.28	1.58	0.18	0.12	1.31	0.13	0.12	10.8	0.07	0.20
Córdoba	0.02	0.00	0.41	0.58	0.10	0.03	0.56	0.07	0.04	239.71	0.08	0.03
Granada	0.29	0.05	0.21	0.93	0.20	0.02	1.15	0.36	0.05	164.3	0.32	0.02
Huelva	0.20	0.02	0.30	1.78	0.38	0.01	1.58	0.37	0.00	79.85	0.29	0.01
Jaén	0.07	0.00	0.25	0.36	0.03	0.32	0.29	0.02	0.10	210.37	0.65	0.00
Málaga	0.16	0.02	0.35	0.65	0.18	0.07	0.40	0.05	0.17	6.22	0.09	0.01
Seville	0.30	0.05	0.11	1.00	0.22	0.05	0.69	0.10	0.20	−317.75	0.09	0.08

calculates the sum of degree days or forcing units over a given threshold temperature (T_b) fitted for each area from a starting date of accumulation (t0). t0 is the date when the accumulation of forcing units starts and F^* is the critical sum of forcing units to be accumulated for the phenological event, in this case the start of pollen season, to take place.

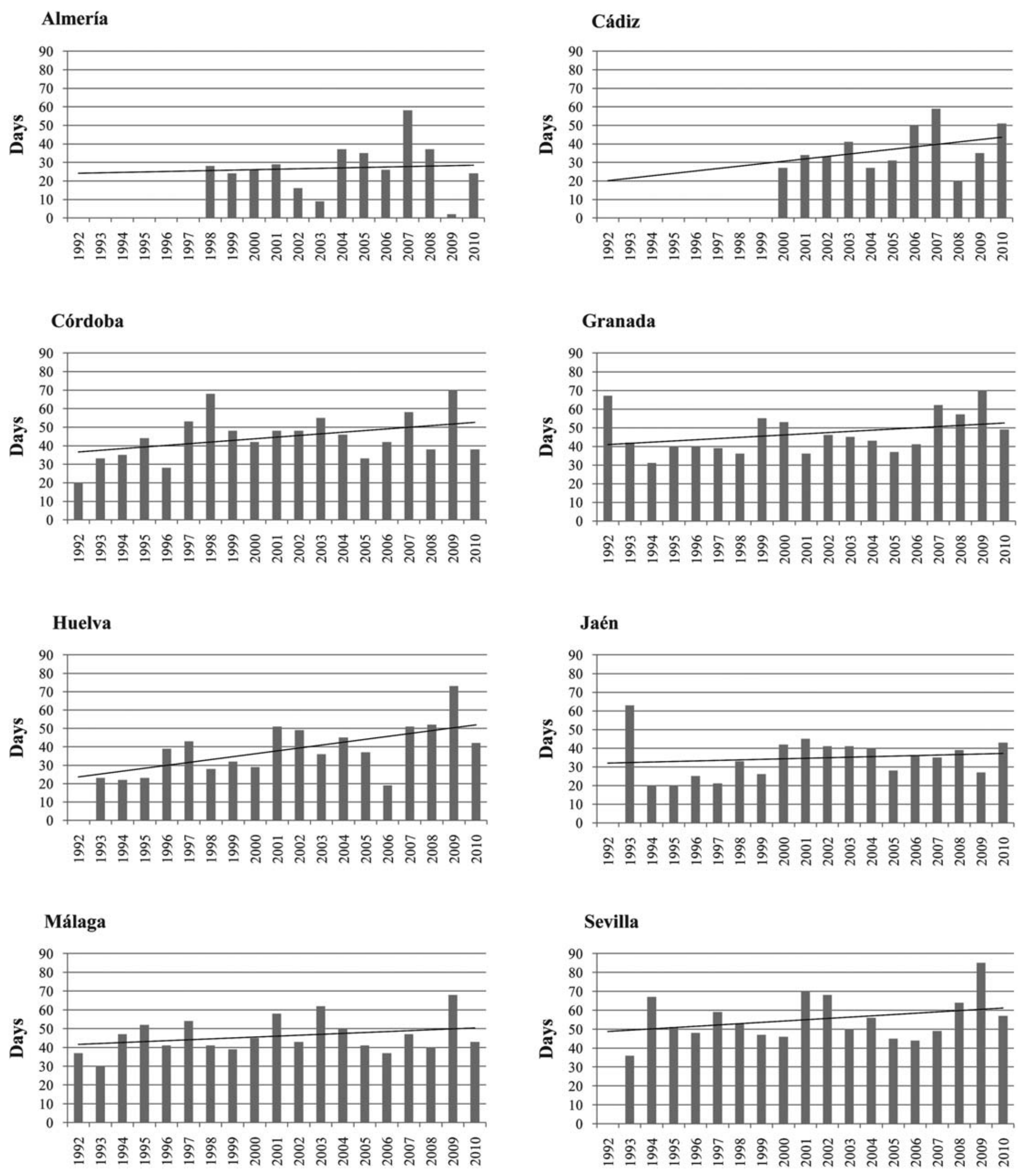

Fig. 2 Pollen season duration in Andalusia during the study years.

First, a separate model was constructed for each sampling-site; second, a simplified model was constructed for all sites taken together; and finally, various sub-regional models were tested. For this latter purpose, data from several sampling stations were pooled, following grouping by proximity and by climate characteristics (*i.e.* general coastal, east coastal, west coastal and inland models). The resulting patterns were termed sub-regional models. Models were fitted using the least-squares method and the Metropolis simulated-annealing algorithm.[20] After complete fitting, models were also fitted by extracting data for some years. Predicted results were validated by comparing real and expected data.

Stability of model estimates across environments. Different local and regional model results were analysed to test the hypothesis that results obtained using phenological models fitted using data from neighbouring *Platanus* populations growing under similar climate characteristics would not differ significantly.

Models were fitted:

1) using data for each separate site, Local Model (LM)

2) using pooled data for all sites, Simplified Model (SM)

3) using data for a group of sites, Regional Model (RM)

The F value, which measures the distance between individual distributions, was calculated as:

$$F = [(SS_1 - SS_2)/(df_2 - df_1)]/[SS_2/(df_{TOT} - df_2)]$$

where SS_1 and SS_2 are the residual sum of squares of models, df_2 and df_1 are the degree of freedom of models, and df_{TOT} is the

