

Climate change impact on the olive pollen season in Mediterranean areas of Italy: air quality in late spring from an allergenic point of view

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Abstract Recent studies have shown that there are many effects of climate change on aeroallergens, and thus on allergic diseases in humans. In the Mediterranean region, despite the importance of the olive tree for production, there is high allergenicity of olive pollen and related risks to human health. Aerobiological sampling techniques can be used to analyse the pollinosis phenomenon through determination of mean daily pollen concentrations per cubic metre of air. The present study was carried out from 1999 to 2008 in 16 olive-growing areas in Italy, to update the information on the pollinosis characteristics of *Olea europaea* in the study areas. The analysis of the average flowering season over the study period highlights a temporal scaling of pollen in the atmosphere that depends on the different climatic characteristics. This is mainly dependent on temperature, and in part, determined by latitude. Generally, the levels of *O. europaea* pollen in the atmosphere are higher from mid-April to the end of June, with the period of greatest risk to human health due to this olive pollen in this area currently limited primarily to the last 10 days of May. However, the pollen season can move, depend-

ing on the climate scenario considered, and data here can be used to determine potential time shifts in pollinosis that might cause more precocious asthma and allergy problems. The allergy season for this type of pollen might be significantly precocious in future decades (20–30 days earlier in the year), which will impact on the severity and duration of allergies attributable to olive tree pollen.

Keywords Global warming · Human health · Allergic illnesses · Pollen grains · Italy

Abbreviations

ADC	Average daily pollen concentration
APC	Average annual pollen counts
%DC	Percentage of days with a concentration of grains per cubic metre air >400
EF	End of flowering
FF	Full flowering date
PI	Total pollen index
MDC	Maximum pollen counts (grains/days)
MPP	Main pollination period
NDC	Number of days with a concentration >400 grains/m ³ air
SF	Start of flowering
T_{Ave_MAM}	Average temperature during the 3 months, March–April–May
TCC	Critical threshold of pollen concentration (>400 grains/m ³ air)

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Introduction

Global warming can be expected to affect plants and animals worldwide, especially in the cooler parts of the world, although its effects will vary regionally and according to species (Brown et al. 1999). Many studies have established the relationships between the different phenological phases and climate trends in different species of plants and animals (Sparks et al. 2000; Beaubien and Freeland 2000; Jaagus and Ahas 2000; Menzel et al. 2001; Peñuelas et al. 2002; Chmielewski and Rötzer 2002; Bonofiglio et al. 2008). Future climate change will determine the spatial distributions of the most sensitive species and the temporal shifts in the appearance of various phenological phases (Higgins and Richardson 1999; Schwartz and Reiter 2000; Neilson et al. 2005). These so-called phenological changes are likely to have a wide range of consequences for many ecological processes, such as agriculture and forestry, and also for human health and the global economy in general (Peñuelas and Filella 2001).

Most of these data have originated from the last four to five decades, and these predominantly reveal more precocious flowering and leaf unfolding in Europe and North America at 1.2 to 3.8 days earlier per decade, on average (Menzel 2002). Data on shifts in flowering dates are abundant, and they show similar trends (Beaubien and Freeland 2000; Osborne et al. 2000; Schwartz and Chen 2002; Fitter and Fitter 2002; Emberlin et al. 2002; Galán et al. 2005; Stach et al. 2007). Furthermore, climatic changes caused by global warming are likely to have significant effects on the distributions and abundance of allergenic plants in Europe in the decades to come (Emberlin 1994).

Changes in the timing and length of the pollen season will lead to changes in human exposure, which can affect susceptibility as well as exacerbate allergic illnesses (Reid and Gamble 2009). A large number of people suffer from hay fever, or pollinosis, which is caused by repeated exposure to pollen grains emitted by pollinating plants (Shea et al. 2008). Therefore, environmental conditions will have great impacts on the quality of life of residents local to such plants. These effects will include a decline in the quality of life of allergy sufferers, plus increased socioeconomic costs due to absence from school or work, and to potential long and expensive treatments, among other such problems (Cariñanos et al. 2002).

Many different species of pollen grains are dispersed in the atmosphere, and they correlate with the flora of each region (Staffolani et al. 2011). In Europe, the main pollination period (MPP) covers about half of the year, from spring to autumn, and the distribution of airborne pollen taxa of allergological interest is related to five vegetational areas: the Arctic, Central Europe, Eastern Europe, the Mountains and the Mediterranean areas (D'Amato et al. 2007). In the Mediterranean region, although the olive tree is of great economic importance, many studies have shown the high allergenicity of olive pollen and the related risks for human health (Lauzurica et al. 1988; González-Minero and Candau 1997; Canu et al. 2006; Quiralte et al. 2007; Barber et al. 2007; D'Amato et al. 2007). This problem has been reported throughout most of the olive-producing areas that border on the Mediterranean, but it is especially prevalent in Italy, Spain, France and Greece (Emberlin 1994).

In recent decades, the olive species *Olea europaea* L. has been introduced into several countries, including North America (especially California and Arizona), South America (Chile and Argentina), Australia and South Africa, with environmental consequences (i.e. allergies) for the local population (Bousquet et al. 1985; D'Amato et al. 1994). It is therefore important for individuals who are allergic to pollen to be accurately informed of the flowering period of the olive trees in their region. Moreover, it is essential to understand the flowering behaviour of this species in response to climate change. Through aerobiological sampling techniques, it is possible to analyse this pollinosis phenomenon by determination of the mean daily pollen concentrations per cubic metre of air, which are a direct consequence of the intensity of anthesis (Orlandi et al. 2003; Fornaciari et al. 2005; Murray et al. 2007; García-Mozo et al. 2008). The use of these techniques allows the creation of pollen calendars for many species of anemophilous plants that produce highly allergenic pollens (Levetin 2004; Gioulekas et al. 2004a).

