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Airborne pollen calendar for Trieste (Italy), 1990–2004

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Abstract

Daily airborne pollen grains were collected in Trieste (1990–2004) using a Hirst-type trap. A large quantity of pollen grains was found, the mean annual total being 48 082 grains. Daily counts were particularly high between March and June, the highest values being recorded between April and May. A total of 123 different pollen taxa from 80 families were identified. Almost half of the total pollen content came from introduced trees and shrubs, one fifth from natural woodlands, and one quarter from herbaceous taxa. This composition reflects the ornamental and ruderal flora of the town, as well as the natural vegetation surrounding the urban area. The pollen richness of both mesophilous and thermophilous taxa reflects the complexity of this zone, considered a “crossroad” of species of different chorological types. Total daily pollen concentrations were positively correlated with temperatures only in the pre-peak period. The main taxa, except for Urticaceae, *Pinus* and Gramineae, displayed positive correlations with temperatures both in the main pollen season and in the pre-peak period. The annual pollen sum of *Ostrya* was negatively correlated with total rainfall of the previous summer, and that of *Pinus* was negatively correlated with the winter severity.

Keywords: Pollen calendar, pollen, meteorological parameters, Trieste, Italy

Much aerobiological research examines the airborne pollen content and compiles pollen calendars for the diagnosis and prevention of pollinosis (D’Amato et al., 1991, 2001). Other studies aim for the acquisition of more general data, to clarify the dispersion methods and transport of the pollen grains in the atmosphere or the relations among aerobiological content and meteorological and ecological factors, environmental and vegetation changes, phenology, pollen production and pollen deposition (Newnham, 1999; Valencia-Barrera et al., 2001; Kasprzyk, 2003; Helbig et al., 2004).

The aim of this study was to establish the pollen calendar of the town of Trieste by collecting pollen records on a daily basis for a relatively long period (15 years). The data presented were obtained with a Hirst-type sampler, and are a further contribution to earlier aerobiological studies carried out in Trieste with a Cour trap (Rizzi-Longo & Cristofolini, 1987; Rizzi-Longo, 1990, 2003; Rizzi-Longo & Martini,

2000). This paper adds to previous detailed studies on the aerobiology of some taxa in this area (Pizzulin-Sauli et al., 1992; Rizzi-Longo et al., 1992; Larese Filon et al., 1998, 2000; Rizzi-Longo et al., 2004, 2005). The relationships between pollen concentrations and meteorological parameters are presented too.

Study area

Trieste (250 a.s.l.) is located on sandstone hills at the northern end of the Adriatic Sea (Figure 1), at the border between the Mediterranean and the continental climate (Stravisi, 1983). The steep slope of the Karst plateau surrounds the town. The 1990–2004 annual mean temperature in Trieste is 15.1°C, and the total precipitation 984 mm (Table I). Moving inland to the Karst highland, temperature decreases by about –0.8°C/100 m and precipitation increases by about +60 mm (Stravisi, 1980a, b).



Figure 1. Map of the studied area showing the location of the pollen trap (★, 45°38'47"N, 13°46'28"E) in city of Trieste and the direction of the two main winds: Bora (ENE) and Sirocco (SE). The urban area, the thermophilous natural vegetation surrounding the town and the Karst plateau are distinguished by different grey tones.

Local coastal sea (north-west) and land (east) breezes prevail during the warm season and stable weather situations (Stravisi, 1977). The mesoscale flow is dominated by the continental dry wind Bora (east-north-east), with an annual run about 40 000 km (Figure 2) and higher speeds and frequency during the cold season (Stravisi, 2001). This wind is peculiar to Trieste and the neighbouring

regions of Slovenia and Croatia. Its occurrence is due to the local geomorphology which features narrow gaps that convey the cold air masses of the Siberian anti-cyclone in their move towards the Mediterranean cyclonic areas. Secondary events are represented by moist south-east winds along the Adriatic Sea (mainly Sirocco winds). The annual mean wind velocity in Trieste is rather low, 3.1 m/s, but Bora gusts in the range from 20 to 40 m/s are usual, and some values up to 50 m/s have been recorded (Table I).

