Possible role of climate changes in variations in pollen seasons and allergic sensitizations during 27 years

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Background: Climate changes may affect the quality and amount of airborne allergenic pollens. The direct assessment of such an effect requires long observation periods and a restricted geographic area.

Objective: To assess variations in pollens and allergic sensitizations across 27 years in relation to climate change in a specific region.

Methods: We recorded pollen counts, season durations, and prevalences of sensitizations for 5 major pollens (birch, cypress, olive, grass, and *Parietaria*) in western Liguria between 1981 and 2007. Pollen counts were performed using a Hirst-type trap, and sensitizations were assessed by means of skin prick testing. Meteorologic data for the same period included average temperatures, direct radiation, humidity, number of sunny days, and rainfall.

Results: There was a progressive increase in the duration of the pollen seasons for *Parietaria* (+85 days), olive (+18 days), and cypress (+18 days), with an overall advance of their start dates. For *Parietaria*, there was an advance of 2 months in 2006 vs 1981. Also, the total pollen load progressively increased for the considered species (approximately 25% on average) except for grasses. Percentages of patients sensitized to the pollens increased throughout the years, whereas the percentage of individuals sensitized to house dust mite remained stable. These behaviors paralleled the constant increase in direct radiation, temperature, and number of days with a temperature greater than 30°C.

Conclusion: The progressive climate changes, with increased temperatures, may modify the global pollen load and affect the rate of allergic sensitization across long periods.

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INTRODUCTION

Allergic diseases are the result of complex interactions between genetic and environmental factors. The latter include feeding, maternal smoking, and infections in early life. Among these factors, timing and modality of exposure to sensitizing agents are potentially important in determining the prevalence of allergic diseases. In the case of pollens, the magnitude of the exposure depends on the number of pollen grains, their allergenicity, and the duration of the pollen season. These variables are strictly related to the local climate. Thus, it is expected that climate variations may result in changes in the pollen load and in the prevalence of sensitizations.[1–4] Of note, the allergenicity of pollens is not the same throughout the years (variable total allergenicity and major allergen content), and this may also be a critical factor affecting the sensitization rate.

Several retrospective studies, based on historical data, have shown that there has been a global heating of the atmosphere, with the average increase in the earth's surface temperature estimated to be 0.7°C in the past century.[5] Some macroscopic consequences of these changes are progressive reductions of glaciers, increases in sea levels, and variations in patterns of animal migrations.[2] As mentioned previously herein, climate may affect the duration and intensity of the pollen seasons and, consequently, the total pollen load. Menzel[6] showed that in Europe there has been an overall 6-day anticipation of the blossoming of some flowers during the past 45 years, and Fitter and Fitter[7] evidenced a 4- to 5-day advance in blossoming in Great Britain for 10 years. Similar results have been found for the elm and birch pollen seasons in the past 30 years.[8,9] Temperature, directly dependent on radiation, seems to be the most relevant factor in determining changes in pollen seasons.[10] In addition, a temperature increase can modify the allergenic content of pollen granules.[11] Nonetheless, there are only sparse data on the direct correlation among climate changes, pollen seasons, and allergic sensitizations. Such data, in fact, would require years of detailed pollen counts and meteorologic monitoring, with parallel recording of the clinical data of the resident population. Moreover, owing to the large geographic variability in climate conditions and flora, studies must be conducted in a limited geographic area. In western Liguria (a coastal region of northwest Italy), for historical reasons, a complete set of pollen counts and meteorologic and clinical

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data spanning 27 years are available.[12,13] Thus, we attempted to verify whether some correlation exists among climate, pollen seasons of the major allergenic species, and sensitizations.

METHODS

Geographic Area

The region of interest, surrounding Bordighera (western Liguria), covers an area of approximately 290 km^2 and is located at 4.35°E and 47.25°N, east of France, on the Mediterranean Sea. The resident population is approximately 190,000, and this number remained stable throughout the study period. The region is characterized by a typical mild Mediterranean climate. The mean (SD) temperature during the past 30 years was 17.1C (0.53C) and varied from a minimum of 11C (2.37C) to a maximum of 26C (2.91C). Mean (SD) annual rainfall was 552 (174) mm, with a maximum of 1051 mm and a minimum of 362 mm. Rainfall is concentrated in late spring and autumn, with minimum rainfall during the summer.