The present study was carried out from 1999 to 2008 over 16 olive-growing areas in Italy. While the aim here was partly to update the information on the pollinosis characteristics of *O. europaea* in the study areas, the particular main study objectives were (1) to determine the pollinosis periods and the mean daily pollen concentrations in the air; (2) to evaluate the effects of the temperature on this pollen monitoring;

and (3) to evaluate the future changes of the pollen season, and therefore the future hay fever complaints that can be expected in the light of future climate change.

Materials and methods

The study area

The location of the study area and the diffusion of the olive crops throughout central and southern Italy are shown in Fig. 1. This represents a long and relatively narrow area, which reaches from about 37°N to 43°N, over a total distance of about 700 km. The climate of all of the areas studied is Mediterranean, with a relatively mild temperature. The average yearly temperature over the study period was 16.7 °C, and the median annual rainfall ranged from 210 mm at the Foggia station to 1,430 mm at the Sibari station. These data were obtained from the meteorological stations that

are situated near the monitoring areas and are part of the Military Aviation Network and the National Agro-Meteorological Network. The data are measured at 2 m above the ground, in accordance with the recommendations of the World Meteorological Organisation.

Olive groves in this area cover a surface area of roughly 1.1 million hectares (ha), for a total of about 200 million trees (ISTAT 2002). In particular, the olive is widespread in the regions of Apulia, Calabria and Sicily, at 340,000 ha (849,667 acres), 167,000 ha (413,242 acres) and 138,000 ha (345,770 acres), respectively. The resident population in this area is approximately 31 million people, with those with chronic allergies are estimated at 10.8 % (ISTAT 2002). In southern Italy, the frequency of positivity to *Olea* pollen allergens among all of the skin-prick-test-positive patients is 13.49 % of adults and 8.33 % of children (D'Amato et al. 2007). The highest levels of atopic sensitization to olive pollen have been reported for the Apulia region, in 30 % of the resident population (Caiaffa et al. 1991). Sensitization to olive

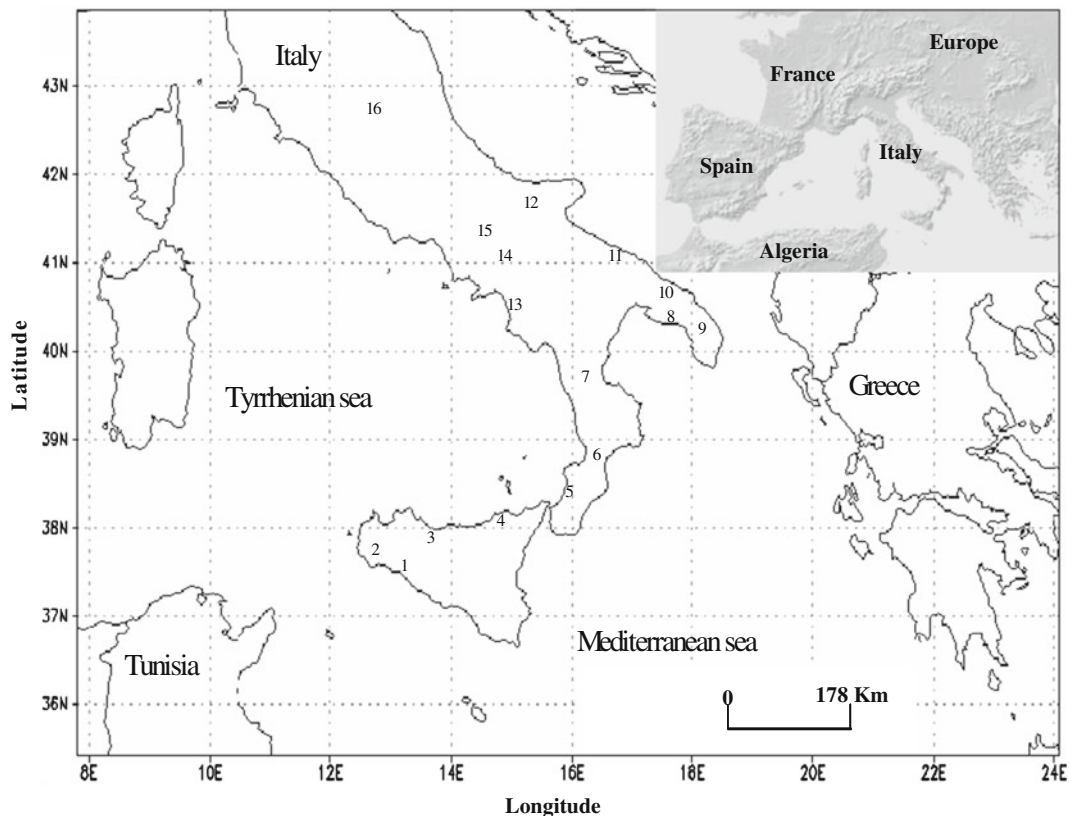


Fig. 1 Locations of the 16 sampling areas with relative coordinates. For names, see Tables 1, 2 and 3. *Inset*: location of Italy within Europe

pollen has also been reported through many Mediterranean countries, including Greece, Spain, Israel, southern France, Turkey and others (D'Amato and Spieksma 1992; Domínguez Vilches et al. 1993; Rodríguez et al. 2001; Gioulekas et al. 2004b).