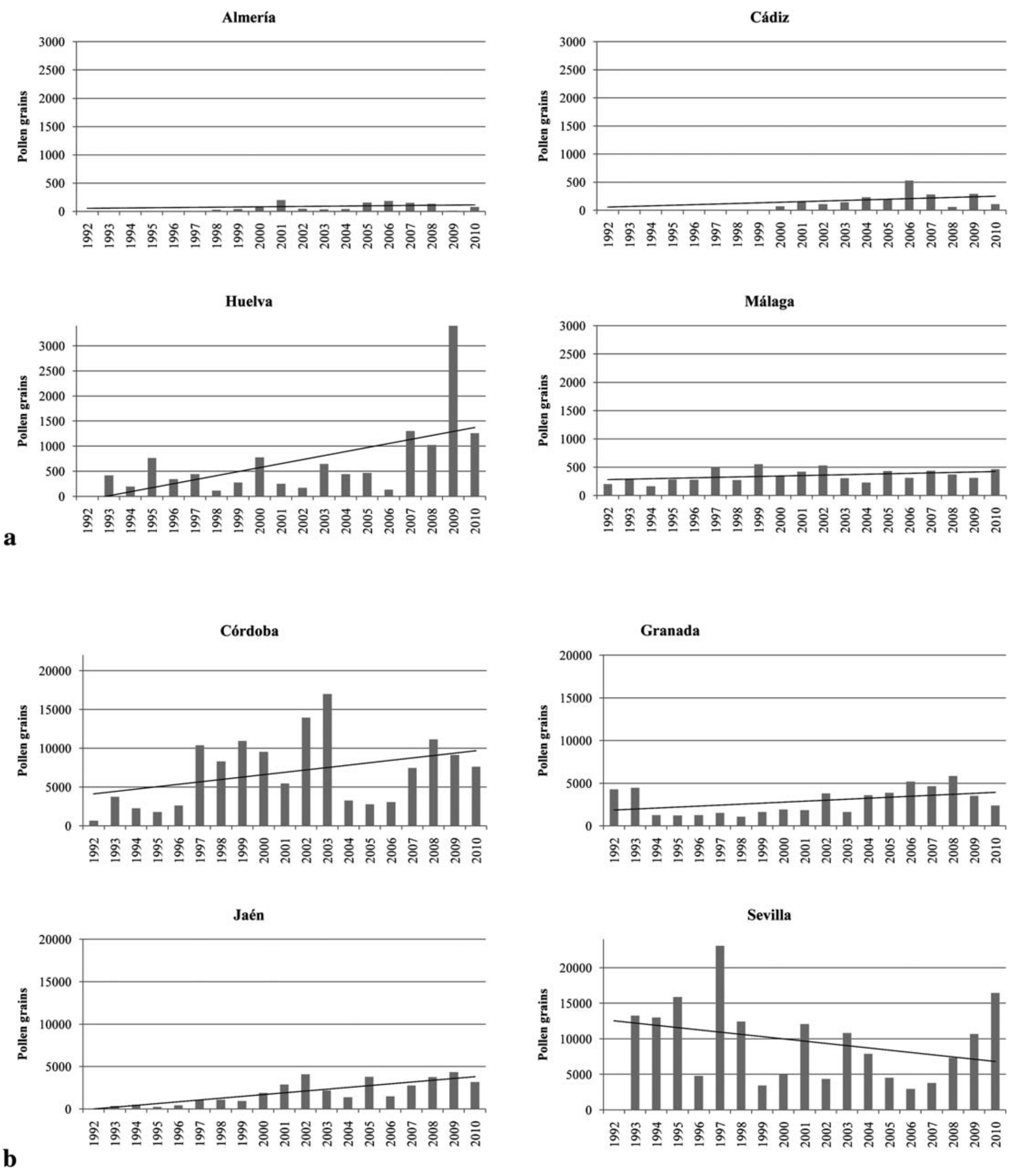

Fig. 3 (a) Pollen index in the coastal cities during the study years. (b) Pollen Index in the inland cities during the study years.

total degree of freedom. Model estimates were deemed to vary with environment if the F value was significantly higher than the critical value of F ($df_2 - df_1$, $df_{TOT} - df_2$).

SMs and RMs were tested against LMs for the sites concerned. The percentage variation between populations was defined as:

$$100 \times [(SS_1 - SS_2)/(SS_{TOT})]$$

where SS_{TOT} is total variance. The population effect was deemed significant if this value was significantly higher than the critical value of F ($df_2 - df_1$, $df_{TOT} - df_2$).

Results

The *Platanus* pollen season usually starts during March and ends in April, lasting an average of 41 days in Andalusia, the total duration of the pollen season always being less than two months (Table 1).

During the study period, pollen-season start-dates were very similar at all sites, usually occurring in early March. The average start-date (from January 1st) was 67 days in Andalusia. The sequence of *Platanus* flowering in Andalusia was as follows: the pollen season started first in Málaga and western Andalusia (Huelva, Cádiz, Seville and Córdoba) and later in eastern Andalusia (Jaén, Granada and Almería) (Table 1).

The pollen-season start-date trend displayed a positive slope at all study sites (Fig. 1, Table 2) indicating a tendency towards later onset, although it is not statistically significant. The trend for pollen-season end-dates also indicated a progressive delay, significant in some cases ($p < 0.05$) (Fig. 1, Table 2). Consequently, the pollen season as a whole was delayed over the study period. Pollen-season duration tended to be longer, with a positive slope for all study sites (Fig. 2), but significant only in Córdoba and Huelva.

Year-on-year variations in the PI are shown in Fig. 3. The highest *Platanus* pollen counts were recorded in Córdoba and Seville, in some years exceeding 16 000 and 20 000 pollen grains, respectively. Lower figures were recorded in Granada and Jaén (reaching around 5000 in some years), while the lowest figures were detected in Almería, Cádiz, Huelva and Málaga. Trend analysis indicates that PI has increased throughout the region with a significance level of 95% ($p < 0.05$) in most cities or even 99% ($p < 0.01$) in some cases, with the exception of Seville, although in this case the tendency is not statistically significant ($p > 0.05$) (Table 2, Fig. 3).

