

First aerobiological study in Mediterranean part of Croatia (Dalmatia): pollen spectrum and seasonal dynamics in the air of Split

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Abstract The aim of this study was to investigate aerobiological dynamics of pollen in the Mediterranean part of Croatia in the air of the city of Split. Pollen monitoring during the period from 2005 to 2013 was performed using a Hirst volumetric trap. Among the identified pollen of 50 taxa, 21 were allergenic. The average annual pollen index was 33,513. Three pollination seasons were established: early winter season dominated by tree pollen, spring–summer season dominated by herbaceous plants and summer–autumn season with lower amounts of *Parietaria* and Cupressaceae pollen. According to the abundance, the main taxa were: Cupressaceae, *Parietaria/Urtica*, *Pinus*, *Quercus*, *Olea*, *Carpinus/Ostrya*, Poaceae, *Platanus* and *Ambrosia*. The annual pollen index together with the daily maximum concentrations showed an upward trend for selected taxa during the study period. The highest monthly pollen index and the highest biodiversity were

recorded in April and the lowest during the late autumn and winter months. The pollen calendar created for the city of Split confirmed Mediterranean features of the pollen spectrum. The longest pollen seasons were recorded for Cupressaceae, *Parietaria/Urtica* and Poaceae pollen types. The correlations between pollen concentrations and meteorological parameters were analyzed. The correlations between pollen concentrations and temperature were positive, while the humidity and the precipitation mostly showed negative influence.

Keywords Airborne pollen · Pollen spectrum · Pollination season · Pollen calendar · Mediterranean · Croatia

1 Introduction

General climatic trends, along with daily variations of weather conditions have a direct impact on plant's physiological processes, such as flowering and pollen production. Pollen grains as components of natural bioaerosol are a major cause of pollinosis and thus of major interest in both, aerobiology and allergology. Specific allergen proteins located on the pollen grain wall and minor allergens known as panallergens are responsible for both, immune system response and pollen-specific cross-reactions (Hauser et al. 2010). For a better understanding of airborne pollen and its

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human health impact, aerobiological researches originated in the context of medicine. Today, aerobiology intersects with numerous natural sciences. Over the decades, we have witnessed a growing number of people with allergenic difficulties, especially among children (D'Amato et al. 2007; Banac 2012). Airborne pollen monitoring in order to create pollen calendars for a particular geographical area provides information about pollen type diversity and pollen season characteristics. Information about pollen content in the air is of great importance for allergy patients and physicians as it allows appropriate medical treatment. According to D'Amato et al. (2001), people who live in urban areas tend to be more affected by pollen-induced respiratory allergy than those from rural areas. Furthermore, chemical airborne pollutants of various origins could be closely associated with an increased incidence of allergic respiratory diseases due to the interaction between pollen grains and air pollutants (D'Amato et al. 2007). Recent aerobiological studies (Frenguelli 2002; D'Amato et al. 2007; Cecchi et al. 2010; Beggs 2010; García-Mozo et al. 2010; Ziello et al. 2012) have shown that climate change will influence aeroallergens by altering pollen amounts, greater pollen allergenicity, prolonging the pollen season and changing geographical prevalence of plants.

Throughout Europe, pollinosis is mainly caused by Poaceae pollen, as the strongest allergen in Central and Eastern Europe and *Betula* pollen in Northern Europe (D'Amato et al. 1998; Rodríguez-Rajo et al. 2003; Myszkowska and Majewska 2014). The increasing incidence of atopic diseases caused by pollen allergens is also evident in European areas characterized by a Mediterranean climate. Mild winters, dry summers and geographical characteristics allow the development of plants poorly represented in Central and Northern Europe (D'Amato et al. 1998). The most important arboreal sources of allergens belong to *Olea* and Cupressaceae pollen types (Marth et al. 2014). The most relevant herbaceous allergens are Poaceae and *Parietaria* pollen types (D'Amato et al. 2007). Due to geographical position, Croatia is characterized by both, a continental and Mediterranean climate with associated allergen pollen types. The first aerobiological data for Croatia have been published for the continental region (Peternel et al. 2003, 2005, 2007; Štefanić et al. 2007; Špehar et al. 2010). Regarding pollen allergy, clinical studies for Southern Croatia

showed sensitization to *Olea*, *Parietaria*, Poaceae and *Ambrosia* pollen types (Cvitanovic 1999; Skitarelić et al. 2004; Cvitanovic et al. 2004, 2007).

So far, there are no published aerobiological reports on pollen spectrum for the Mediterranean region of Croatia. The aim of the study was to provide basic aerobiological data during nine years of pollen monitoring. The main objective was to determine the pollen spectrum, pollen season dynamics and pollen calendar. The second goal of this study was to investigate the relationship between the main meteorological parameters and pollen content in the air. The study provides data for a new region which allows comparative studies and an analysis of geographical variability in airborne pollen over Europe.

2 Materials and methods

2.1 Study area

Split (43°30'N; 16°26'E) is the second largest Croatian city. It is the capital of Split-Dalmatia County and occupies the central part of the coastal area of Dalmatia region (Fig. 1). The city of Split is situated on a peninsula between the Gulf of Kaštela to the east and the Split Channel to the south. The hill Marjan (178 m) rises in the west, and the islands of Brač, Šolta, Hvar are located in the south. The mountains that stretch from the northwest (Kozjak, 779 m) to the southeast (Mosor, 1339 m) in the hinterland of Split are natural climatic boundaries between continental and maritime meteorological influences. Furthermore, an around 1700-year-old historical complex of Split has been on the UNESCO World Heritage List since 1979. In terms of phytogeography, the area of Split belongs to the eastern part of the Adriatic Province of the Mediterranean Region and Eumediterranean Zone. This is the least humid area of the entire eastern Adriatic coast, characterized by a pronounced and prolonged period of summer heat and drought that reflect in its vegetation. Natural vegetation is composed of a Mediterranean forest dominated by holm oak and shrubs. The area of Split, according to basic climatic elements is characterized by a *Csa* climate type by Köppen (Mediterranean climate with hot, dry summers and mild winters, known as "Olive climate") (Šegota and Filipčić 2003). The meteorological data for the period from 2005 to 2013 showed that the

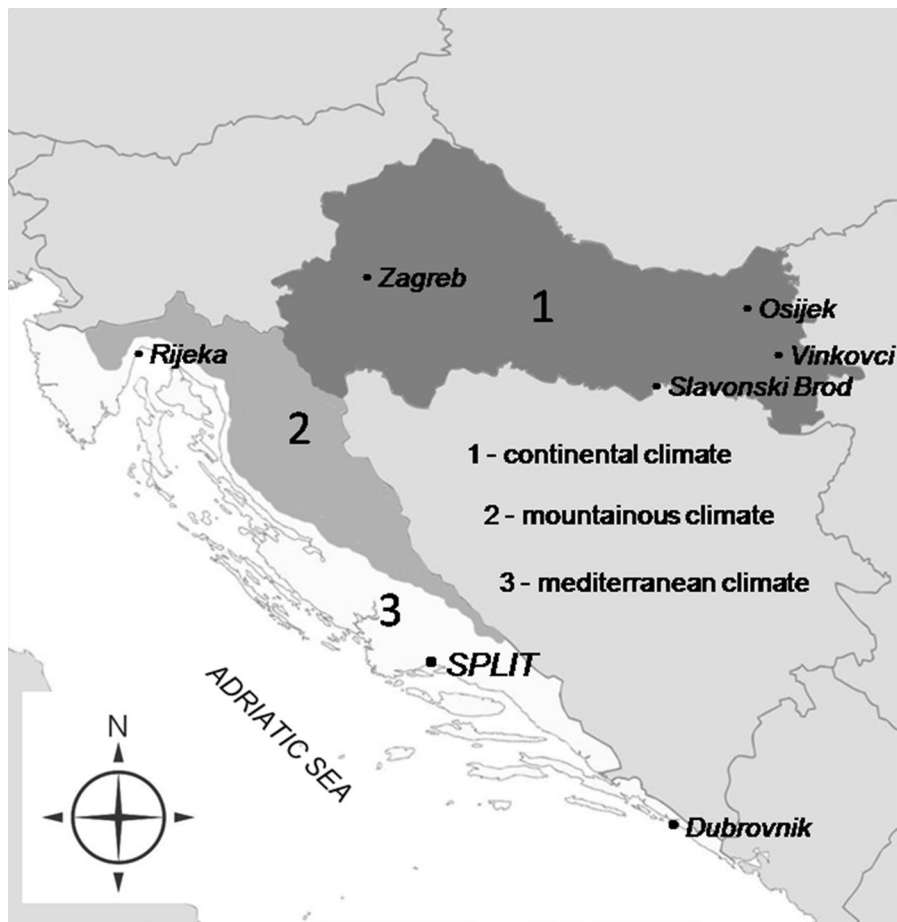


Fig. 1 Location of the city of Split, Croatia

average annual temperature was 16.9 °C. The coldest months were January and February with an average temperature of 8.3 and 8.0 °C, respectively. July was the warmest month with an average air temperature of 27.3 °C. Irregular interannual variations of total rainfall were recorded with the highest values in 2010 (1126 mm) and 2005 (1003.3 mm), which are much higher than annual averages. The driest year was 2011 (583.9 mm). Regarding the average monthly rainfall distribution during the study period, the lowest total rainfall was recorded in July (31.1 mm) and August (35.6 mm) while the rainiest months were November (117.4 mm) and December (102.3 mm).