The main scenario for climate change in the Mediterranean basin

The warming of the climate system appears unequivocal, as is now evident from the reported increases in mean global air and ocean temperatures, and as is seen by the widespread melting of the Earth ice caps and the rising mean global sea level. The magnitude and rate of future climate change will depend on the amounts of greenhouse gases that are emitted, the sensitivity of the climate to these gases and the degree to which the effects are modified by aerosol emissions. The Intergovernmental Panel on Climate Change (IPCC) has presented six scenarios for future emissions (A1B, A1T, A1F, A2, B1 and B2), all of which are at present equally plausible. These are based on widely differing assumptions of future populations and economic growth, and of energy consumption, technological developments and land use. If nothing is done to reduce emissions, by 2100, the current climate models predict a global temperature increase from 2 °C to 4.5 °C, and from 2.2 °C to 6.0 °C in southern Europe and the Mediterranean (SEM) (IPCC 2007). Analogous results are obtained if we focus the analysis over the entire Italian region (Faggian and Giorgi 2009).

In the present study, the most pronounced surface air temperature increase over the region occurs in the summer season, with a warming of up to +6 °C predicted for 2071–2100, and with the minimum warming over the Mediterranean in the range of 2 °C to 3 °C in the autumn and winter. A substantial reduction in precipitation is also predicted for the spring and summer seasons over the entire Italian territory. Relative to this variable, the greatest changes will be in the summer season, with precipitation decreasing by around 20 % by 2071–2100 (Hertig and Jacobeit 2008).

Aerobiological survey and determination of the pollen seasons

Sampling was carried out using the 'volumetric' method, which is based on the capturing of pollen and other biological particles that are in the atmosphere using

the principle of depression impact (Fornaciari et al. 1997). The equipment used was VPPS 2000 Lanzoni systems, located in 16 provinces of central and southern Italy. The pollen counts were monitored from 1999 to 2008, using the standard sampling procedure proposed by the Italian Association for Aerobiology. The qualitative and quantitative compositions of the samples were determined in preparations on glass slides, and the pollen concentrations are expressed as the number of grains in 1.0 m³ of air.

The beginning and the end of the MPP were determined using the criteria described by Galán in 2000. By subtracting 1 % of the total pollen [total pollen index (PI)] from the initial and final parts of the pollination curve, the dates of the start of flowering (SF) and the end of flowering (EF), respectively, can be determined. At the same time, the full flowering date (FF) corresponds to the day with the maximum daily pollen concentration (MDC). The dates of these flowering parameters are also expressed according to the day of the calendar year (i.e. from 1 to 365). The critical threshold pollen concentration (TCC) required to elicit symptoms of seasonal allergic rhinitis is around 400 grains/m³ air (Florido et al. 1999). Based on this value, the average number of days when the pollen concentration will cause severe allergic rhinitis and bronchial asthma was calculated. Along with the average daily pollen concentrations (ADC), these calculations were performed in all of the 16 selected areas from 1999 to 2008. Furthermore, to determine the characteristics of the *Olea* species in these areas, the following indices were calculated: the average annual pollen counts (APC; grains/year), the MDC (grains/days), the number of days with >400 grains/m³ air (NDC) and the percentage of days per year with >400 grains/m³ air (%DC).

Evaluation of temperature effects on pollen monitoring

To determine the future changes in the pollen season in the areas monitored relative to the quarterly and monthly mean values of minimum, maximum and average temperatures, data from a previous investigation were used (Orlandi et al. 2010a). In this study by Orlandi et al. (2010a), they considered a cause–effect relationship between the FF dates and the meteorological variables recorded from the late spring (May) of the previous year ($t-1$), to the late-spring of that

flowering year (t), so as to consider all of the possible phenomena related to the fertilisation processes in plants with a 2-year reproductive cycle like the olive (e.g. flower induction, chilling and forcing). In their study, there was a high linear correlation between the flowering period and the mean temperature, especially during spring. Thus, in the different areas, an increase in the temperature of 1 °C on average during March, April and May (MAM) produced precocious FF dates that were between 5.5 and 7.6 days earlier in the year.

Determining future changes in the pollen season

As the average temperature recorded during these three spring months of MAM proved to be one of the variables that best correlated with the olive pollen emissions for virtually all of the monitoring sites, this period was selected here to evaluate the potential future trends of the pollen season. The average temperature during MAM (T_{AveMAM}) was used to estimate the FF dates considering two warming scenarios, the first a ‘soft’ scenario (B1), and the second a ‘hard’ scenario (A2), on the basis that the T_{Ave} will increase by 1.0 °C to 1.4 °C (as best estimates) by the future date of 2050, and by 1.8 °C to 3.4 °C (as best estimates) by 2100.

Results

The olive pollen season

Intra- and inter-annual variations of the start, full and ending dates of the *Olea* MPP for the 16 areas are indicated in Table 1. These data show that throughout the study period, the pollen season generally started in late April and lasted until the middle to the end of June. The day of maximum pollen concentration was recorded, on average, in the last 2 weeks of May. The very first pollen was caught in the sampling area of Termini I (at 108 days from 1 January), and the last was caught in the sampling area of Perugia (at 185 days from 1 January). On average, comparing these two areas, the flowering showed a delay of 21, 23 and 27 days for the start (SF), maximum (MF) and end (EF) dates, respectively.