Pollen Counts

The pollen counts of the 5 major allergenic species (birch, grass, cypress, olive, and *Parietaria*) were regularly recorded between January 1, 1981, and December 31, 2007. Between 1981 and 1988, a Burkard spore trap (Burkard Ltd, Newcastle, England) was used; it was then replaced, for economical and practical reasons, with a VPPS 2000 (Lanzoni, Bologna, Italy). Before replacing the equipment, the 2 machines were used in parallel for 3 months, and the interreading variability was never greater than 5%. The orifice of the spore trap (2 × 14 mm) was set 0.5 mm from the trapping surface (sticky tape). The airflow was 10 L/min, and the speed of the trapping surface was 2 mm/h. The apparatus always remained in the same place, 20 m above ground level and far from any pollution source, and it was permanently exposed to wind by means of a rotating air vane. The Hirst-type sample provides daily pollen trapping on sticky tape, which is transferred to microscope slides. Each slide is stained with fuchsin and is read using an optical microscope at ×250 magnification. The beginning of the pollen season was defined as the first of 3 consecutive days with a count of 10 grains/m^3 for the pollen of interest. Similarly, the end of the season was the first of 3 consecutive days with less than 10 grains/m^3.

Meteorologic Data

Meteorologic data included the yearly average values for temperature, rainfall, relative humidity, atmospheric pressure, direct normal radiation, and wind speed. The number of sunny and rainy days per year was also recorded. Temperature, pressure, and humidity were recorded on site in Bordighera using a WMR80 mini meteo weather station (Oregon Scientific, Hong Kong). All the data were collected and managed by the "Meteo Europa 71" observatory of Sanremo, Italy, which kindly provided the final reports. Because the region has a low degree of pollution, no systematic measurement of carbon dioxide is available, so we used a cumulative estimate for selected periods provided by the Regional Agency for Environmental Protection.[14]

Clinical Data

Patients. Data for patients first referred to the Allergy Unit, A.S.L. n°1, Imperia, for respiratory symptoms (rhinitis, asthma, or both) were systematically collected and ordered into a database starting January 1, 1981. Individuals of both sexes 5 years or older were included. In addition, participants had to have lived uninterrupted in the area of interest for the previous 5 years. Individuals living outside the region or with other diseases were not included; those with negative skin test results were excluded as well. An average of 1000 patients per year were seen at the Unit. Recorded data were demographics, clinical history, physical examination findings, and skin prick test results.

Skin Prick Tests. These tests were performed according to European recommendations after 1983.[15] The standard panel of allergens tested, according to the allergen distribution in the region, consisted of house dust mite, *Parietaria*, grass, olive, cypress, mugwort, birch, hazelnut, cat, and dog. Standardized commercial extracts from the same manufacturer (Stallergenes, Milan, Italy) were used throughout the study period. Negative (saline) and positive (0.1% histamine) controls were always applied. A reaction greater than 3 mm was considered positive. Patients had to be free of possibly interfering medications for at least 2 weeks before skin testing. The yearly percentage of patients with skin test positivity (sensitization) for the 5 pollens of interest was calculated, as was the percentage of patients with skin test positivity to house dust mite for comparison.

Data Analysis

All the data were tabulated using a commercial database program. Descriptive statistics were used for multiple observations. A linear correlation test was applied to pollen counts, season durations, and percentages of sensitized patients across time. Correlation analyses among series of data were performed using the Pearson test.

RESULTS

Pollen Seasons

Overall, the pollen season start date tended to be in advance (to begin earlier) across the years for several species (Table 1). The most relevant and consistent advances were found for *Parietaria*, olive, and cypress (Fig 1). For example, the *Parietaria* pollen season in 2007 began 66 days earlier than in 1981. To reduce the effect of yearly variability, 5-year means (7-year means for the final period) were also analyzed, confirming an overall advance from 1981-1985 to 2001-2007 of 83 days for *Parietaria*, 46 days for olive, 27 days for birch, 26 days for grass, and 9 days