The pollen peak day generally occurred in March. Maximum daily pollen counts were also recorded in Córdoba (4650 pollen grains m^{-3} in 2003), followed by Seville and Granada (Table 3). The lowest values were recorded in coastal cities (Huelva, Almería, Cádiz and Málaga) where maximum daily pollen counts in some years were below 100 pollen grains m^{-3} (Table 3).

Annual average mean temperatures declined over the study period for all study sites. Average mean temperatures during January and February also tended to decrease over time (Fig. 4).

Phenological models were fitted at various regional scales. Parameter estimates for each model and the explained variance in flowering dates (R^2) are shown in Table 4. In all cases, the starting date (t0) for temperature accumulation was around the 10th February, although threshold temperatures varied by site, from 2.5 °C in Granada to 9.72 °C in Almería; as a result, different F^* values were calculated for different sites. The percentages of variance explained by local models were greater than in regional models (25% to 69%). The results obtained by constructing 4 different sub-regional models were studied: Coast (Málaga + Almería + Cádiz + Huelva), East Coast (including Mediterranean coastal sites, Málaga + Almería), West Coast (including Atlantic coastal sites, Huelva + Cádiz) and Inland (Córdoba + Seville + Granada + Jaén). Good results for explained variance were also obtained using sub-regional models; except for the Coast model, where the lowest value was found (15%); this value was even lower than that for the SM model including all Andalusia sites (27%). Three sub-regional models can thus be considered optimal: Inland, East Coast and West Coast.

Statistical results for the measurement of local variations are shown in Table 5, which includes F-test results for comparison

Table 3 Maximum daily pollen concentration (pollen grains m^{-3}) and peak date

	Almería	Cádiz	Córdoba	Granada	Huelva	Jaén	Málaga	Seville
1992			646 (15/3)	726 (22/3)			59 (14/3)	
1993			606 (21/3)	971 (23/3)	130 (22/3)	57 (30/3)	43 (21/3)	1813 (16/3)
1994			531 (13/3)	128 (18/3)	37 (08/3)	80 (22/3)	18 (19/3)	2535 (13/3)
1995			175 (22/3)	135 (26/3)	156 (13/3)	45 (28/3)	53 (19/3)	2332 (13/3)
1996			711 (29/3)	183 (05/4)	124 (29/3)	65 (29/3)	59 (29/3)	1188 (29/3)
1997			1475 (06/3)	218 (08/3)	92 (09/3)	133 (09/3)	50 (19/3)	3278 (04/3)
1998	13 (11/3)		1297 (18/3)	169 (22/3)	13 (20/3)	103 (18/3)	21 (31/3)	2129 (06/3)
1999	9 (17/3)		2690 (22/3)	235 (05/4)	148 (23/3)	146 (30/3)	63 (17/3)	417 (23/3)
2000	15 (11/3)	10 (02/3)	1769 (10/3)	294 (11/3)	229 (10/3)	215 (16/3)	38 (11/3)	2400 (05/3)
2001	32 (04/3)	21 (13/3)	1519 (18/3)	243 (22/3)	61 (14/3)	588 (20/3)	48 (06/3)	3845 (13/3)
2002	7 (24/3)	13 (22/3)	2932 (22/3)	591 (21/3)	22 (27/3)	715 (23/3)	57 (21/3)	513 (23/3)
2003	10 (31/3)	17 (14/3)	4650 (16/3)	344 (26/3)	87 (20/3)	413 (15/3)	29 (16/3)	2126 (13/3)
2004	7 (13/3)	26 (13/3)	489 (20/3)	682 (22/3)	60 (21/3)	282 (22/3)	23 (22/3)	1186 (17/3)
2005	34 (26/3)	26 (23/3)	821 (31/3)	470 (01/4)	81 (31/3)	1239 (25/3)	38 (31/3)	877 (24/3)
2006	22 (19/3)	63 (19/3)	1003 (26/3)	935 (27/3)	35 (12/3)	228 (24/3)	39 (22/3)	385 (26/3)
2007	15 (31/3)	26 (13/3)	1103 (16/3)	446 (16/3)	226 (13/3)	507 (15/3)	54 (06/3)	724 (13/3)
2008	13 (17/3)	8 (05/3)	2325 (14/3)	1464 (15/3)	145 (05/3)	665 (14/3)	33 (04/3)	1259 (04/3)
2009	11 (21/4)	63 (21/3)	2828 (17/3)	418 (16/3)	582 (13/3)	1133 (15/3)	28 (24/3)	1888 (16/3)
2010	18 (20/3)	41 (21/3)	1264 (23/3)	262 (28/3)	202 (23/3)	992 (23/3)	54 (25/3)	2795 (23/3)