For pollen release, the earliest MPP dates were in the areas of Termini I, Castelvetro and Ribera, which are all located at the lower latitudes, while the

Table 1 Dates from 1 January of *Olea* flowering season for the 16 areas studied, plus the descriptive statistics

Sampling areas		SF	FF	EF
1 - Ribera (AG), $N=10$	Min	114	121	140
	Max	128	144	159
	Mean	123	133	153
	SD	5.40	7.28	6.16
	CV	0.0441	0.055	0.0403
2 - Castelvetro (TP), $N=10$	Min	112	122	139
	Max	128	147	158
	Mean	122	133	148
	SD	5.59	7.76	5.25
	CV	0.0458	0.059	0.0354
3 - Termini I. (PA), $N=9$	Min	108	121	140
	Max	135	144	168
	Mean	123	134	152
	SD	7.9	8.08	9.87
	CV	0.0646	0.06	0.0651
4 - Ficarra (ME), $N=10$	Min	124	132	145
	Max	151	159	168
	Mean	132	144	156
	SD	8.17	8.84	7.73
	CV	0.0621	0.062	0.0495
5 - Palmi (RC), $N=10$	Min	121	135	148
	Max	136	150	162
	Mean	132	144	154
	SD	5.63	4.87	4.17
	CV	0.0426	0.034	0.0200
6 - Staletti (CZ), $N=10$	Min	123	141	151
	Max	144	159	169
	Mean	135	149	159
	SD	7.43	5.32	5.21
	CV	0.0552	0.036	0.0327
7 - Spezzano A. (CS), $N=10$	Min	121	129	147
	Max	135	159	165
	Mean	130	140	156
	SD	4.61	8.47	6.70
	CV	0.0354	0.06	0.043
8 - Avetrana (TA), $N=10$	Min	122	133	143
	Max	144	158	170
	Mean	131	142	156
	SD	7.28	6.72	8.01
	CV	0.0557	0.047	0.0515
9 - Squinzano (LE), $N=10$	Min	124	133	144
	Max	141	150	160
	Mean	133	142	153
	SD	5.67	4.88	4.87
	CV	0.0427	0.0343	0.0318
10 - Pezze G. (BR), $N=10$	Min	120	132	149
	Max	138	147	159

Table 1 (continued)

Sampling areas		SF	FF	EF
11 - Bitonto (BA), N=9	Mean	130	141	155
	SD	6.04	4.62	2.76
	CV	0.0463	0.0329	0.0178
	Min	126	133	151
	Max	138	153	161
	Mean	132	141	156
	SD	4.47	5.60	4.88
12 - S. Severo (FG), N=10	CV	0.0340	0.0396	0.0316
	Min	122	130	151
	Max	142	151	161
	Mean	135	143	156
	SD	6.00	5.56	3.24
13 - Campagna (SA), N=10	CV	0.0446	0.0390	0.0208
	Min	128	138	151
	Max	146	157	73
	Mean	138	147	160
	SD	6.53	5.23	8.24
14 - Ariano I. (AV), N=10	CV	0.0473	0.0355	0.0515
	Min	134	151	164
	Max	160	170	177
	Mean	142	160	169
	SD	8.37	7.04	6.19
15 - Solopaca (BN), N=10	CV	0.0589	0.0440	0.0367
	Min	133	139	150
	Max	147	159	171
	Mean	139	144	162
	SD	4.50	6.11	6.98
16 - Perugia (PG), N=10	CV	0.0324	0.0423	0.0431
	Min	133	144	163
	Max	158	168	185
	Mean	144	156	179
	SD	7.39	7.04	7.89
	CV	0.0324	0.0423	0.0431

SF start of flowering, FF full flowering, EF end of flowering, N number of sampling years, Min minimum value, Max maximum value, SD standard deviation, CV coefficient of variation

latest dates were in the areas of Ariano I, Solopaca and Perugia, at the higher latitudes. Therefore, there is a scaling in the olive flowering between the different areas that is related to their latitudes. The standard deviations and coefficients of variation calculated for the MPP dates were similar in all of the areas studied, and these showed little variability within each individual area. The lowest values were calculated for the areas of Pezze di G, Bitonto and Palmi, and the highest for the areas of Termini I and Avetrana.

The average pollen concentrations determined in the atmosphere, as the ADC, are shown in Fig. 2, as calculated from 1999 to 2008, along with the relative TCC, in each of the 16 sampled areas. These data indicate that the TCC is dramatically exceeded in almost all of the areas, and especially in Pezze di G and Squinzano. In these areas, the maximum ADC exceeded 6,000 grains/m³ air. Similarly, several areas had only slightly lower values, such as Ficarra, Avetrana, Spezzano A, S. Severo and Campagna. The lowest ADC levels were calculated for the areas of Ribera and Solopaca, and Perugia in particular, with a maximum count of 540 grains/m³ air. Analysis of these mean pollination curves (Fig. 2, ADC) shows that the MDC were seen between 20 May and 30 May, except for the areas of Perugia and Ariano I, where this occurred on 5 June and 9 June, respectively.

Table 2 presents the data relative to the various indices that are important for a better understanding of the characteristics of the olive pollen season in all of these areas. These data indicate that per year, the highest quantities of olive pollen (as the APC) were collected for the areas of Pezze di G and Spezzano, with average values of 38,247 grains and 34,209 grains, respectively. Instead, the lowest APC were calculated for the areas of Ribera and Solopaca, and in particular, in the area of Perugia, with only 3,270 grains of pollen every year. These different annual quantities of pollen calculated in these areas mainly depend on the degree of diffusion of the *O. europaea* crops.