Table 1. Start and End Dates[a] and Durations of the Pollen Seasons

Year	Birch			Cypress			*Parietaria*			Olive			Grass		
	Start	End	Duration, d	Start	End	Duration, d	Start	End	Duration, d	Start	End	Duration, d	Start	End	Duration, d
1981	44	117	73	310	125	180	81	350	269	149	188	39	130	212	82
1982	93	149	56	345	148	168	122	280	158	145	207	62	135	215	80
1983	60	170	120	327	135	175	117	346	229	133	190	57	123	232	109
1984	40	148	108	301	128	183	82	340	258	157	229	72	125	219	94
1985	71	165	100	309	146	191	107	291	184	151	202	51	144	230	86
1986	88	148	60	356	152	161	68	283	215	135	186	51	136	232	96
1987	88	152	64	332	116	149	68	307	239	128	222	94	123	222	99
1988	72	165	93	304	89	155	83	278	195	138	214	76	152	240	88
1989	89	142	53	356	143	153	67	282	215	120	176	56	137	234	97
1990	42	148	106	305	96	157	55	279	224	124	240	116	102	257	105
1991	54	111	57	304	64	125	55	303	248	125	239	114	87	250	163
1992	56	147	71	312	76	129	60	309	249	119	234	115	107	240	133
1993	48	149	101	328	68	106	50	329	279	121	233	112	128	231	103
1994	49	140	91	320	64	110	42	344	302	130	232	102	120	231	111
1995	57	141	84	326	61	101	44	317	273	118	226	108	115	229	114
1996	56	181	125	325	97	137	45	322	268	120	186	66	115	230	115
1997	43	182	139	324	97	138	58	322	264	135	186	51	140	230	90
1998	44	136	92	322	118	161	42	318	276	122	179	57	105	223	118
1999	70	175	105	303	130	183	15	296	281	125	216	91	126	222	96
2000	45	133	88	303	121	183	33	296	263	120	182	62	136	216	80
2001	35	128	93	301	127	192	26	288	262	121	219	98	130	228	98
2002	73	153	80	300	123	189	35	330	295	111	183	72	122	189	67
2003	50	127	77	314	126	178	33	359	326	115	177	62	126	202	76
2004	45	121	76	303	145	207	32	348	316	116	195	80	122	191	69
2005	67	128	61	312	138	195	59	354	295	125	178	53	124	177	53
2006	84	141	57	300	125	190	24	352	328	105	180	75	118	207	89
2007	45	145	100	293	138	216	15	342	312	104	180	76	118	204	86

[a] Day of the year from January 1.

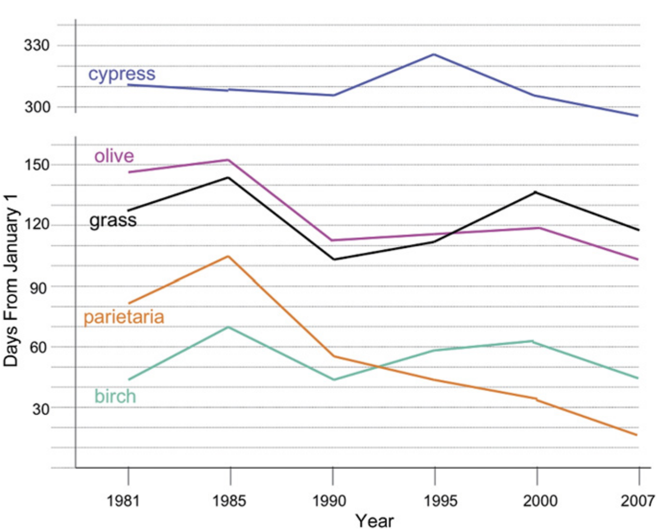

Figure 1. Start date (day of the year from January 1) of the pollen seasons of the 5 plants throughout the study years.

for cypress (Table 2). A progressive delay in the end of the pollen seasons was also seen for *Parietaria*, cypress, and olive. As a result, the duration of the pollen season for some plants progressively increased across time, but not for grasses (Figs 2-6). In analyzing the 5-year averages, the duration of the pollen season increased overall for *Parietaria* (+85 days), olive (+18 days), and cypress (+18 days). The duration of the pollen season was approximately unchanged for grasses and birch, for which the linear regression test was not statistically significant ($P = .35$). Also, total pollen counts, except for grasses, displayed an overall increase throughout the years. The linear regression test provided significant results ($P < .05$) for the total pollen count across time for all plants except for grasses.