of variance in models for different groups of sites. Statistically-significant differences indicate explained variance (variability) between groups. The results suggested that the Inland, East Coast and West Coast sub-regional models were as effective as the sum of related local models and that a comparison between populations was feasible at that regional level. Models fitted with local data did not provided greater accuracy in explaining variations in flowering-times between populations. By contrast, the regional model for Andalusia failed to provide sufficiently accurate results compared with sub-regional or local models. For modelling purposes, therefore, three sub-regions are recommended: Inland, East Coast and West Coast. These 3 models would appear to be sufficient for effective forecasting of *Platanus* flowering start-dates in southern Spain.

Discussion

Recent years have seen considerable research into airborne *Platanus* pollen counts throughout Europe; interest in *Platanus* is increasing because its widespread use as an ornamental plant has led to high pollen counts, with the consequent implications for pollen-allergy sufferers.[6,7,8,9,10,11,12,21,22] All these papers report, as the present study showed, that *Platanus* pollen appears abruptly in the air and is recorded over a short period of time during March and early April; the highest proportion of the PI is recorded over a period of 2 or 3 weeks, and temperature is the parameter most influencing airborne pollen counts. This is a typical urban pollen type, scarce in natural areas: while very high counts are recorded in Córdoba city, counts are very low, indeed almost non-existent, in non-urban areas of Córdoba province.[23]