The zone of Trieste represents a phytoclimatic boundary, where the Mediterranean and Alpine flora are in direct contact and Euro-Siberian and Mediterranean vegetation associations coexist (Poldini, 1989). A narrow range of rocky slopes facing the sea (Costiera Triestina) is covered by thermophilic evergreen vegetation (*Ostryo-Quercetum ilicis*, the Illyric-Mediterranean maquis); deciduous oakwoods (*Seslerio autumnalis-Quercetum petraeae*) cover the sandstone hills surrounding the town. On the Karst highland, where the climate is more continental, the main vegetation types are broadleaved woods rich in Illyric species (*Ostryo-Quercetum pubescentis*), often interrupted by introduced *Pinus nigra* plantations. The most frequent herbaceous vegetation types are thermophilous grasslands rich in endemites (*Carici humilis-Centaureetum rupestris*) and mesophilous *Molinio-Arrhenateretea* grasslands, which disappear step by step because of the decline of grazing and agricultural activities. A narrow cultivated belt, mostly with vineyards, olive grove and vegetable gardens is found in the suburbs. Ruderal species prevail in the town

Table I. Monthly climatic data for Trieste (1990–2004); departures from secular data.

Months	Air temperature		Precipitation		Wind		Sunshine		Global solar irradiation
	1990–2004	reference 1901–2000	1990–2004	reference 1901–2000	mean 1990–2004	max 1990–2004	1990–2004	reference 1901–2000	1990–2004
	°C	°C	mm		m/s	m/s	h		MJ/m ²
Jan	6.4	+1.3	50	78%	3.5	50 ENE	107	110%	131
Feb	7.0	+1.1	47	81%	3.1	42 NE	131	112%	210
Mar	10.2	+1.1	48	69%	2.9	46 ENE	170	114%	343
Apr	13.2	+0.2	79	101%	2.9	42 ENE	173	102%	451
May	18.5	+0.8	75	92%	2.7	38 NE	244	107%	599
Jun	22.1	+0.8	78	81%	2.7	41 ENE	259	105%	638
Jul	24.4	+0.6	67	86%	2.8	32 NE	299	102%	690
Aug	24.9	+1.4	76	85%	2.7	39 NE	288	104%	594
Sep	20.0	+0.1	116	112%	3.0	35 ENE	195	97%	425
Oct	15.9	+0.8	151	140%	3.3	45 NE	143	96%	273
Nov	11.3	+1.1	124	113%	3.4	44 ENE	95	96%	151
Dec	7.4	+0.7	73	86%	3.7	50 ENE	95	116%	110
year	15.1	+0.9	984	97%	3.1	50 ENE	2 199	104%	4 616

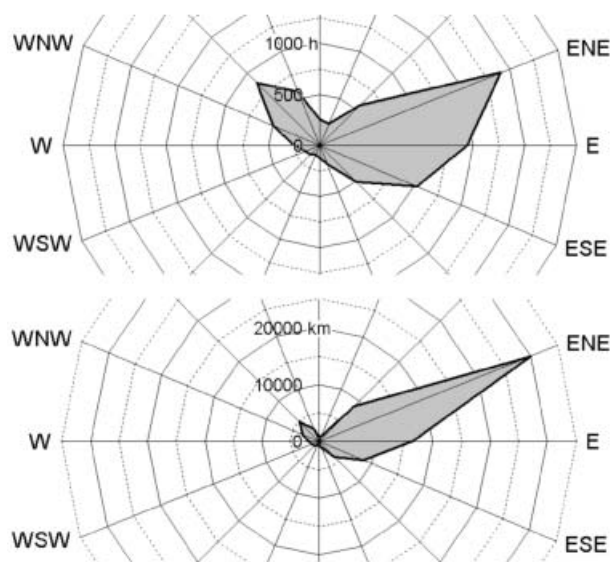


Figure 2. Trieste (1990–2004): mean distributions of the annual wind duration (in hours) and wind run (in kilometres).

which is poor in green areas: parks and gardens are few and small, avenues are rare. Among the over 1 000 wild and cultivated species found in the town during the field work of the mapping project of the urban flora, 264 plants of allergological interest were recorded (Rizzi-Longo et al., 2003). Anthropogenic vegetation types, belonging to *Artemisietea*, *Chenopodietea*, *Plantaginetea majoris* and *Parietarietea* are frequent in the town and the outskirts, due to the broadening of urban area with its commercial and industrial activities, the construction of roads, highways and industrial ducts (Poldini et al., 1997/1998; Martini et al., 2002).