2.2 Pollen data analysis

This aerobiological study was made in the city of Split, Croatia during a 9-year period (2005–2013). A Hirst

sampler (Lanzoni VPPS 2000) was placed on the flat roof of the building of the Public Health Institute, Split-Dalmatia County at a height of 15 m above ground level. The research methodology followed the recommendations of the International Association of Aerobiology. Qualitative and quantitative microscopic analysis of the sampled airborne pollen was performed on three longitudinal slides' transects (Frenguelli 2003; Galán et al. 2014). Daily average pollen concentrations were expressed as the number of pollen grains per cubic meter of air. The main pollen season (MPS) for pollen types selected in order of importance was defined as the period from which the sum of daily mean pollen concentrations reaches 2.5 % of the total sum until the time when the sum reaches 97.5 %, i.e., the time with 95 % of the whole pollen amount (Andersen 1991; Jato et al. 2006). The pre-peak period (PPP) can be defined as the period

from the start of the main pollen season until the maximum daily value (DMV) of pollen concentration was reached (García-Mozo et al. 2006). The pollen calendar, which was based on the Spieksma model (1991), was created for 30 plant taxa whose pollen occurred regularly in the air of Split during the investigated period. Taxa were ordered according to appearance and reaching maximum daily values. The meteorological data were provided by the Meteorological and Hydrological Service (DHMZ). The distance between the meteorological station and the aerobiological monitoring station is less than 2 km. Meteorological data were used for the nonparametric Spearman's rank correlation analysis. Spearman's correlation test was selected, since airborne particles are constantly modified by meteorological parameters and thus aerobiological data fail to fit a normal distribution pattern. The statistical dependence between daily pollen concentration and meteorological data was analyzed during the pre-peak period and the main pollen season. To get single dataset for each pollen type selected, all pre-peak days were merged together. This was also done to get a single dataset for main pollen season days.

3 Results

During the 9-year continuous aerobiological monitoring, in the atmosphere of Split, a total of 50 different pollen types were identified. Among them, 31 were tree taxa and 19 were herbaceous taxa. The average annual pollen index was 33,513 with interannual differences ranging from 11,232 in 2006, with the prevalence of *Pinus* (2943) and Cupressaceae (2036) taxa, to 65,897 in 2013, due to the extremely high concentrations of Cupressaceae (33,496), Urticaceae (9540) and *Pinus* (6460) pollen types (Table 1).

The pollen season in Split lasted, on average, from the end of January to the end of October. Seasonal distribution of pollen types showed that the highest biodiversity of pollen types was recorded during spring, while summer, and especially autumn and winter, was characterized by a lower number of taxa present in the atmosphere of Split (Fig. 2). The highest values of airborne pollen were recorded during the spring season which attributed to 89 % of the total annual pollen index. Furthermore, the highest monthly pollen indices were observed during March (2005 and

2012) and April (2006, 2007, 2008, 2009, 2010, 2011 and 2013) and in decreasing order followed by May, February, June and July. The months with the lowest quantities of pollen were January and from August to December (Figs. 2, 3).

Average daily pollen concentration on some days in the period from February to April exceeded 1000 pollen grains/m³. The maximum daily pollen concentration was recorded on the 5th of March in 2013 (4364 pg/m³). Daily peaks were mainly contributed by Cupressaceae pollen grains, along with *Pinus*, *Carpinus/Ostrya*, *Platanus* and Urticaceae pollen types. Urticaceae taxa were continuously pollinating from April to September. Taxa that joined Urticaceae pollen emission in May were *Quercus*, *Olea* and Poaceae with average maximum daily concentrations that on some days exceeded 500 pg/m³. In the early summer months, June and July, pollen concentration started to decline, without significant peaks recorded. Only a few taxa flowered in this time of the year, mainly herbaceous plant species belonging to the families: Urticaceae and Poaceae and genus *Plantago*. Average daily maximum concentrations never reached 100 pg/m³ in August. *Ambrosia* pollen type, along with autumn flowering of Cupressaceae taxa, contributed the pollen concentration in September. The period from October to December was characterized with low daily concentrations of pollen in the atmosphere of Split (Fig. 3).

The most relevant pollen types in the air of Split, that together represent 92.6 % of the total pollen concentration were: Cupressaceae (49.9 %), Urticaceae (14.3 %), *Pinus* (10.6 %), *Quercus* (5.6 %), *Olea* (4.8 %), *Carpinus/Ostrya* (3.2 %), Poaceae (2.2 %), *Platanus* (1.1 %) and *Ambrosia* (0.8 %) (Table 1). *Ambrosia* pollen type is included in this study as an invasive taxa that releases one of the most strongest aeroallergens although its annual total share was lower than 1 %.

Analysis of interannual variations of pollen concentration resulted with high deviations and coefficients of variation above 30 % for aforementioned taxa. The highest value of variation coefficients for the most important taxa was calculated for the *Platanus* pollen type (125 %) since the annual pollen index ranged from 24 in 2006 to 1342 in 2013 and followed by *Carpinus/Ostrya* (90.6 %), *Quercus* (81.9 %) and *Ambrosia* (74.6 %). Lower coefficients of variation and lesser dispersion of data around the average were