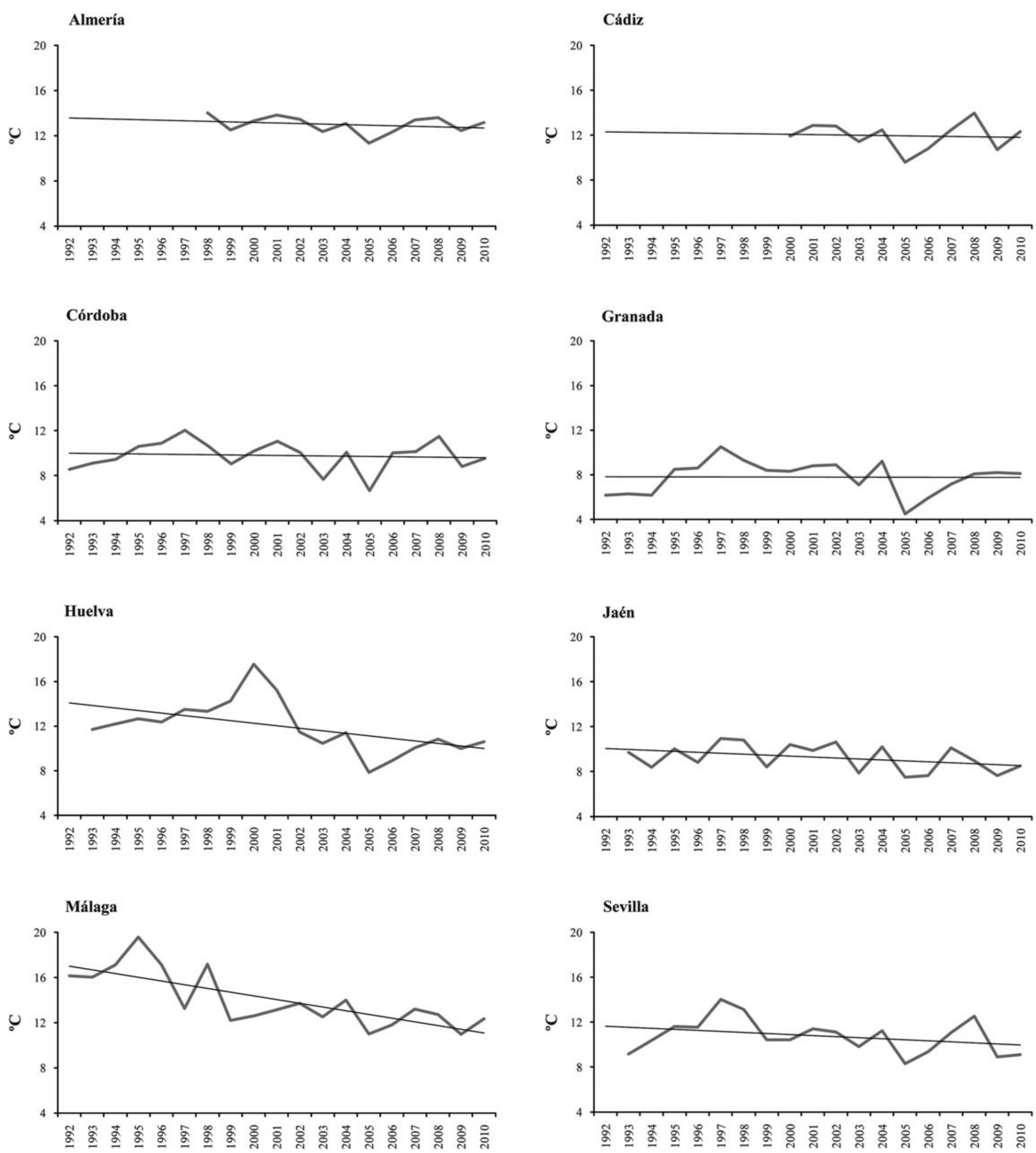

Fig. 4 Annual average of mean temperatures recorded during January and February in Andalusia during the study years.

Table 4 Parameter estimates for each model and the explained variance in flowering dates (R^2)[a]

Model Type	Region/Locality	Model Code	R^2	*P* value	Ssres	T_0	Tb	F^*	RMSE
SM	Andalucia	SM	0.27	0.000	5349.94	40	0.00	304.48	6.60
RM	Coast	RMCoast	0.15	0.004	2619.40	40	0.00	364.03	6.90
	Inland	RMInland	0.60	0.000	1592.12	40	2.64	203.94	4.84
	East Coast	RMECoast	0.46	0.001	777.62	40	7.24	254.82	5.95
	West Coast	RMWCoast	0.53	0.000	1535.82	40	3.92	203.74	6.82
RM	Córdoba	LMC	0.69	0.000	301.00	40	8.15	95.40	4.09
	Seville	LMS	0.51	0.001	416.73	40	5.05	136.52	4.81
	Granada	LMG	0.54	0.001	390.14	40	2.50	203.39	4.66
	Jaén	LMJ	0.68	0.000	327.39	40	4.20	184.34	4.26
	Málaga	LMM	0.51	0.001	352.28	40	6.39	200.65	4.05
	Almería	LMA	0.40	0.026	530.30	40	9.72	119.52	6.65
	Cádiz	LMCa	0.25	0.112	299.42	40	4.74	226.89	4.99
	Huelva	LMH	0.56	0.010	1016.28	40	5.51	252.7	6.93

[a] SM: Simplified Model; RM: Regional Model; LM: Local Model.

In this study of the eight provincial capitals of Andalusia, the *Platanus* pollen season started in March, first in Málaga and western Andalusia and later in eastern Andalusia; this coincides with the overall flowering pattern reported for other species in the region. No trend towards a biannual rhythm in the PI for *Platanus* pollen was found, as reported by González and Candau[22] in Seville. The results obtained here agreed with others indicating no regular flowering pattern.[9,21]

Annual pollen counts increased over time, a finding noted for most Spanish sites in the literature.[7,21,6,10] An increase in annual pollen counts was recorded in all study cities, probably due to the planting of more plane trees over the years. The exception was Seville, where the pollen index declined over the study period, probably due to drastic pruning prior to flowering.