The highest maximum pollen counts (MDC) were calculated in the areas of S. Severo (14,282 grains/day), Ficarra (12,822 grains/day), Spezzano A. (12,546 grains/day) and Pezze di G (11,825 grains/day). For this index also, the lowest value was calculated for Perugia, with a count of 1,355 grains/day. Relative to the average pollination duration (as the MPP), the shortest periods were calculated for the areas of Ribera, Castelvetro and Squinzano, with an average duration of 20 days, while the longest period was calculated for the area of Perugia, with an average duration of 35 days. Thus, in contrast to the pollination intensity (the MDC), Perugia showed the longest duration, i.e. the longest period for olive pollen to be present in the atmosphere.

Table 2 also shows the NDC data, for those days with a pollen concentration >400 grains/m³ air, with the longest periods calculated for the areas of Pezze di G and Avetrana (18 days), and Campagna and

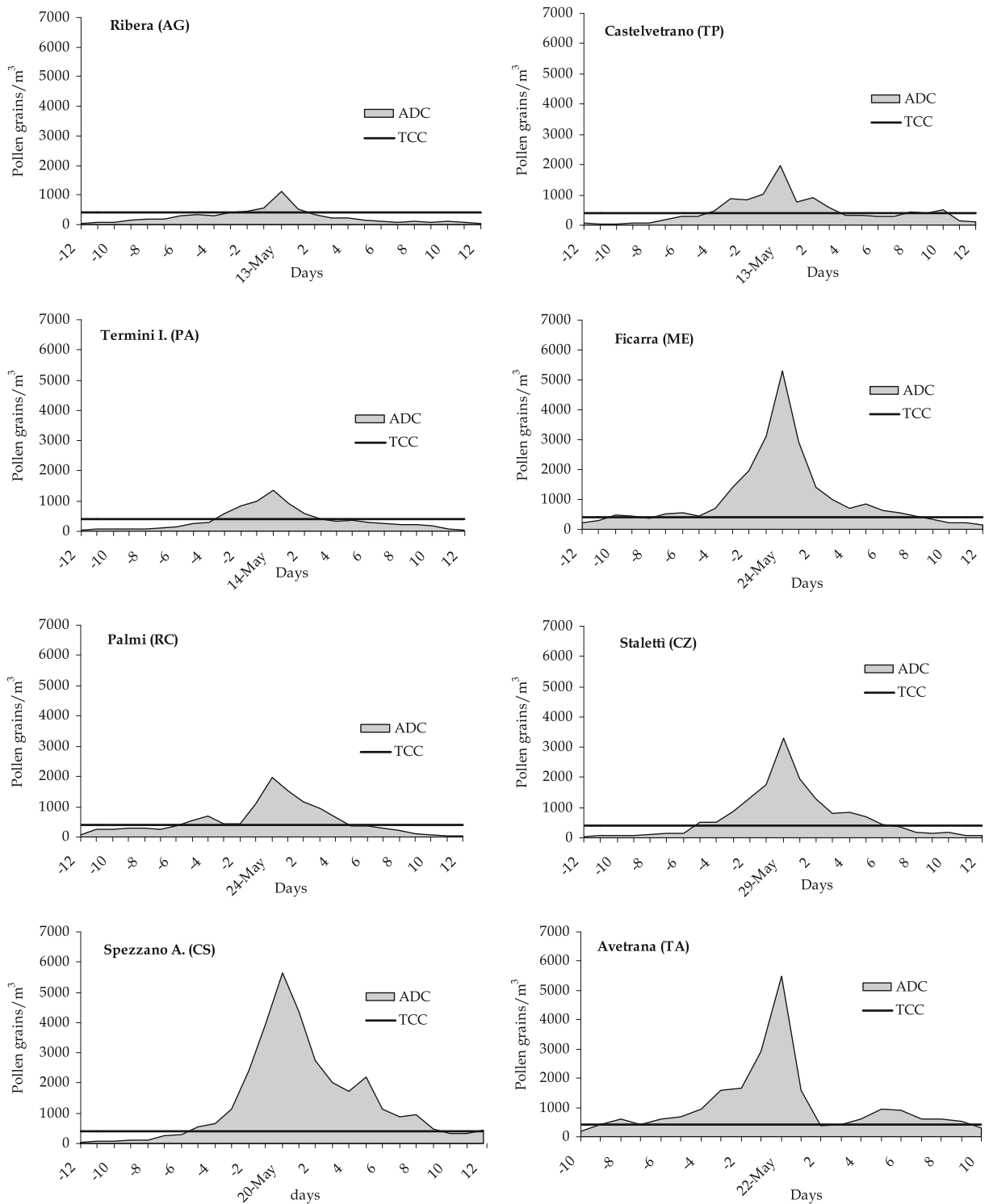


Fig. 2 Average pollen concentrations in the atmosphere from 1999 to 2008 for each of the sampling areas (*shaded*). *ADC* average daily concentration, *TCC* critical threshold concentration (400 grains/m³ air). Date of full flowering (FF) as shown