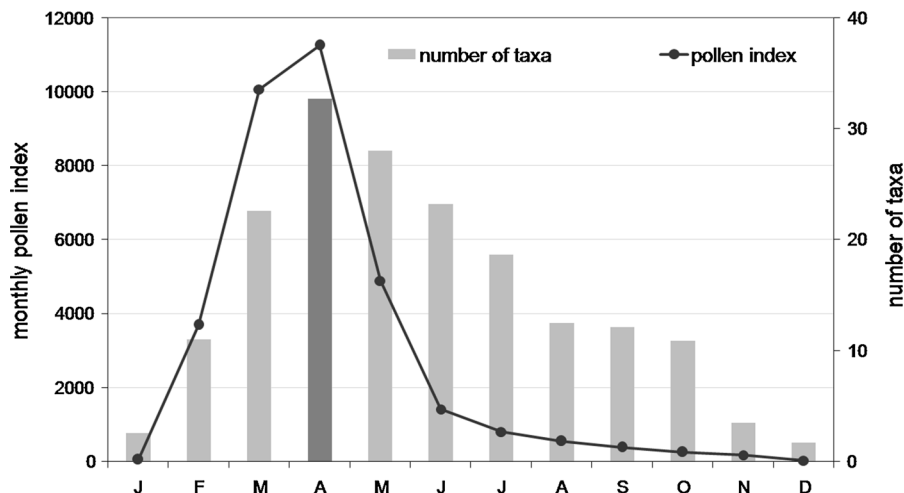
Table 1 Pollen spectrum in the air of the city of Split (2005–2013)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total	Max	Min	Average (%)	SD	CV (%)
<i>Alnus</i>	63	9	29	28	36	43	49	90	97	444	97	9	49 (0.1 %)	29.21	59.2
<i>Ambrosia</i>	120	27	32	142	476	231	380	461	538	2408	538	27	268 (0.8 %)	199.64	74.6
<i>Artemisia</i>	38	17	3	23	55	35	49	74	52	346	74	3	38 (0.1 %)	21.80	56.7
<i>Betula</i>	85	1	168	649	85	33	89	77	47	1234	649	1	137 (0.4 %)	197.43	144.0
<i>Carpinus/Ostrya</i>	184	316	531	557	384	770	2069	2116	2860	9787	2860	184	1087 (3.2 %)	984.97	90.6
<i>Castanea</i>	18	0	118	3	28	47	152	307	135	808	307	0	90 (0.3 %)	100.18	111.6
<i>Celtis</i>	37	1	92	101	11	228	76	513	229	1288	513	1	143 (0.4 %)	161.71	113.0
<i>Chenopodium</i>	93	43	11	53	43	59	47	58	58	465	93	11	52 (0.2 %)	21.42	41.5
<i>Corylus</i>	393	334	70	24	3	57	59	133	59	1132	393	3	126 (0.4 %)	140.09	111.4
Cupressaceae	9915	2036	10,468	10,509	10,030	22,806	17,381	33,774	33,496	150,415	33,774	2036	16,713 (49.9 %)	11,147.28	66.7
<i>Fagus</i>	35	2	26	18	5	4	128	24	166	408	166	2	45 (0.1 %)	59.47	131.2
<i>Fraxinus</i>	246	346	102	47	100	243	48	103	202	1437	346	47	160 (0.5 %)	103.78	65.0
<i>Mercurialis</i>	33	0	58	10	76	81	47	161	657	1123	657	0	125 (0.4 %)	205.10	164.4
<i>Morus</i>	78	23	48	18	2	76	33	230	572	1080	572	2	120 (0.4 %)	182.55	152.1
<i>Olea</i>	464	1246	745	1704	953	1343	2000	2913	2972	14,339	2972	464	1593 (4.8 %)	895.05	56.2
<i>Pinus</i>	4286	2943	2588	1546	3308	3712	4120	2891	6460	31,854	6460	1546	3539 (10.6 %)	1376.71	38.9
<i>Pistacia</i>	49	0	15	3	10	32	129	122	380	740	380	0	82 (0.2 %)	121.88	148.2
<i>Plantago</i>	43	12	43	247	212	258	224	220	227	1486	258	12	165 (0.5 %)	100.69	61.0
<i>Platanus</i>	125	24	103	111	170	71	456	1022	1342	3424	1342	24	380 (1.1 %)	477.47	125.5
Poaceae	536	594	383	381	469	793	927	993	1542	6618	1542	381	735 (2.2 %)	377.08	51.3
<i>Populus</i>	311	4	39	50	46	156	41	221	160	1028	311	4	114 (0.3 %)	103.63	90.7
<i>Quercus</i>	789	496	132	1588	1296	2416	2175	5224	2907	17,023	5224	132	1891 (5.6 %)	1549.10	81.9
<i>Rumex</i>	100	86	16	100	98	238	187	112	144	1081	238	16	120 (0.4 %)	63.55	52.9
<i>Salix</i>	170	0	72	929	296	32	260	161	119	2039	929	0	227 (0.7 %)	280.96	124.0
<i>Ulmus</i>	109	60	88	159	39	101	143	635	183	1517	635	39	169 (0.5 %)	180.86	107.3
Urticaceae	793	1918	3053	3840	3978	5609	7869	6658	9540	43,258	9540	793	4806 (14.3 %)	2850.59	59.3
Indet.	0	21	155	33	20	153	40	71	80	573	155	0	64 (0.2 %)	56.93	89.4
Annual pollen concentration	19,858	11,232	19,408	23,346	22,594	39,859	39,607	59,818	65,897	301,619	65,897	11,232	33,513	19,113.25	57.0

With annual pollen indices

SD standard deviations, CV coefficients of variation

Fig. 2 Average monthly variations of pollen types and indices in the air of the city of Split, 2005–2013 (months are represented by initial letters)



recorded for Cupressaceae (66.7 %), Urticaceae (59.3 %), *Olea* (56.2 %) and Poaceae (51.3 %) pollen types. The most stable pattern of annual pollen index ranging from 1546 in 2008 to 6640 in 2013 resulted with the lowest coefficient of variation for *Pinus* pollen type (38.9 %) (Table 1).

Main pollen season (MPS) analysis for each of the 9 taxa showed that, among tree species, Cupressaceae pollen type had the longest pollen season, which lasted, on average, 140 days. Other arboreal taxa with long pollen season were *Carpinus/Ostrya* (on average 73 days), followed by *Pinus* and *Quercus* (around 60 days) and *Olea* (on average 43 days). The *Platanus* pollen type had the shortest pollen seasons lasting on average 30 days between 2005 and 2011. The pollen seasons in 2012 and 2013 were extended and lasted around 180 days. The pollen seasons of herbaceous taxa, Urticaceae and Poaceae were long (around 170 days), since they are comprised of wide variety of species which flower over the whole pollen season. An exception was the *Ambrosia* pollen type with an average length of 54 days (Table 2).

An upward trend of the daily maximum pollen concentrations for particular taxa was recorded, with an exception for *Pinus* and Poaceae pollen type with a low slope value. Throughout the study period, among tree taxa, the highest pollen peak concentrations were recorded for Cupressaceae and *Pinus* followed by *Quercus*, *Olea*, *Carpinus/Ostrya* and *Platanus*. Among herbaceous taxa, daily peaks were much

higher for the Urticaceae pollen type, than those for Poaceae and *Ambrosia* pollen type (Fig. 4; Table 2).

Spearman's rank correlation analysis of daily pollen concentration for 9 taxa during both, pre-peak period (PPP) and main pollen season (MPS) with meteorological variables (temperature, humidity, rainfall and wind speed) was calculated. During the PPP, significant positive correlations between daily pollen concentrations for all tree taxa and temperatures were found. On contrary, during the MPS correlation coefficients were negative for Cupressaceae, *Pinus* and *Platanus* pollen type. Temperature was slightly to moderately correlated with pollen concentration and statistically significant during the PPP of herbaceous taxa Urticaceae and Poaceae and not significant during MPS. Opposite results were obtained for *Ambrosia* correlation analysis. In the case of the humidity variable, during the PPP correlation was negative for all taxa, and in 7 out of 9 taxa during the MPS. Positive and nonsignificant correlation for Cupressaceae taxa, as an exception, was found. Significant correlation with negative and low coefficients was obtained between rainfall and 6 out of 9 different pollen types in the PPP. Significant and positive correlations during the MPS for all taxa, except for *Carpinus/Ostrya*, were recorded for the same variable. Finally, the wind speed was negative and significant for the Cupressaceae and *Pinus* pollen type during the PPP and positive and significant during the MPS for Cupressaceae, *Pinus* and *Platanus* (Table 3).