Material and methods

Pollen sampling

In order to prepare a pollen calendar for Trieste, daily airborne pollen records were collected over a 15-year period (1990–2004). During this period, a Hirst type 7-day volumetric spore trap (Burkard until 1999, VPPS 2000 Lanzoni since 2000) was operating at about 20 m above ground level on the roof of Bastione Fiorito of San Giusto Castle in the town centre. Sampling method, slide preparation and data interpretation were performed according to the standard method adopted by the Italian Aeroallergen Network (Mandrioli, 1990). Pollen grain counts are expressed as pollen grains per cubic meter of air (p/m^3). Pollen were identified using published keys (Fægri & Iversen, 1989; Moore et al., 1991) and by comparison with a local pollen collection.

The pollen calendar was constructed following the technique adopted by Spieksma (1991): daily pollen

counts of 10-day periods were summed, and averaged over the 15 years considered. These average sums were placed in exponential classes (Spieksma, 1991) and depicted by column growth heights in the calendar.

For each year, the main pollen season (MPS) of each taxon was determined by taking 90% of the annual total pollen concentration, using cumulative values (Nilsson & Persson, 1981).

Meteorological data

The meteorological data was supplied by the Department of Earth Sciences, University of Trieste. The meteorological station of Trieste is located 700 m west of the pollen sampling site (Stravisi & Purga, 2006). The main parameters (with instruments and symbols of the corresponding SI units given in parenthesis) recorded were: a) *atmospheric pressure* (digital barometer Vaisala PTB200A; hPa); b) *air temperature* (Micros Pt100; °C); c) *relative humidity* (Vaisala Humitter; %); d) *wind velocity* (Micros cup anemometer; m/s); e) *wind direction* (Micros vane; ° from north); f) *precipitations* (1 000 cm^2 Micros tilting bucket pluviometer; mm); g) *global and diffuse solar irradiance* (Kipp & Zonen pyranometers; W/m^2). The measures were continuously acquired by means of a Micros data logger, and averages over 10 min period were recorded. A conventional Campbell-Stokes recorder (Thies; h) gave hourly values for the sunshine duration. All instruments were calibrated in the laboratory, and periodically checked by means of direct measurements; precipitation records were always compared with the corresponding collected water. The Trieste meteorological station has continuous high quality meteo-climatic records since 1819 (Stravisi, 2006).

Statistical analyses

Pearson's correlation coefficient was used to establish the relationship between the total daily pollen counts and selected daily meteorological parameters: mean, maximum and minimum temperature (°C); relative, minimum and maximum humidity (%); precipitation (mm) and mean wind speed (m/s). The correlations were calculated both on the whole temporal sequence from year 1990 to 2004 and separately for each year, except for 1997 because of missing values during one month in spring. In the first case both MPS and pre-peak period were considered and in the last case only the pre-peak period was considered. In order to eliminate the influence of the annual variations in pollen concentrations, daily pollen counts were standardised calculating their percentage on the cumulative yearly

pollen count according to the formula adopted by other authors (Emberlin & Norris-Hill, 1991):

$$x_s = \frac{1000x}{\Sigma x}$$

where x is the daily pollen count, x_s is the standardised count and Σx is the cumulative yearly pollen count. The logarithmic transformation was used both for pollen concentration by $\log(x+1)$ and for standardised pollen concentration by $\log(x_s+1)$ in order to normalize their distributions. The same correlations were calculated for each of the main taxa.

Correlations between the total yearly sum and meteorological parameters were computed both for the MPS and for the pre-peak period. The same correlations were calculated for each of the main taxa.

SPSS 12.0 (2004) and STATISTICA (2005) software packages were used for all statistical analyses.