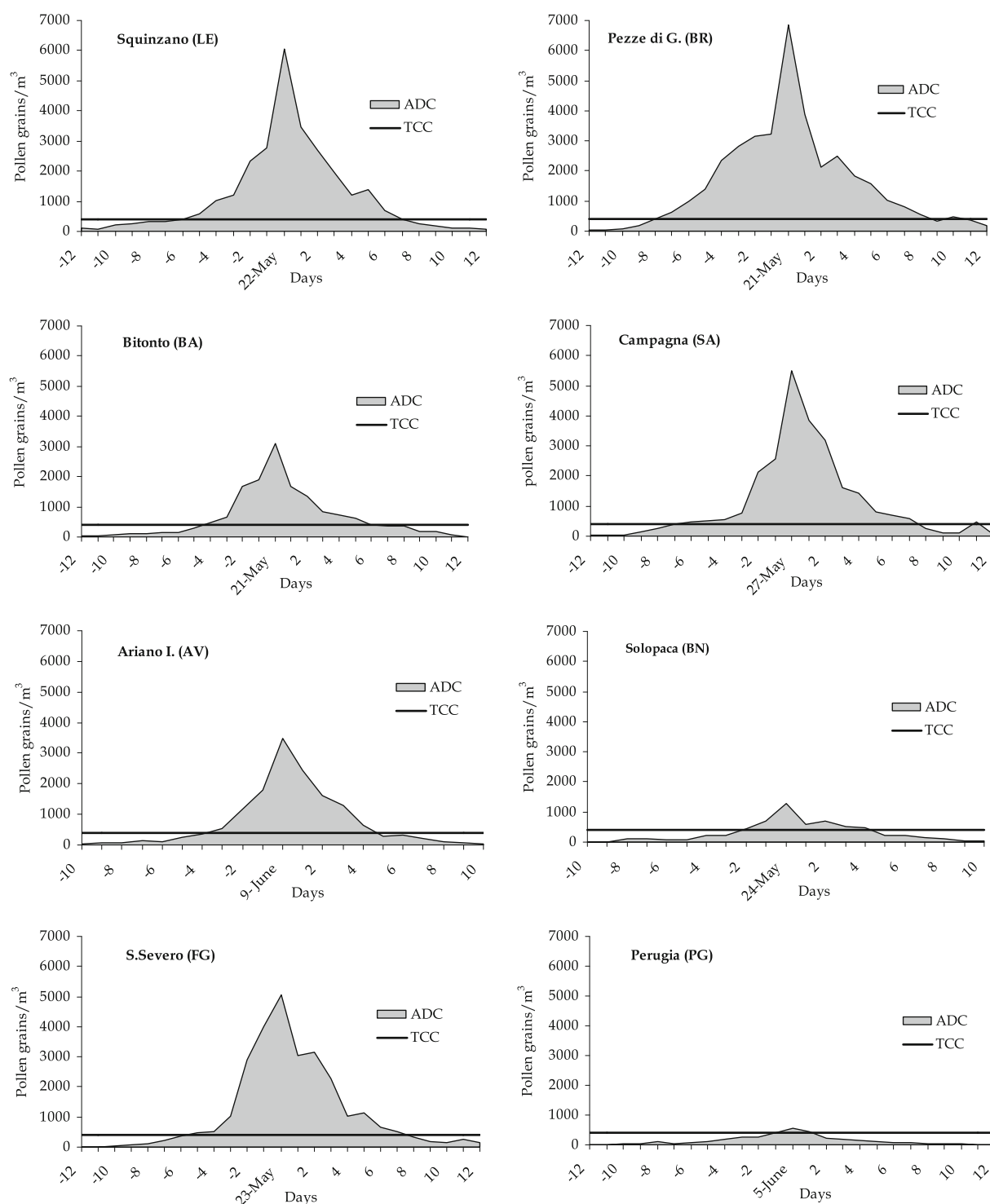


Fig. 2 continued.

Spezzano A (16 days). The shortest periods were registered for the areas of Ribera and Termini I (6 days), and

again in particular for Perugia (3 days). The highest %DC levels reflected these highlighted areas as

Table 2 Characteristics of the *Olea europaea* pollen seasons in the study areas in Italy

Sampling areas	APC	MDC	MPP	NDC>400	%DC>400
1 - Ribera (Ag)	6.423	3.955	20	6	30
2 - Castelvetro (TP)	11.947	7.617	20	11	55
3 - Termini I. (PA)	9.393	2.092	29	6	21
4 - Ficarra (ME)	27.136	12.822	24	10	42
5 - Palmi (RC)	12.987	5.465	22	10	46
6 - Staletti (CZ)	16.348	7.327	24	12	50
7 - Spezzano A. (CS)	34.209	12.546	26	16	62
8 - Avetrana (TA)	18.616	10.292	25	18	72
9 - Squinzano (LE)	29.643	9.736	20	13	65
10 - Pezze G. (BR)	38.247	11.825	25	18	72
11 - Bitonto (BA)	19.884	7.219	24	10	42
12 - S. Severo (FG)	28.232	14.282	21	13	62
13 - Campagna (SA)	26.879	10.152	22	16	73
14 - Ariano I. (AV)	15.400	11.388	27	8	30
15 - Solopaca (BN)	6.485	4.316	23	7	30
16 - Perugia (PG)	3.270	1.355	35	3	9
Mean	19.069	8.274	24	11	47

APC average annual pollen counts, MDC maximum pollen counts (grains/days), MPP main pollination period, NDC>400 number of days with >400 grains/m³ air, %DC>400 percentage of days with a concentration >400 grains/m³ air compared to MPP

Campagna (73 %), Pezze di G (72 %), Avetrana (72 %) and Squinzano (65 %). Thus, in these areas, over 65 % of the MPP exceeded the pollen threshold concentration that potentially generates serious allergenic pathologies. The lowest %DC levels were calculated for the areas of Termini I (21 %) and, in particular, Perugia (9 %). Therefore, in the areas of Termini I and Perugia, the average number of days in which pollen concentrations exceeds the TCC were relatively low.