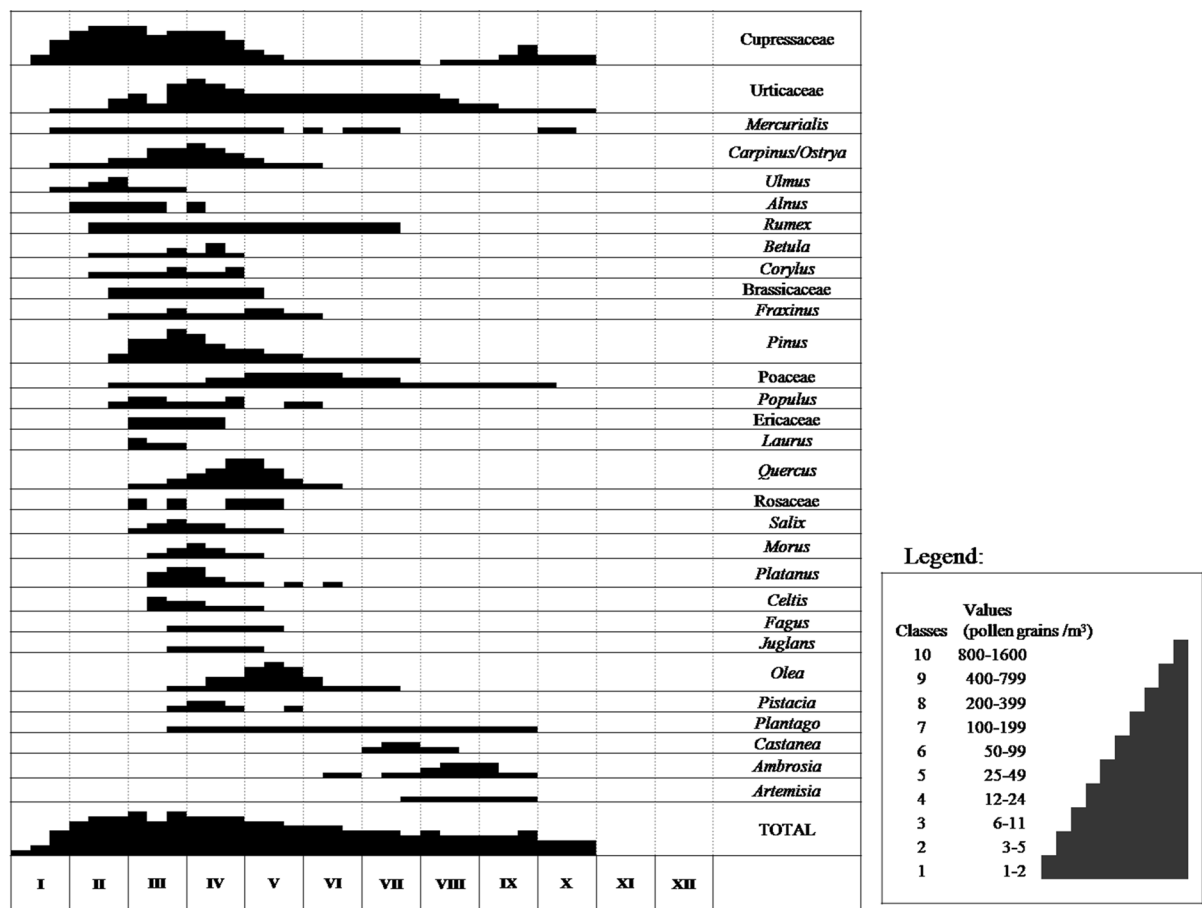


Fig. 3 Pollen calendar for the city of Split, 2005–2013

4 Discussion

Aerobiological and allergological studies have been evolving rapidly over the last three decades in most of the European countries and in the Mediterranean area, as well. This has highlighted the interdisciplinary approach and special need for the exchange of the most recent findings. Data about the presence and the incidence of pollen allergens in the atmosphere enable us to create pollen calendars with an approximation of flowering periods for the most common allergenic plant species in a study area. This, among the various forms of aerobiological data analysis, is important for allergy sufferers as it should help them to reduce or avoid, if possible, exposure to airborne allergens.

The pollen calendar for Split created as a graphical presentation of the occurrence and frequency of the most common pollen types is characterized by long

tails. This particularly refers to Cupressaceae, Urticaceae, Poaceae and *Plantago* pollen types. The long tails point to the prolonged flowering periods, a characteristic of Mediterranean pollen calendars. This is due to the mild climate and gradual flowering of species that grow at different heights since the Mediterranean basin is surrounded with the mountains close to the sea as already stated by other authors (D’Amato and Spieksma 1990; Recio et al. 2006; Pérez-Badía et al. 2010). Pollen grains of above mentioned species were present in the atmosphere of Split for more than 6 months, since they are comprised of a wide variety of species and depending on the favorable weather conditions may be present in the air throughout the year. When comparing the pollen calendars of Split and Zagreb (Peternel et al. 2003; http://www.plivazdravlje.hr/img/themes/phfrontend/kalendar_peludi/home.html), differences due to the

Table 2 Characteristics of the main pollen season (MPS) for the most important taxa in the air of the city of Split, 2005–2013

	2005	2006	2007	2008	2009	2010	2011	2012	2013
<i>Cupressaceae</i>									
Pollen season	26.2.–28.4.	21.2.–16.10.	2.2.–17.4.	25.2.–15.5.	22.2.–5.10.	16.2.–4.5.	9.2.–25.4.	29.2.–3.10.	15.2.–8.10.
Season length	61	237	74	55	225	77	75	217	235
DMV (date)	1537 (18.3.)	120 (26.4.)	1046 (15.2.)	2826 (20.4.)	1105 (25.2.)	1676 (26.2.)	2699 (1.3.)	2028 (8.3.)	4288 (5.3.)
PPP	20	64	13	55	3	20	20	8	18
<i>Parietaria/Urtica</i>									
Pollen season	27.4.–5.9.	6.2.–21.12.	14.3.–1.8.	21.3.–25.8.	8.4.–24.8.	7.4.–3.9.	3.4.–22.8.	30.3.–2.10.	10.4.–27.8.
Season length	131	318	140	157	138	149	141	186	139
DMV (date)	143 (27.4.)	72 (25.6.)	188 (11.4.)	132 (31.5.)	261 (12.4.)	275 (18.4.)	582 (8.4.)	426 (13.4.)	1100 (20.4., 21.4.)
PPP	0	139	28	71	4	11	5	14	10
<i>Pinus</i>									
Pollen season	8.4.–29.5.	3.4.–11.7.	8.3.–3.4.	13.3.–2.6.	4.4.–26.5.	25.3.–9.6.	27.3.–7.6.	27.3.–19.6.	29.3.–15.5.
Season length	50	99	26	81	52	76	72	84	47
DMV (date)	1618 (16.4.)	664 (11.4.)	460 (14.3.)	172 (18.3.)	1189 (6.4.)	484 (30.3.)	1653 (5.4.)	372 (5.4.)	1124 (7.4.)
PPP	8	8	6	5	2	5	9	9	9
<i>Quercus</i>									
Pollen season	8.4.–26.5.	12.4.–30.5.	9.3.–27.6.	11.4.–5.6.	14.4.–28.5.	5.4.–9.6.	5.4.–5.6.	13.4.–1.6.	6.4.–24.5.
Season length	48	48	110	55	44	65	61	49	48
DMV (date)	118 (13.5.)	74 (19.5.)	19 (30.4.)	244 (2.5.)	212 (14.5.)	246 (10.5.)	558 (11.5.)	636 (9.5.)	293 (12.5.)
PPP	35	37	52	21	30	35	36	26	36
<i>Olea</i>									
Pollen season	5.5.–30.6.	17.5.–20.6.	2.5.–2.6.	7.5.–14.6.	10.5.–7.6.	27.4.–18.6.	21.4.–11.6.	26.4.–12.6.	1.5.–18.6.
Season length	56	34	31	38	28	52	51	47	48
DMV (date)	120 (1.6.)	186 (24.5.)	159 (11.5.)	180 (28.5.)	133 (20.5.)	105 (22.5.)	163 (28.5.)	265 (21.5.)	473 (19.5.)
PPP	27	7	9	21	10	25	37	25	18
<i>Carpinus/Ostrya</i>									
Pollen season	5.4.–22.5.	21.2.–28.5.	14.3.–30.4.	25.2.–13.5.	27.2.–22.5.	27.2.–11.5.	15.2.–16.5.	29.2.–10.5.	5.3.–12.5.
Season length	47	96	47	78	84	73	90	71	68
DMV (date)	33 (27.4.)	38 (29.3.)	174 (15.4.)	66 (28.3.)	39 (7.4.)	56 (9.4.)	217 (8.4.)	217 (29.3.)	390 (21.4.)
PPP	22	36	32	32	39	41	52	29	47
<i>Poaceae</i>									
Pollen season	30.3.–14.10.	5.4.–8.10.	11.3.–9.9.	16.3.–7.9.	12.4.–23.9.	1.4.–2.9.	29.3.–3.9.	18.3.–16.9.	9.4.–16.9.
Season length	196	186	182	175	164	154	158	182	160

Table 2 continued

	2005	2006	2007	2008	2009	2010	2011	2012	2013
DMV (date)	51 (1.6.)	42 (20.5.)	18 (24.5.)	19 (7.5.)	25 (5.5.)	41 (24.6.)	34 (28.5.)	30 (19.5.)	66 (19.5.)
PPP	63	45	74	52	23	84	60	62	40
<i>Platanus</i>									
Pollen season	7.4.–18.5.	30.3.–13.5.	14.3.–11.4.	18.3.–28.4.	4.4.–23.4.	29.3.–22.4.	30.3.–13.4.	26.3.–27.9.	6.4.–10.10.
Season length	41	44	28	41	19	24	14	185	187
DMV (date)	31 (11.4.)	4 (12.4.)	19 (11.4.)	41 (30.3.)	25 (10.4.)	10 (4.4.)	142 (5.4.)	109 (28.3.)	204 (12.4.)
PPP	4	13	28	12	6	6	6	2	6
<i>Ambrosia</i>									
Pollen season	27.8.–30.9.	26.7.–30.10.	28.7.–24.9.	5.8.–21.9.	5.8.–18.9.	9.7.–21.9.	7.8.–3.10.	8.8.–21.9.	5.8.–26.9.
Season length	34	96	58	47	30	74	57	44	48
DMV (date)	45 (3.9.)	11 (28.8.)	5 (25.8.)	30 (8.9.)	114 (11.9.)	31 (14.9.)	27 (28.8.)	57 (7.9.)	111 (4.9.)
PPP	7	33	28	34	23	67	21	30	27
DMV maximum daily value, PPP pre-peak period									

local flora composition and climate conditions can be observed. The central part of Croatia, with continental climate is characterized by the presence of pollen types with high allergenic importance, especially those belonging to the families of Betulaceae and Poaceae, and taxa like *Ambrosia* and *Castanea*. On the contrary, Cupressaceae and Urticaceae pollen grains show lower concentration classes. A greater number of similarities were found with the pollen calendars created for the city of Rijeka and the city of Dubrovnik, both of them situated on the Adriatic coast (http://www.plivazdravlje.hr/img/themes/phfrontend/kalendar_peludi/home.html). When comparing the pollen calendar of Split with the pollen calendars for cities in Southern Spain, the beginning of Cupressaceae and Urticaceae pollen seasons, as well as reaching the highest concentration levels for Cupressaceae, Poaceae, *Olea* and *Quercus*, was similar (Cariñanos et al. 2004; Recio et al. 2006; Docampo et al. 2007; Rodríguez-de la Cruz et al. 2010).