The pollen-season start-date displayed a positive slope in all study cities, indicating a progressively-delayed onset of the pollen season. Similar findings have been reported elsewhere in Spain, whereas in Italy data point to an advance in the start of the pollen season.[12]

In Italy, where plane trees are also commonly grown, an advance in the onset of the pollen season has been reported for spring-flowering plants,[24,25] while for winter-flowering plants there appears to be a progressive delay in the start of the pollen season.[24,26] *Platanus* starts to flower at the end of winter in Andalusia, so the pattern observed for winter-flowering plants in Italy was also observed here, with a delay in the start of the pollen season over the study period.

A trend towards lower temperatures in the months prior to *Platanus* flowering was observed over the study period; these are the temperatures most influencing the start of the pollen season. Although global average surface temperature has increased over the past 100 years it is possible to find periods with decreasing

Table 5 Statistics results of the measurement of local variations[a]

	SS	df	MS	*F*	*p*	R^2
SM/Ma + Al + Ca + Hu + Co + Se + Gr + J	5349.94	3	1783.31			
Effect site	916.40	21	43.64	0.97	0.50	0.28
Residue	4433.54	99	44.78			
Total	3230.67	123	26.27			
RMCoast + RMInland/SM						
SM	5349.94	3	1783.31			
Effect site	1138.42	3	379.47	10.54	0.00	0.35
Residue	4211.52	117	36.00			
Total	3230.67	123	26.27			
Ma + Al + Ca + Hu/RMCoast						
RMCoast	2619.4	3	873.13			
Effect site	431.12	9	47.90	0.94	0.50	0.79
Residue	2188.28	43	50.89			
Total	543.06	55	9.87			
RMECoast + RMWCoast/RMCoast						
RMCoast	2619.4	3	873.13			
Effect site	305.96	3	101.99	2.16	0.10	0.56
Residue	2313.44	49	47.21			
Total	543.06	55	9.87			
Co + Se + Gr + J/RMInland						
RMInland	1592.12	3	530.71			
Effect site	156.86	9	17.43	0.68	0.72	0.07
Residue	1435.26	56	25.63			
Total	2371.43	68	34.87			

[a] SM: Simplified Model; RM: Regional Model; LM: Local Model; ECoast: East Coast; WCoast: West Coast; Ma: Málaga; Al: Almería; Ca: Cádiz; Hu: Huelva; Co: Córdoba; Se: Seville; Gr: Granada; J: Jaén.

temperatures, as in this study. This fact could be the cause for the delay in the *Platanus* pollen season during the study period. Although the trend for many species is to an advance in the start of the pollen season, it is important to avoid generalizations to contribute with specific studies that clarify the current effects of temperatures in different plants, periods of time and geographical areas.

Though the models were constructed with data for a wide geographical area displaying different climate features, the response of *Platanus* to temperature was clear. In studies carried out elsewhere Europe, earlier-flowering species, including *Platanus*, have proved to be more sensitive to temperature, and therefore better indicators for global changes in temperature, than later-flowering species.[27]

Model parameters were fitted to data for populations at local and regional levels, to ascertain whether any significant variation existed in the response of phenology to environment, and whether it would be necessary to build different phenological models. The R^2 statistic was significant ($p < 0.05$) for most of the model runs, even highly significant in most cases (99%, $p < 0.01$), except in local model for Cádiz ($p > 0.05$).

The percentages of variance explained by local models were on average greater than those explained by regional models. Nevertheless, acceptable results were obtained using some of the proposed sub-regional models. Analysis of the results obtained suggests that model estimates of the response to temperature in individuals growing in similar climate areas are not significantly different, and thus that sub-regionally-simplified phenological models are sufficient to provide a general idea of *Platanus* phenological behaviour in southern Spain. There were no significant differences ($p > 0.05$) in the *Platanus* flowering response to temperature in similar bioclimatic areas (Table 5). Model estimates did not vary greatly as a function of environment within similar climate areas where the same species grew; thus, model estimates of the temperature response of individuals growing in similar climate areas did not differ significantly. Similar findings are reported for flowering start-date in other early-flowering spring species in southern Europe,[13] including Spain.[14]

Conclusions

Temperature is a parameter that influences the *Platanus* pollen season. In Andalusia, the pollen season start-date showed a progressively delayed onset influenced by a trend towards lower temperatures. The pollen season tendency is to longer seasons and higher PI over time. Acceptable results were obtained using the proposed sub-regional model, avoiding the necessity of local studies that need a great amount of work.

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