Patients and Sensitizations

During a 27-year period, 25,543 individuals (aged 5-64 years; 56% male) were included in the database. Of these patients, 54% had rhinitis only, 35% had asthma plus rhinitis, and 11% had asthma only. The mean (SD) duration of the diseases was 6 (4.5) years. The percentage of patients sensitized to the considered species increased for the considered allergens (linear regression test: $P < .05$) but not for grasses. The percentages of patients positive for the 5 considered pollens, total pollen counts, and season durations are plotted in Figures 2 to 6. The percentage of patients sensitized to house dust mite remained high, around 70%, but stable throughout the years (Fig 7).

Table 2. Start and End Dates[a] and Durations of the Pollen Seasons (5-Year Averages)

Pollen	1981-1985			1986-1990			1991-1995			1996-2000			2001-2007		
	Start	End	Duration, d	Start	End	Duration, d	Start	End	Duration, d	Start	End	Duration, d	Start	End	Duration, d
Birch	71	165	91	42	148	76	57	141	81	45	133	104	44	145	79
Cypress	309	146	178	305	96	154	326	61	112	303	121	161	300	138	196
Parietaria	107	291	219	55	279	217	44	317	270	33	296	275	24	342	304
Olive	151	202	56	124	267	78	118	226	109	120	182	65	105	180	74
Grass	144	230	97	102	257	105	115	229	106	136	216	99	118	214	87

[a] Day of the year from January 1.

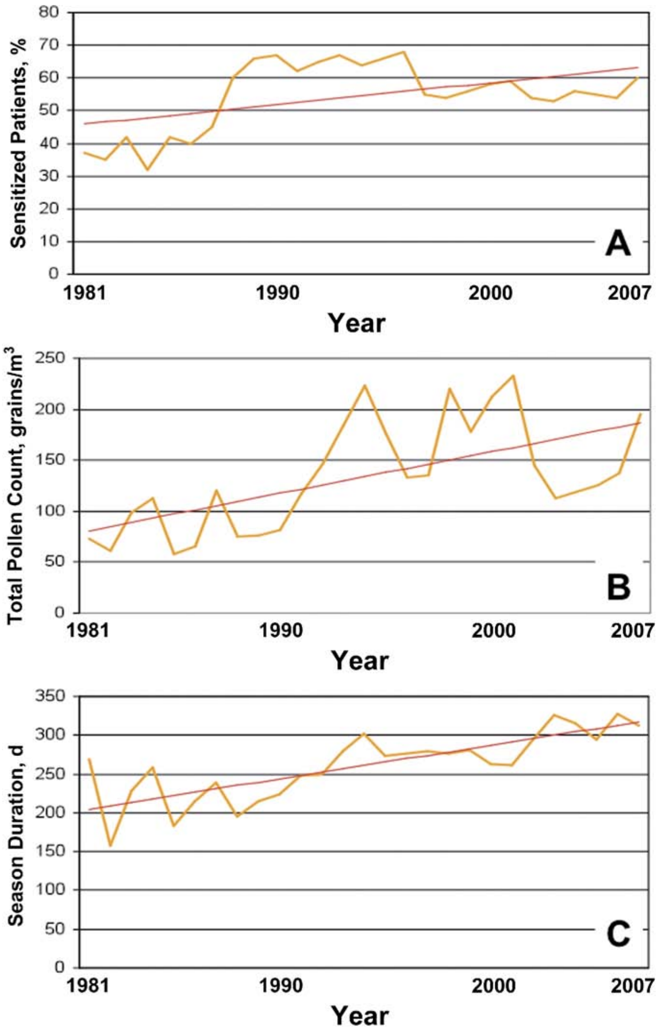

Figure 2. *Parietaria*. A, Percentage of sensitized patients. B, Total pollen count. C, Duration of the pollen season. Linear trend lines are shown in red.