Analysis of seasonal variations accentuated three major allergy periods as a characteristic of the Mediterranean area. The first one corresponds to early winter months, from January to late March in which a predominance of Cupressaceae pollen was found. In the air of Split, this plant family amounted to 49.9 % of the total pollen with maximum daily values exceeding 1000 pg/m³ in 8 out of 9 study years. Such high pollen concentrations remained floating in the air for several days, depending on the season. Cupressaceae pollen type is the main cause of winter pollinosis as already stated by several authors (Cariñanos et al. 2004; D'Amato et al. 2007; Pérez-Badia et al. 2010, 2011). Pollinosis induced by Cupressaceae pollen is closely associated with the increased use of different species of Cupressaceae (*Cupressus*, *Juniperus*, *Taxus*) as ornamental trees, as well as being a natural constituent of the surrounding area. According to Cariñanos and Casares-Porcel (2011) in cities with a temperate climate, overabundant Cupressaceae ornamental trees act as chimneys, simultaneously releasing large amounts of pollen into the air during the main pollen season. During this period, other allergenic pollen types recorded were *Ulmus*, *Alnus* and *Quercus* in lower concentration levels and *Celtis*, *Platanus*, *Fraxinus*, *Carpinus*/*Ostrya* and *Pinus* in higher concentration levels. *Celtis* and *Platanus* pollen grains originate mostly from shadow forming alleys in the city. Typical urban

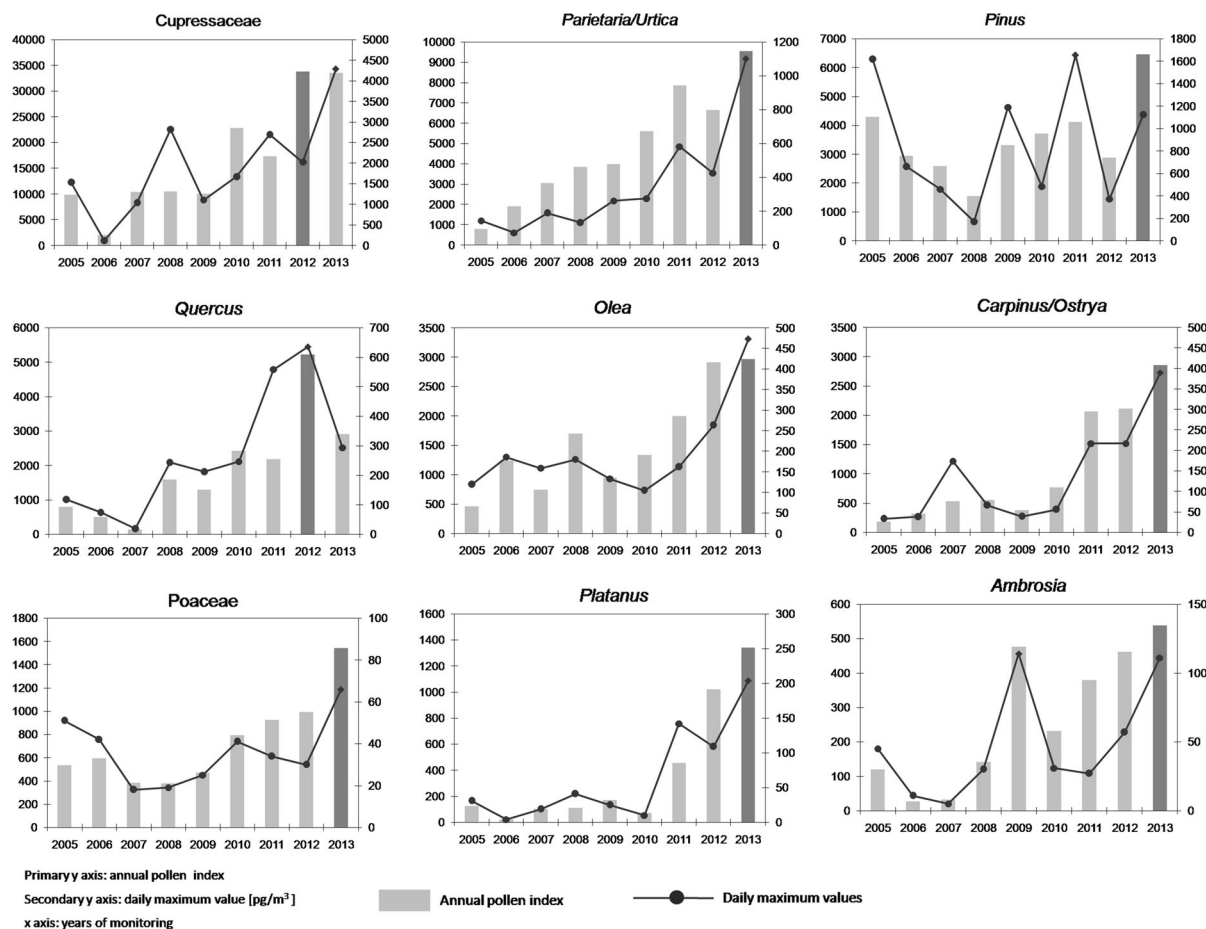


Fig. 4 Seasonal dynamics of the nine most important pollen types in the air of the city of Split, 2005–2013

Platanus pollen type appears abruptly in the air and is recorded over a short period of time during March and April as reported in Southern Spain (Alcazar et al. 2011). The *Platanus* pollen index in the air of the city of Split increased over time. In years 2012 and 2013, unusual behavior appeared which manifested in re-pollinating in September and October. Possible reasons might be in planting new trees or response to the global climate change in temperature, but more complete understanding requires thorough research. Inside the Betulaceae family, as already spoken, the high prevalence of the *Betula* taxa is characteristic for the continental region and *Carpinus/Ostrya* for the coastal region. The *Carpinus/Ostrya* taxa and along with the *Quercus* and *Pinus* are part of the forest vegetation which is known as the most stable Mediterranean ecosystem. Together with other

forest and shrub species, they predominate the hill of Marjan, the mountains in the hinterland of Split and the surrounding islands. The *Quercus* and *Pinus* taxa are, to a lesser extent, represented throughout the urban city zone in the parks, gardens and along the main city streets, as well as in the vicinity of the sampler.