Potential future changes in the pollen season

The data relative to the potential changes in the olive pollen season are given in Table 3. These indicate the probable increased precocity of the FF dates (expressed as days from the start of the calendar year) on the basis of two climate scenarios outlined by the IPCC in the Fourth Assessment Report (AR4) released in 2007. The average FF dates observed during the entire period vary from 133 days (13 May) for the areas of Ribera and Castelvetro to 160 days (9 June) for Ariano I. These data indicate earlier dates in all of the cases outlined and in all of the areas monitored. In particular, for the 2050 date, a precocity of 19 days (10 May) is

predicted for the Staletti area, and of 15 days (28 April) for the area of Ribera, while the lowest precocities are predicted for the stations of Bitonto and Spezzano A. For scenario B1, in 2050, the average precocity of the FF date over the whole study area is 8 days earlier in the year. Prediction of the FF dates is slightly earlier if scenario A2 is considered, with an average of 10 days.

The estimates of the average precocity for 2100 are, as expected, decidedly higher, at 13 days earlier in the year for scenario B1, and 23 days for scenario A2. For this latter scenario, the estimations indicate a maximum precocity of about 30 days for the areas of Staletti (29 April) and Castelvetro (13 April), and a minimum of 14 days for the Bitonto area (7 May). Thus for 2050, the FF dates could become earlier in the year by an average of 8 to 10 days, while for 2100, an average precocity of 13 to 23 days might occur, depending on the climate scenario taken into consideration.

Discussion

Although the olive pollen concentrations in the atmosphere are not continuous throughout the whole year,

Table 3 Observed and calculated full flowering dates (FF) of the pollen season in *Olea europaea* under two (B1 and A2) potential scenarios for the Mediterranean climate, as determined by the IPCC 2007

Sampling area	Mean FF date 1999–2008	Mean temp. MAM 1999–2008	T° variation 2050 (best estimate)			T° variation 2100 (best estimate)		
			1 °C (B1)		1.4 °C (A2)	1.8 °C (B1)		3.4 °C (A2)
			Predicting FF date	Advance (days)	Predicting FF date	Predicting FF date	Advance (days)	Predicting FF date
1 - Ribera	133 (13 May)	13.51	118	15	116	114	19	107
2 - Castelvetro	133 (13 May)	15.78	124	9	120	117	16	103
3 - Termini I.	134 (14 May)	16.62	128	6	126	123	11	113
4 - Ficarra	144 (24 May)	17.21	136	8	133	130	14	117
5 - Palmi	144 (24 May)	16.99	137	7	134	131	13	120
6 - Staletti	149 (29 May)	14.84	130	19	129	127	22	119
7 - Spezzano A.	140 (20 May)	14.97	138	2	136	133	7	123
8 - Aettrana	142 (22 May)	13.56	131	11	129	127	15	118
9 - Squinzano	142 (22 May)	14.42	135	7	134	132	10	124
10 - Pezze di G.	141 (21 May)	13.76	135	6	133	131	10	123
11 - Bitonto	141 (21 May)	13.56	139	2	137	135	6	127
12 - S. Severo	143 (23 May)	14.52	137	6	135	133	10	125
13 - Campagna	147 (27 May)	14.06	140	7	136	133	14	121
14 - Ariano I.	160 (9 June)	13.49	150	10	147	144	16	132
15 - Solopaca	144 (24 May)	13.12	139	5	136	133	11	120
16 - Perugia	156 (5 June)	12.70	150	6	147	144	12	131
Mean	143 (23 May)	14.57	135	8	133	130	13	120

FF measured as day of the year from 1 January

throughout the study area, it is one of the main factors in pollen allergies. Generally, the levels of *Olea* pollen in the atmosphere are higher over the period from mid-April to the end of June, and this is primarily influenced by climate parameters, such as temperature and rainfall (Bonofiglio et al. 2008, 2009). Our analysis of the average MPP calculated from 1999 to 2008 highlights a temporal scaling of this pollen in the atmosphere according to latitude. In reality, this scaling is caused by the different climatic characteristics, which are mainly the temperature, and in part, latitude (Orlandi et al. 2010b). The mean dates of the maximum pollen concentrations (FF) also highlight the same scaling, and these are primarily between the 20 May and 30 May. This indicates that over the entire study area, which covers from latitude 37°N to 43°N, the maximum pollen concentration counts are seen chiefly during this period. Identification of this period of pollination in each individual area is decisive for preventive action against the allergies that are triggered by all types of airborne pollen.

Another consideration is the low variability (low coefficient of variation) of the FF dates calculated in each individual area, which range from between 0.0208 (S. Severo) and 0.0651 (Termini I). These data indicate that the *O. europaea* species responds uniformly to the stimuli of climate variability, essentially independent of geographical position (Orlandi et al. 2009). The low variability calculated over these 10 years demonstrates that the FF date will indeed occur during the flowering interval determined for each individual area (FF $\pm$ standard deviation).

The data in Fig. 2 highlight the high quantities of olive pollen in the atmosphere during the flowering period of this species. Indeed, the TCC (400 grains/m³ air) is exceeded in all of the study areas, although with differing intensities. In particular, in the areas of Pezze di G, Squinzano, Campagna, S. Severo, Avetrana and Spezzano A, the ADC levels reach 12-fold to 15-fold the TCC. These high levels of olive pollen in the atmosphere derive from the widespread diffusion of this species in these areas, where its cultivation exceeds 40,000 ha. Most of these areas are located in the Apulia region (Pezze di G, Squinzano, S. Severo and Avetrana).

The exceeding of the critical threshold to such a high degree appears to be related to the high incidence of allergic diseases in these affected areas. Indeed, it is estimated that about 30 % of the residents in the

Apulia region are affected by allergies to pollen, which is far greater than the national average (Caiaffa et al. 1991). Therefore, in these areas, to safeguard the health of the population that is susceptible to this type of pathology, careful attention needs to be paid to this period between 20 May and 30 May.