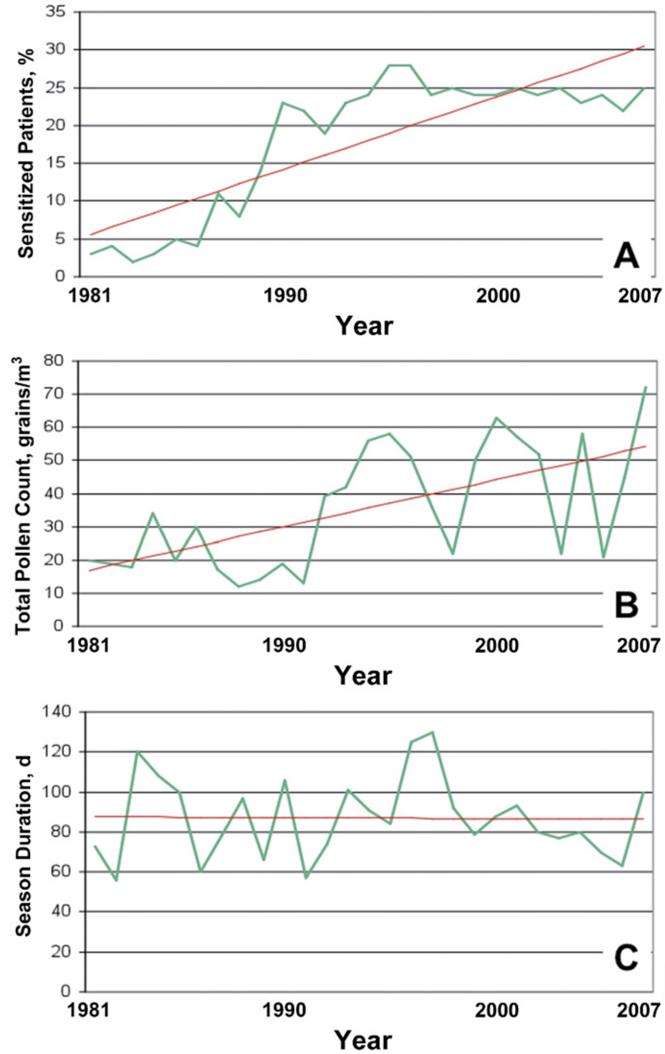

Figure 3. Birch. A, Percentage of sensitized patients. B, Total pollen count. C, Duration of the pollen season. Linear trend lines are shown in red.

Meteorologic Data

The most apparent finding was the overall increase in average normal radiation, paralleled by an increase in temperature and in the number days with a temperature greater than 30°C (Fig 8). For these 3 variables, there was a significant linear trend across time. Mean atmospheric pressure showed an increase (first 5 years: 1013.8 millibars; last 7 years: 1016.5 millibars). No change was detected in yearly rainfall, number of rainy days, average

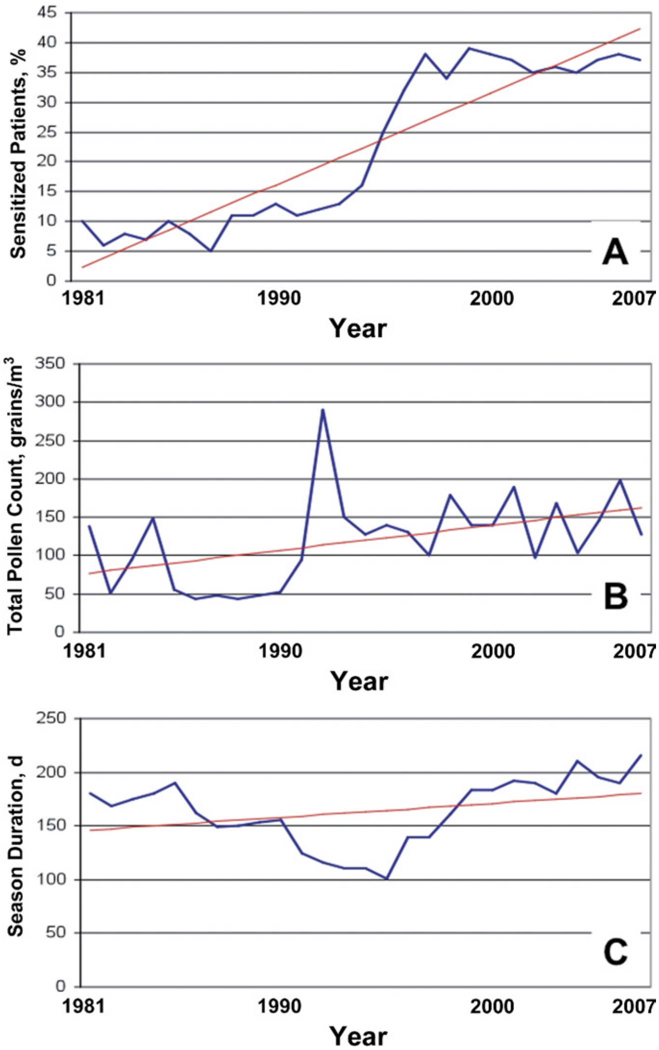

Figure 4. Cypress. A, Percentage of sensitized patients. B, Total pollen count. C, Duration of the pollen season. Linear trend lines are shown in red.