The second pollination period from April to July is characterized with wider species diversity. April and May are months with a high concentration of *Quercus* and *Pinus* pollen although their allergenic capacity is low. It must be highlighted that the shortest pre-peak period was recorded for the *Pinus* pollen type. When comparing daily peak concentrations of *Quercus* and *Pinus* pollen types, those recorded in our study were higher than in the continental part of Croatia (Nadih et al. 2012; Sikora et al. 2013). *Olea* pollen is one of

Table 3 Spearman's rank test

	Cupressaceae		<i>Parietaria/Urtica</i>		<i>Pinus</i>		<i>Quercus</i>		<i>Olea</i>	
	PPP	MPS	PPP	MPS	PPP	MPS	PPP	MPS	PPP	MPS
T_{av} (°C)	0.214**	−0.583**	0.270**	0.004	0.297*	−0.402**	0.497**	0.130**	0.260**	0.096
T_{max} (°C)	0.222**	−0.580**	0.270**	0.003	0.193	−0.397**	0.471**	0.119**	0.257**	0.076
T_{min} (°C)	0.205**	−0.582**	0.240**	−0.009	0.135	−0.411**	0.445**	0.093**	0.246**	0.106*
Humidity (%)	−0.042	0.178**	−0.171**	−0.110**	−0.218	−0.048	−0.252**	−0.219**	−0.196**	−0.045
Rainfall (mm)	0.036	0.223	−0.061**	0.103**	0.184	0.134	−0.036**	0.054**	−0.027**	0.012**
Wind speed (bof)	−0.147*	0.131**	−0.111**	−0.017	0.121	0.192**	−0.002	0.080	0.064	0.053
	<i>Carpinus/Ostrya</i>		Poaceae		<i>Platanus</i>		<i>Ambrosia</i>			
	PPP	MPS	PPP	MPS	PPP	MPS	PPP	MPS	PPP	MPS
T_{av} (°C)		0.384**	0.300**	0.532**	0.032	0.301**	−0.274**	0.054	0.240**	
T_{max} (°C)		0.414**	0.323**	0.507**	0.029	0.283*	−0.282**	0.082	0.264**	
T_{min} (°C)		0.325**	0.245**	0.486**	0.017	0.318**	−0.265**	0.086	0.238**	
Humidity (%)		−0.270**	−0.276**	−0.231**	−0.087**	−0.246*	0.279**	−0.280*	−0.293**	
Rainfall (mm)		−0.146**	−0.123**	−0.088**	0.104**	−0.073*	0.363*	0.271	0.268	
Wind speed (bof)		−0.017	−0.084*	−0.024	0.049	−0.131	0.229*	0.053	0.048	

Correlation coefficients between daily pollen concentration and the main meteorological variables during the pre-peak periods (PPP) and during the main pollen seasons (MPSs), for selected pollen types in the air of the city of Split, 2005–2013

PPP pre-peak period, MPS main pollen season, T temperature

Significance levels * 95 %; ** 99 %

the principal causes of allergy in this period. The maximum daily concentrations of *Olea* pollen recorded in second decade of May showed an increasing trendline throughout the study period. Main pollination season lasted 43 days on average and ended during June. Pollen grains of *Olea*, together with Poaceae and Urticaceae, are responsible for most spring allergies in the Mediterranean area (Rodríguez-Rajo et al. 2004; D'Amato et al. 2007; Tormo-Molina et al. 2010; Pérez-Badia et al. 2010, 2011, Marth et al. 2014). Within the Urticaceae family, *Parietaria* species is of the most allergological importance. According to Díaz de la Guardia et al. (1998), it is considered as the second largest cause of pollinosis within the Mediterranean basin. This species is also known as lichwort or pellitory-of-the-wall, and its preferred habitat is the walls of old or derelict buildings on highly disturbed, nitrified soil (Cariñanos et al. 2004). In the city of Split, *Parietaria* species has already colonized the old town and due to the poor maintenance it has spread all over the city. Regarding

the total annual concentration, Urticaceae was the second abundant pollen type with a clear increasing trendline. Urticaceae pollen presence in the atmosphere of Split was noticeable already in early winter months. Depending on the year of the study, pollen season lasted from March/April until August/September with the average length of 170 days. In Spain (Pérez-Badia et al. 2011; Rodríguez-Rajo et al. 2004) and Italy (Rizzi Longo et al. 2004) Urticaceae shows a similar length of pollen season. In other Mediterranean countries, Greece (Syrigou et al. 2003) and Turkey (Ufuk Altıntaş et al. 2004) Urticaceae pollen seasons were slightly shorter and lasted from March to July. Maximum daily concentrations in Split were reached mainly in April, similar to those in Spain (Docampo et al. 2007; Pérez-Badia et al. 2010, 2011). The last year of monitoring was characterized with two consecutive days of extremely high pollen concentrations reaching 1100 pg/m^3 . High daily pollen concentrations over 1000 pg/m^3 were also recorded in Spain and Italy (Pérez-Badia et al. 2011; Rizzi Longo et al.

2004). Poaceae pollen is the main cause of pollinosis almost all over the world, including in Europe, due to the high allergenic capacity of pollen and the high number of species present in large extensions of most European ecosystems (Pérez-Badia et al. 2010). Studies across Mediterranean area confirmed earlier flowering of Poaceae species than in the rest of Europe (Laaidi 2001; Rodríguez-Rajo et al. 2003, 2004; Syrigou et al. 2003; Ufuk Altıntaş et al. 2004; D'Amato et al. 2007; Docampo et al. 2007; Abreu et al. 2008; Aboulaich et al. 2009; Pérez-Badia et al. 2010, 2011). Although characterized by a long pollination period, Poaceae participated with only 2.2 % in the pollen spectrum during the study period. Poaceae pollen grains were present in the air of Split almost throughout the year, similar as in Turkey and Spain (Ufuk Altıntaş et al. 2004; Pérez-Badia et al. 2010). The highest daily concentration recorded during May didn't reach 100 pg/m³. The length and duration of the pollen season and peak dates for the Poaceae pollen type were similar to those obtained in continental Croatia (Štefanić et al. 2007; Nadih et al. 2012). Higher maximum daily concentrations were reported for the continental part of Croatia (Štefanić et al. 2007; Nadih et al. 2012) and different areas of Spain (Rodríguez-Rajo et al. 2003, 2004; Docampo et al. 2007; Pérez-Badia et al. 2010, 2011).

Finally, the last pollination period, the summer–autumn season between August and November was characterized by the second peak pollen concentration of Cupressaceae and Urticaceae taxa, although less pronounced. In this time of the year, the pollen of *Ambrosia* was recorded with an increasing trend of the annual pollen index during the study period. Ragweed pollen is increasingly important from an allergological point of view in parts of Central and Eastern Europe. *Ambrosia* is colonizing Europe, and not only Central Europe, but also some parts of the Mediterranean area such as Northern Italy (D'Amato et al. 2007). In the continental part of Croatia, especially in the Pannonian valley, *Ambrosia* is an aggressive agricultural weed. This is contributed by high daily pollen concentrations recorded during aerobiological monitoring in the city of Slavonski Brod (Nadih et al. 2012), Vinkovci (Štefanić et al. 2007) and Zagreb (Peternel et al. 2003, 2005). The incidence of *Ambrosia* pollen in the air of Split is low, and the pollination period is interrupted by days without pollen. This may indicate long-distance transport over mountain barriers in the

hinterland of Split, stretching from the northwest to the southeast. *Ambrosia* pollen grains transport over large distances has already been stated in different studies provided across the European countries (Cecchi et al. 2007; Thibaudon et al. 2010; Kasprzyk et al. 2011; Fernández-Llamazares et al. 2012). Also, new patterns of atmospheric circulation over Europe due to the climate changes might contribute to the episodes of long-distance transport of allergenic pollen, increasing the risk of new sensitizations among the allergenic population (Cecchi et al. 2007).

The flowering, pollination and dispersal of airborne pollen are modified by meteorological factors as stated by different authors (Docampo et al. 2007; García-Mozo et al. 2010; Pérez-Badia et al. 2010, 2011). Atmospheric weather conditions define seasonal and daily pollen concentrations in a certain area. Studies of many authors showed that the global climate change observed in the last decades has caused an increase in the amount of pollen produced by plants, which has been demonstrated in relation to various plant species (Ziello et al. 2012; Piotrowska-Weryszko and Weryszko-Chmielewska 2014). In our aerobiological study, an upward trendline for the annual pollen index was found. This was also attested for the most abundant pollen types included in this study. Similar results for annually increasing pollen indices were found in Spain (Rodríguez-Rajo et al. 2003; Cariñanos et al. 2004; Rodríguez-de la Cruz et al. 2010) and in several cities of Western Europe in the case of *Quercus*, *Urtica* and *Artemisia* pollen type (Spieksma et al. 2003).

In the city of Split, no data about the relation between pollen concentrations and meteorology were published prior to this study. Correlation analysis between airborne pollen concentration of the nine most relevant taxa and air temperature matched results reported by other authors (Rodríguez-Rajo et al. 2003; García-Mozo et al. 2006; Pérez-Badia et al. 2010; Tormo-Molina et al. 2010). During the pre-peak period, significant positive correlation for eight of nine taxa was found. The exception was the *Ambrosia* species on which the temperature had a statistically positive influence during the main pollen season but not during the pre-peak period. This may be explained by the already increased temperature during the summer months. During the main pollen season, significant positive coefficients were also found for *Quercus* and *Carpinus/Ostrya* and positive but not

significant for *Olea*, Urticaceae and Poaceae. Furthermore, in the same period, significant negative correlation coefficients for Cupressaceae, *Pinus* and *Platanus* were noted. These later results, as already stated by García-Mozo et al. (2006) are characteristic for some tree taxa which have long pollination periods and in which the temperature increase in the late spring or early summer days matches with the decrease of pollen concentrations.