The ADC is lower for the areas of Ribera and Solopaca, and especially for that of Perugia, where olive cultivation occupies less than 20,000 ha. In these areas, the ADC barely reaches one- to twofold the TCC levels. In the Perugia area in particular, the highest ADC level is just 540 grains/m³ air. The presence of such modest levels of olive pollen in the atmosphere is less likely to have serious effects on allergic individuals in this area. However, in all of the other areas sampled, the ADC counts can exceed 2,000 grains/m³ air; hence, in these areas also, these levels well over the TCC can trigger severe allergic reactions in the individuals affected by these pathologies.

To better understand the potential gravity for human health of the presence of this pollen in the atmosphere, we can analyse the indices shown in Table 2. High APC levels indicate that during the 10 years of sampling activity, there was a strong presence of olive pollen in the atmosphere. We can deduce that in the areas where high levels of this index were calculated (Pezze di G, Spezzano A, Squinzano, Ficarra and S. Severo), the presence of olive pollen is not incidental, but rather depends on the high diffusion of this species as a crop and therefore as a source of 'pollen emission' during flowering.

The MDC allows us to obtain better knowledge of the intensity of the olive pollination in all of the areas sampled. The results show that during these 10 years, in some areas, very high pollen concentrations per cubic metre air were seen. Here too, the highest levels were calculated in the areas of greatest olive cultivation (S. Severo, Spezzano A, Pezze di G and Ficarra). Even relative to a single day, such high pollen concentrations provide an indication of their potential impact on the health of all individuals who are sensitive to this pollen. Therefore, the concentrations detected in many subzones constitute a serious environmental problem for the resident population, as well as for the visitors to these areas during late spring. For this index also, the lowest value was calculated in the area of Perugia, with only 1,355 grains/m³ air.

In analyzing the results relative to the MPP, it can be seen that the presence of olive pollen in the atmosphere is not overly extensive throughout the year: for only 24 days, on average, with the MPP oscillating from 20 to 35 days. In comparison with other plant families of allergological interest in this area (e.g. Graminaceae and Urticaceae), the olive pollination period proves to be relatively short and hence will be easier to manage. Furthermore, from an analysis of the NDC, we can deduce that the 'critical' period further decreases to an average of 11 days over the entire area. Nonetheless, the NDC was relatively long in some areas, such as Avetrana (18 days), Pezze di G (18 days), Spezzano A (16 days) and Campagna (16 days). In this case also, the high levels of NDC are caused by the high diffusion of olive growing in these areas. Climate change, in part, gives rise to variations in the temperature patterns that characterise the different seasons of the year. Thus, plants might vary their pollination calendar, with more precocious and prolonged pollination periods (Bonofiglio et al. 2009; Fitter and Fitter 2002).

The data obtained here indicate that the pollen season could become more precocious, depending on the climate scenario considered. Therefore, the allergy season for this type of pollen could occur in the first 10 days of May in 2050, and even the last 10 days of April in 2100. This scenario could cause problems in terms of preventive actions relative to allergies caused by olive pollen. Moreover, numerous studies have highlighted that the rise in mean global temperature could generate a transfer of olive growing northwards by several hundred kilometres (Fornaciari et al. 2007). This would significantly extend the area of potential olive production and the regions affected by this aeroallergen (Emberlin 1994; Spieksma et al. 1995). The expectation then is that there will be increasing numbers of robust allergenic plants and an increasing aeroallergen burden for people with an inhalant allergy (Shea et al. 2008).

The roles of changes in pollen and spore exposure on the development of atopy and asthma in future scenarios deserve more attention. Furthermore, this needs to be considered in national and international guidelines for the diagnosis and management of allergic respiratory diseases (Cecchi et al. 2010). For this reason, a number of adaptation measures have been identified: aeroallergen monitoring; aeroallergen forecasting; allergenic plant management; planting

practices and policies; urban/settlement planning; building design and heating, ventilation and air-conditioning; access to health care and medications; education; and research (Beggs 2010). Also, to mitigate the potential effects, the following processes are recommended at an international level: aerobiological data collection in a continuous capillary network; promotion, creation and support of multidisciplinary research groups in this area; and increased awareness of policy makers towards the issues related to these allergies, and thus to human health.

Conclusions

Global climate change is now measurably affecting many physical and biological systems that are critical to human health. Effects that are pertinent to allergic disease and asthma are changes in the distribution, quantity and quality of aeroallergens (Emberlin 1994; Reid and Gamble 2009; Domínguez Vilches et al. 1993). Over the last decades, many studies have shown changes in production, dispersion and allergen content of pollen and spores, and that the nature of these changes can be different in different regions and species. Currently, the period at higher risk to human health due to olive pollen in the study area is limited primarily to the last 10 days of May. Moreover, the greatest risk is shown here to be in those areas where olive cultivation covers over 20,000 ha.

Despite the limited number of years monitored, in our calculations for the future according to the B1 and A2 climate warming scenarios, the olive pollination period might be considerably more precocious. Also, many mitigation strategies for climate change will have various concomitant health benefits, as these can decrease air pollutants other than greenhouse gases, thus decreasing the risks of respiratory and allergic diseases.

A crucial issue here is the need for data in the short and long terms. For this reason, it is essential to improve and extend the National Pollen networks, with the possibility that these can converge on a common European network, which will be particularly useful for the dissemination of the information on the pollen. Continuous aerobiological monitoring is the key need to monitor changes in the production of pollen and spores, as well as the basis for building

up long-duration series, a prerequisite for studies on the effects of climate change. This will help us to document future changes in aeroallergen production and distribution, as well as facilitate epidemiological studies on the impacts of aeroallergens on allergic diseases, with the present lack of data continuing to hinder such analyses.

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