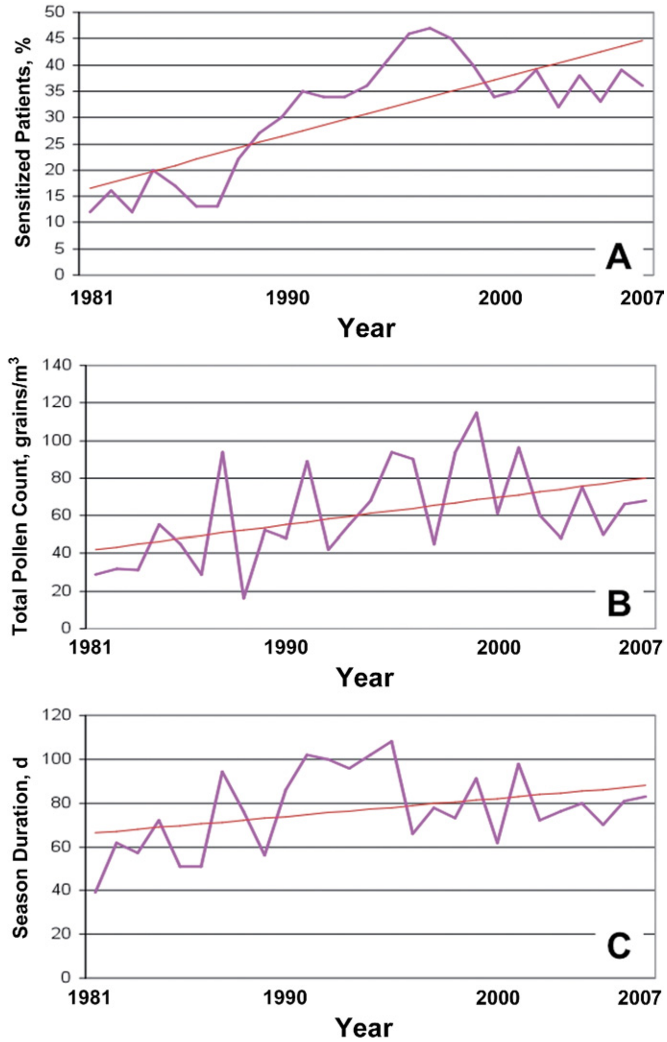

Figure 5. Olive. A, Percentage of sensitized patients. B, Total pollen count. C, Duration of the pollen season. Linear trend lines are shown in red.

humidity, and wind speed (data not shown). The available data for carbon dioxide did not evidence a trend across the years. The cumulative estimated emission was 738,000 tons in 1995, 842,000 tons in 1999, 750,000 tons in 2001, and 748,000 tons in 2005.

Correlations

A significant positive correlation among temperature, radiation, and number of days with a temperature greater than 30°C was present (Pearson $P<.01$). A significant positive correlation was also seen between radiation and season duration and between radiation and total pollen count, again except for grass pollen (Pearson $P<.05$) (Table 3). Total pollen count correlated well with percentage of sensitized patients for all pollens, whereas this correlation with season duration was not confirmed for birch and grass (Table 3).