Once the pollen is airborne along with rainfall, wind speed and air turbulences have a direct influence on pollen content in the air. The negative and significant correlation is observed between wind speed and pollen concentration of Cupressaceae and Urticaceae pollen in the pre-peak period. This may explain the origin of the pollen source nearby the Hirst volumetric trap. Opposite results were obtained for the main pollen season for the Cupressaceae, *Pinus* and *Platanus* taxa. Correlation analysis also showed the absence of wind speed significance during the pollination of the *Quercus*, *Olea*, Poaceae and *Ambrosia* taxa. Similar results with the stronger correlation are reported in the studies throughout Spain (Rodríguez-Rajo et al. 2003; García-Mozo et al. 2006; Pérez-Badía et al. 2011).

5 Conclusion

This aerobiological survey on the pollen dynamics and its correlation with meteorological parameters is of great importance because it fills the gap that existed until now for the Croatian part of the Mediterranean basin. Furthermore, this paper may find practical use in allergological studies, and in improvement of information accessibility about the allergens' presence in the air, particularly during the tourist season, which can be prolonged almost throughout the year.

A significant increase in airborne pollen index was observed. This fact especially refers to the spring months when the highest pollen indices were recorded. Regarding the seasonal variations, three major allergy periods were established: early winter period, spring period and summer–autumn period. As for the influence of meteorological parameters to pollen concentration, the strongest positive correlation was found between temperature and pollen concentration of the most representative pollen types in the air of the city of

Split. These findings could be related to the global climate changes.

Further aerobiological research activities have to be conducted in order to confirm aforementioned conclusions.

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References

- Aboulaich, N., Bouziane, H., Kadiri, M., Mar Trigo, M., Riadi, H., Kazzaz, M., & Merzouki, A. (2009). Pollen production in anemophilous species of the Poaceae family in Tetouan (NW Morocco). *Aerobiologia*, 25, 27–38. doi:[10.1007/s10453-008-9106-2](https://doi.org/10.1007/s10453-008-9106-2).
- Abreu, I., Ribeiro, N., Ribeiro, H., Oliveira, M., & Cruz, A. (2008). Airborne Poaceae pollen in Porto (Portugal) and allergenic profiles of several grass pollen types. *Aerobiologia*, 24, 133–140. doi:[10.1007/s10453-008-9093-3](https://doi.org/10.1007/s10453-008-9093-3).
- Alcazar, P., Garcia-Mozo, H., del Mar Trigo, M., Ruiz, L., Gonzalez-Minero, F. J., Hidalgo, P., et al. (2011). *Platanus* pollen season in Andalusia (southern Spain): Trends and modeling. *Journal of Environmental Monitoring*, 13, 2502–2510.
- Andersen, T. B. (1991). A model to predict the beginning of the pollen season. *Grana*, 30, 269–275.
- Banac, S. (2012). Epidemiological aspects of allergic diseases in children. *Paediatrica Croatica*, 56(Supl 1), 71–76.
- Beggs, P. J. (2010). Adaptation to impacts of climate change on aeroallergens and allergic respiratory diseases. *International Journal of Environmental Research and Public Health*, 7, 3006–3021. doi:[10.3390/ijerph7083006](https://doi.org/10.3390/ijerph7083006).
- Cariñanos, P., & Casares-Porcel, M. (2011). Urban green zones and related pollen allergy: A review. Some guidelines for designing spaces with low allergy impact. *Landscape and Urban Planning*, 101, 205–214. doi:[10.1016/j.landurbplan.2011.03.006](https://doi.org/10.1016/j.landurbplan.2011.03.006).
- Cariñanos, P., Galan, C., Alcazar, P., & Dominguez, E. (2004). Airborne pollen records response to climatic conditions in arid areas of the Iberian Peninsula. *Environmental and Experimental Botany*, 52, 11–22.
- Cecchi, L., D'Amato, G., Ayres, J. G., Galan, C., Forastiere, F., Forsberg, B., et al. (2010). Projections of the effects of climate change on allergic asthma: The contribution of aerobiology. *Allergy*, 65, 1073–1081. doi:[10.1111/j.1398-9995.2010.02423.x](https://doi.org/10.1111/j.1398-9995.2010.02423.x).
- Cecchi, L., Torrigiani Malaspina, T., Albertini, R., Zanca, M., Ridolo, E., Usberti, I., et al. (2007). The contribution of long distance transport to the presence of *Ambrosia* pollen in central northern Italy. *Aerobiologia*, 23, 145–151. doi:[10.1007/s10453-007-9060-4](https://doi.org/10.1007/s10453-007-9060-4).
- Cvitanović, S. (1999). Allergy to *Parietaria officinalis* pollen. *Croatian Medical Journal*, 40(1), 42–48.