DISCUSSION

The effects of climate on human health have been well known for decades. This is of particular relevance when climate conditions affect the presence of environmental agents, such as airborne allergens, as hypothesized for many years.[6] In the case of pollens, the presence and quantity of granules in the atmosphere are strictly related to the geographic pattern of the flora and the environmental conditions. Changes in temperature,[7–10,16–18] carbon dioxide level,[19] rainfall, and humidity can visibly affect the duration of pollen seasons and, consequently, the overall pollen load. Even episodic phenomena, such as storms, can transiently increase pollen dispersion.[20] It has been sug-

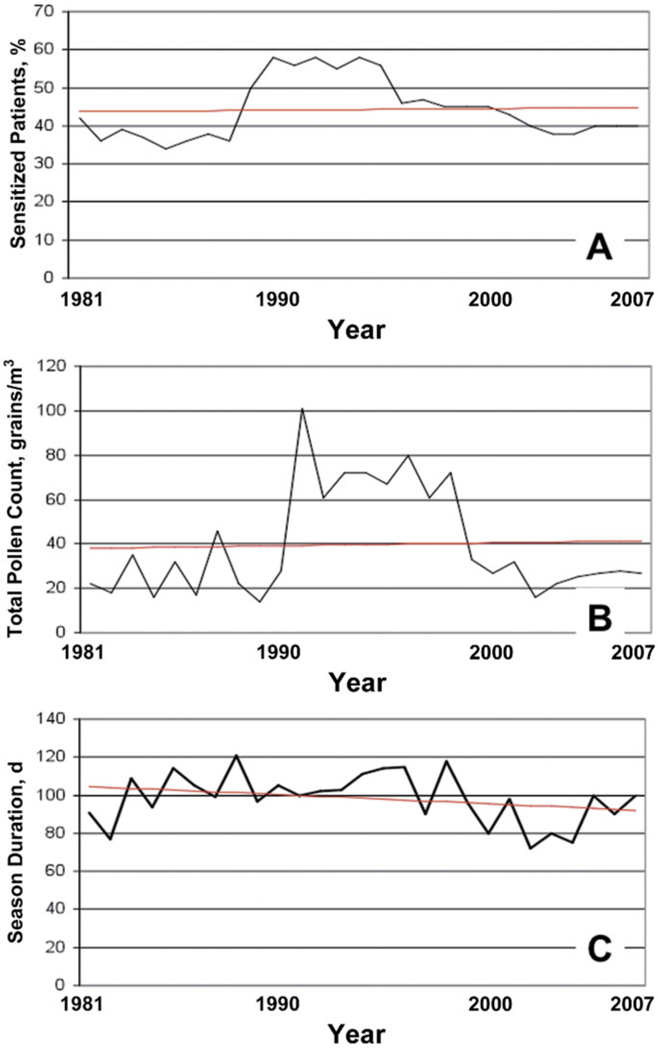

Figure 6. Grass. A, Percentage of sensitized patients. B, Total pollen count. C, Duration of the pollen season. Linear trend lines are shown in red.

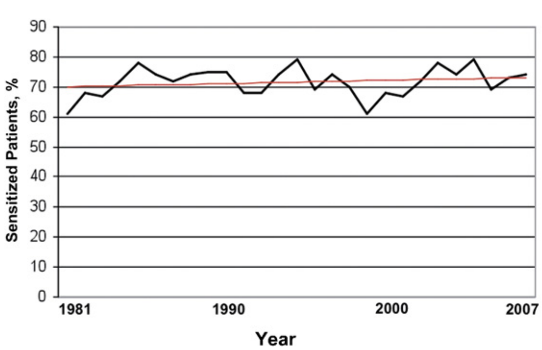

Figure 7. Percentage of patients sensitized to house dust mite during the study period. The linear trend line is shown in red.

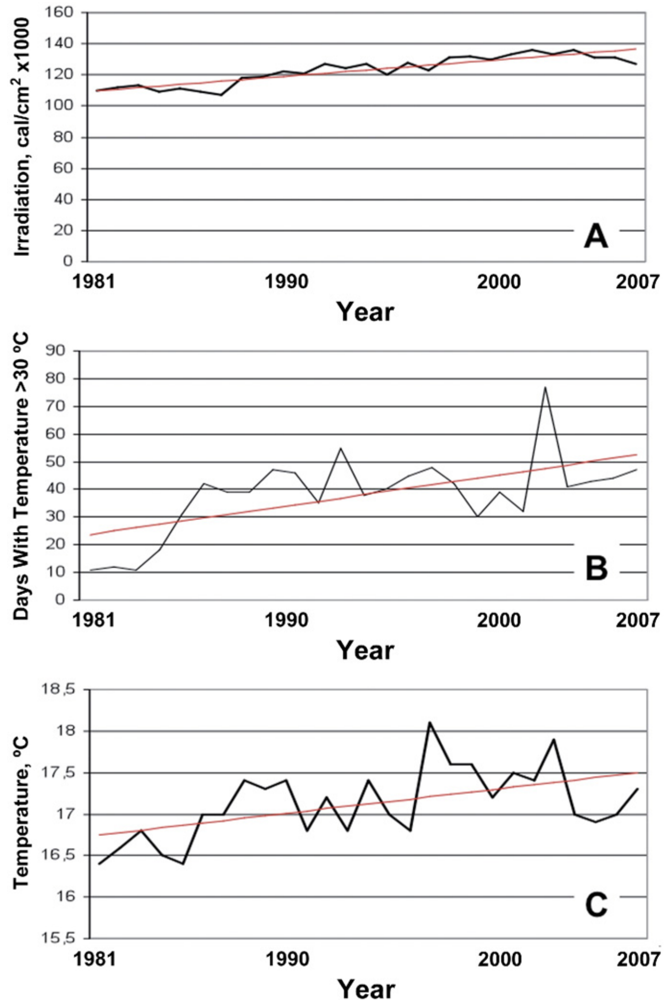

Figure 8. Year-by-year values of radiation (A), number of days with a temperature greater than 30°C (B), and average temperature (C). Linear trend lines are shown in red.

gested that the allergenicity of some pollens to some extent depends on the environmental temperature.[11] The role of increased temperature has been envisaged in previous epidemiologic works. Hales[21] evidenced a good correlation between asthma prevalence and mean temperature, and similar results were reported by Zanolin et al[22] in a large sample of asthmatic children in Italy. The main limitation of epidemiologic studies is that large geographic regions are considered, thus with a large variability in flora. For this reason, we analyzed aeroallergens and clinical data in a very restricted and well-defined geoclimatic area.

During a 27-year period, an advance in the start date of the pollen season was seen for some species, and this was associated with increased season duration and increased pollen load. This phenomenon was particularly apparent for *Parietaria*, perhaps because this plant is more sensitive to temperature, and, partially, also for olive and cypress. There was

Table 3. Statistical correlations among the different parameters (Pearson's test)

	Parietaria		Birch		Cypress		Olive		Grass	
	r	p	r	p	r	p	r	p	r	p
Temperature vs season's duration	.36	**.05**	.16	0.2	.04	0.6	.4	**.03**	.15	0.4
Temperature vs total pollen count	.42	**.03**	.19	0.4	.37	**.05**	.52	**.05**	.02	0.6
Radiation vs season's duration	.70	**<.001**	.1	0.1	.51	**.01**	.39	**.05**	.28	0.1
Radiation vs total pollen count	.62	**.006**	.56	**.002**	.55	**.002**	.42	**.02**	.12	0.2
Total pollen count vs % sensitized	.47	**.01**	.66	**.001**	.55	**.003**	.57	**.003**	.66	**<.001**
Season's duration vs % sensitized	.42	**.05**	.1	0.2	.44	**.02**	.52	**.005**	.25	0.1

also a progressive increase in the percentage of patients sensitized to the considered pollen species. This latter fact cannot be attributed to other environmental factors because all the patients lived in the same geographic area. Also, modification of the potency of diagnostic extracts across time is not expected to affect the results, as testified to by the stability of the percentages of patients sensitized to mite. The only climatic variables likely to be responsible for the changes in pollen seasons are the increases in mean direct radiation and temperature. Carbon dioxide could also play a role in increasing the allergenicity of some pollens,[23,24] but in this region, increased production of this gas was not detectable. Concerning the allergenicity of pollens, we have previously shown[25] that the allergen content of cypress pollens collected in this region remained unchanged between 1994 and 2000. The cultivation of cypress and birch as ornamental plants has increased in this region during the past 20 years, and this can explain, in part, the results.[13] Nevertheless, the increased presence of these plants cannot explain, by itself, the variations in the end and start of the pollen seasons across the years, which can be, in turn, attributable to the temperature change. In addition, there was certainly no change in the presence of *Parietaria* (an infesting plant) and olive (a stable cultivation).

In conclusion, considering a very restricted and homogeneous geographic area and a sufficiently long period, some climate changes were observed. These changes were accompanied by increased pollen loads and sensitization rates, thus suggesting a direct role of climate variations in the epidemiologic impact of pollen allergy.[26]

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