- Cvitanović, S., Znaor, Lj., Kanceljak-Macan, B., Macan, J., Gudelj, I., & Grbić, D. (2007). Allergic rhinitis and asthma in southern Croatia: Impact of sensitization to ambrosia elatior. *Croatian Medical Journal*, 48, 68–75.
- Cvitanović, S., Znaor, Lj., Perišić, D., & Grbić, D. (2004). Hypersensitivity to pollen allergens on the Adriatic coast. *Arhiv za higijenu rada i toksikologiju (Archives of Industrial Hygiene and Toxicology)*, 55(2–3), 147–154.
- D'Amato, G., Cecchi, L., Bonini, S., Nunes, C., Annesi-Maesano, I., Behrendt, H., et al. (2007). Allergenic pollen and pollen allergy in Europe. *Allergy*. doi:10.1111/j.1398-9995.2007.01393.x.
- D'Amato, G., Liccardi, G., D'Amato, M., & Cazzola, M. (2001). The role of outdoor air pollution and climatic changes on the rising trends in respiratory allergy. *Respiratory Medicine*, 95, 606–611. doi:10.1053/rmed.2001.1112.
- D'Amato, G., & Spieksma, F. T. (1990). Allergenic pollen in Europe. *Grana*, 30, 67–70.
- D'Amato, G., Spieksma, F. T., Liccardi, G., Jäger, S., Russo, M., Kontou-Fili, K., et al. (1998). Pollen-related allergy in Europe. *Allergy*, 53, 567–578.
- Díaz de la Guardia, C., Alba, F., Giron, F., & Sabariego, S. (1998). An aerobiological study of Urticaceae pollen in the city of Granada (S. Spain): Correlation with meteorological parameters. *Grana*, 37, 298–304.
- Docampo, S., Recio, M., Mar Trigo, M., Melgar, M., & Cabezudo, B. (2007). Risk of pollen allergy in Nerja (southern Spain): A pollen calendar. *Aerobiologia*, 23, 189–199. doi:10.1007/s10453-007-9063-1.
- Fernández-Llamazares, A., Belmonte, J., Alarcón, M., & López-Pacheco, M. (2012). *Ambrosia* L. in Catalonia (NE Spain): Expansion and aerobiology of a new bioinvader. *Aerobiologia*, 28, 435–451. doi:10.1007/s10453-012-9247-1.
- Frenguelli, G. (2002). Interactions between climatic changes and allergenic plants. *Monaldi Archives for Chest Disease*, 57, 141–143.
- Frenguelli, G. (2003). Basic microscopy, calculating the field of view, scanning the slides, sources of error. *Postepy Dermatologii i Alergologii*, 20(4), 227–229.
- Galán, C., Thibaudon, M., Frenguelli, G., Oteros, J., Gehrig, R., Berger, U., et al. (2014). Pollen monitoring: Minimum requirements and reproducibility of analysis. *Aerobiologia*, 30, 385–395.
- García-Mozo, H., Mestre, A., & Galan, C. (2010). Phenological trends in southern Spain: A response to climate change. *Agricultural and Forest Meteorology*, 150, 575–580. doi:10.1016/j.agrformet.2010.01.023.
- García-Mozo, H., Pérez-Badía, R., Fernández-González, F., & Galán, C. (2006). Airborne sampling in Toledo, Central Spain. *Aerobiologia*, 22, 55–66. doi:10.1007/s10453-005-9015-6.
- Hausen, M., Anargyros, R., Ferreira, F., & Egger, M. (2010). Panallergens and their impact on the allergic patient. *Allergy, Asthma & Clinical Immunology*, 6, 1.
- Jato, V., Rodríguez-Rajo, F. J., Alcazar, P., De Nuntiis, P., Galan, C., & Mandrioli, P. (2006). May the definition of pollen season influence aerobiological results? *Aerobiologia*, 22, 13–25.
- Kasprzyk, L., Myszkowska, D., Grewling, Ł., Stach, A., Sikoparija, B., Ambelas Skjøth, C., & Smith, M. (2011). The occurrence of Ambrosia pollen in Rzeszów, Kraków and Poznań, Poland: Investigation of trends and possible transport of Ambrosia pollen from Ukraine. *International Journal of Biometeorology*, 55, 633–644. doi:10.1007/s00484-010-0376-3.
- Laaide, M. (2001). Forecasting the start of the pollen season of Poaceae: Evaluation of some methods based on meteorological factors. *International Journal of Biometeorology*, 45, 1–7.
- Marth, K., Garmatiuk, T., Swoboda, I., & Valenta, R. (2014). *Tree pollen allergens. Allergens and allergen immunotherapy, subcutaneous, sublingual and oral* (5th ed., pp. 113–132). Boca Raton: CRC Press. doi:10.1201/b16539-12.
- Myszkowska, D., & Majewska, R. (2014). Pollen grains as allergenic environmental factors—New approach to the forecasting of the pollen concentration during the season. *Annals of Agricultural Environmental Medicine*, 21(4), 681–688. doi:10.5604/12321966.1129914.
- Nadih, M., Medverec Knežević, Z., Josipović, R., Grgić, I., & Cvitković, A. (2012). Pollen counts in Slavonski Brod, Croatia during the pollination period 2008 to 2010. *Arhiv za higijenu rada i toksikologiju (Archives of Industrial Hygiene and Toxicology)*, 63, 35–40. doi:10.2478/10004-1254-62-2011-2117.
- Pérez-Badía, R., Rapp, A., Morales, C., Sardinero, S., Galan, C., & García-Mozo, H. (2010). Pollen spectrum and risk of pollen allergy in central Spain. *Annals of Agricultural Environmental Medicine*, 17, 139–151.
- Pérez-Badía, R., Rapp, A., Vaquero, C., & Fernández-González, F. (2011). Aerobiological study in east-central Iberian Peninsula: Pollen diversity and dynamics for major taxa. *Annals of Agricultural Environmental Medicine*, 18, 99–111.
- Petermel, R., Čulig, J., Mitić, B., Vukušić, M., & Hrga, I. (2003). Analysis of airborne pollen concentrations in Zagreb, Croatia, 2002. *Annals of Agricultural Environmental Medicine*, 10, 107–112.
- Petermel, R., Čulig, J., Srnc, L., Mitić, B., Vukušić, I., & Hrga, I. (2005). Variation in ragweed (*Ambrosia artemisiifolia* L.) pollen concentration in central Croatia, 2002–2003. *Annals of Agricultural Environmental Medicine*, 12, 11–16.
- Petermel, R., Musić Milanović, S., Hrga, I., Mileta, T., & Čulig, J. (2007). Incidence of Betulaceae pollen and pollinosis in Zagreb, Croatia, 2002–2005. *Annals of Agricultural and Environmental Medicine*, 14, 87–91.
- Piotrowska-Weryszko, K., & Weryszko-Chmielewska, E. (2014). The airborne pollen calendar for Lublin, central-eastern Poland. *Annals of Agricultural Environmental Medicine*, 21(3), 541–545. doi:10.5604/12321966.1120598.
- Recio, M., Mar Trigo, M., Toro, F. J., Docampo, S., García-González, J. J., & Cabezudo, B. (2006). A three-year aeropalynological study in Estepona (southern Spain). *Annals of Agricultural Environmental Medicine*, 13, 201–207.
- Rizzi Longo, L., Pizzulin Sauli, M., & Ganis, P. (2004). Aerobiology of Urticaceae pollen in Trieste (NE Italy). *Aerobiologia*, 20, 53–61.
- Rodríguez-de la Cruz, D., Sánchez-Reyes, E., Dávila-González, I., Lorente-Toledano, F., & Sánchez-Sánchez, J. (2010).

- Airborne pollen calendar of Salamanca, Spain, 2000–2007. *Allergologia et Immunopathologia (Madr)*, 38(6), 307–312. doi:[10.1016/j.aller.2010.04.001](https://doi.org/10.1016/j.aller.2010.04.001).
- Rodríguez-Rajo, F. J., Iglesias, I., & Jato, V. (2004). Allergenic airborne pollen monitoring of Vigo (NW Spain) in 1995–2001. *Grana*, 43, 164–173.
- Rodríguez-Rajo, F. J., Jato, V., & Aira, M. J. (2003). Pollen content in the atmosphere of Lugo (NW Spain) with reference to meteorological factors (1999–2001). *Aerobiologia*, 19, 213–225.
- Šegota, T., & Filipčić, A. (2003). Köppenova podjela klima i hrvatsko nazivlje. *Geoadria*, 8(1), 17–37.
- Sikora, M., Valek, M., Sušić, Z., Santo, V., & Brdarić, D. (2013). Tree pollen spectra and pollen allergy risk in Osijek-Baranja County. *Arhiv za higijenu rada i toksikologiju (Archives of Industrial Hygiene and Toxicology)*, 64, 115–122. doi:[10.2478/10004-1254-64-2013-2235](https://doi.org/10.2478/10004-1254-64-2013-2235).
- Skitarelić, N., Sindik, N., Mazzi, A., Vuletić, A., & Mišulić, J. (2004). Hypersensitivity to pollen of *Olea europea* in patients with pollen allergy in the areas of Zadar and Dubrovnik, in croatian. *Liječnički Vjesnik*, 126, 65–70.
- Špehar, M., Dodig, S., Hrga, I., Simić, D., Turkalj, M., & Venus, M. (2010). Concentration of IgE in children during ragweed pollination season. *Aerobiologia*, 26, 29–34.
- Spieksma, F. Th M. (1991). Regional european pollen. In G. D'Amato, F. T. Spieksma, & S. Bonini (Eds.), *Allergenic pollen and pollinosis in Europe* (pp. 49–65). Oxford: Blackwell.
- Spieksma, F. T., Corden, J. M., Detandt, M., Millington, W. M., Nikkels, H., Noland, N., et al. (2003). Quantitative trends in annual totals of five common airborne pollen types (*Betula*, *Quercus*, *Urtica* and *Artemisia*), at five pollen-monitoring stations in western Europe. *Aerobiologia*, 19, 171–184.
- Štefanić, E., Rašić, S., Merdić, S., & Čolaković, K. (2007). Annual variation of airborne pollen in the city of Vinkovci, Northeastern Croatia. *Annals of Agricultural Environmental Medicine*, 14, 97–101.
- Syrigou, E., Zanikou, S., & Papageorgiou, P. S. (2003). Grasses, olive, parietaria and cypress in Athens: Pollen sampling from 1995 to 1999. *Aerobiologia*, 19, 133–137.
- Thibaudon, M., Hamberger, C., Guilloux, L., & Massot, R. (2010). Ragweed pollen in France: Origin, diffusion, exposure. *European Annals of Allergy and Clinical Immunology*, 43(6), 209–215.
- Tormo-Molina, R., Gonzalo-Garijo, M. A., Palacios, I. S., & Muñoz-Rodríguez, A. F. (2010). General trends in airborne pollen production and pollination periods at a Mediterranean Site (Badajoz, Southwest Spain). *Journal of Investigational Allergology and Clinical Immunology*, 20(7), 567–574.
- Ufuk Altıntaş, D., Bingöl Karakoç, G., Yilmaz, M., Pinar, M., Güneşer Kendirli, S., & Çakan, H. (2004). Relationship between pollen counts and weather variables in East-Mediterranean Coast of Turkey. Does it affect allergic symptoms in pollen allergic children. *Clinical and Developmental Immunology*, 11, 87–96. doi:[10.1080/10446670410001670544](https://doi.org/10.1080/10446670410001670544).
- www.plivazdravlje.hr/img/themes/phfrontend/kalendar_peludi/home.html. Accessed 28 Aug 2015.
- Ziello, C., Sparks, T. H., Estrella, N., Belmonte, J., Bergmann, K. C., Bucher, E., et al. (2012). Changes to airborne pollen counts across Europe. *PLoS One*, 7(4), e34076. doi:[10.1371/journal.pone.0034076](https://doi.org/10.1371/journal.pone.0034076).