Results

Pollen calendar

The average total annual pollen concentration (1990–2004) was 48 082 pollen grains, the minimum concentration (31 950 grains) being recorded in 1991 and the maximum (73 865 grains) in 1998 (Figure 3). On average, daily pollen concentration increased towards late January, peaked in late February–mid March and also between April and May (Figure 4). The highest values were recorded between April and May (891 grains/m³) and the lowest between mid November and early January. One third of the total annual sum was collected between January and May. In June, the monthly pollen sum fell abruptly (8% of the total annual sum), then decreasing gradually and reaching the minimum in December. When analysing each separate taxa, the Cupressaceae-Taxaceae dominated pollen sums in the winter months, *Ostrya* dominated in April and *Broussonetia* in May. Urticaceae contribution was important during spring and summer months.

Throughout the 15-year sampling period, 123 different pollen taxa from 80 families were identified. A total of 57 taxa, belonging to 37 families, are individually reported in the pollen calendar (Figure 5). Pollen calendar reports only taxa reaching a 10-day mean pollen sum equal to or higher than 3 grains/m³. These 57 taxa made up 99.36% of the total pollen sum. Taxa with very low counts or that was found only sporadically (0.24%) were added to undetermined taxa (0.4%), and included, as others, at the bottom of the calendar.

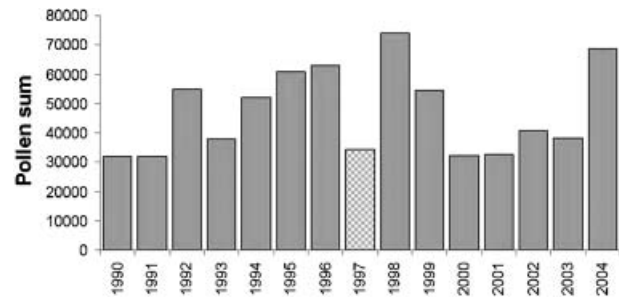


Figure 3. Total annual sums of the daily pollen concentrations in Trieste in each year from 1990 to 2004. Because of the malfunctioning of the trap during May, the total pollen sum for year 1997 is incomplete.

Four principal pollen seasons can be identified in Trieste on the basis of the predominance of different taxa (Figure 5): (1) winter season (*Corylus*, *Alnus*, *Ulmus*, *Fraxinus angustifolia*, *Populus* and Cupressaceae-Taxaceae); (2) spring season (*Carpinus*, *Platanus*, *Betula*, *Ostrya*, *Broussonetia*, *Fraxinus ornus*, *Aesculus*, *Quercus*, Urticaceae, *Picea*, *Pinus*, Gramineae, *Vitis* and *Olea*) (3) summer season (*Castanea*, *Plantago*, *Capparis*, *Humulus*, *Artemisia*, *Ambrosia*, Chenopodiaceae-Amaranthaceae, Urticaceae and Gramineae); (4) autumn season (*Hedera*, *Cedrus*) (Table II).

On average (Table II a), the main pollen season (MPS) of herbaceous taxa lasted over 60 days. Liliaceae, *Mercurialis* and other Asteraceae displayed the highest MPS length (over 150 days). The season of arboreal taxa lasted over 25–60 days; *Alnus* and Cupressaceae-Taxaceae showed a longer season (101 and 65 days, respectively), because of the delayed flowering of *Alnus viridis* growing in the Julian Alps the former, of *Juniperus* the latter. *Olea*, *Platanus* and *Morus* displayed a short and intensive flowering. *Broussonetia*, *Maclura* and *Abies* showed

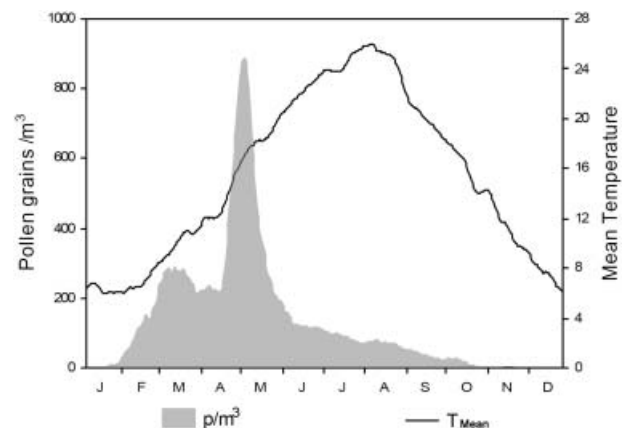


Figure 4. Annual variation in 10-day running mean of total daily pollen counts and daily mean temperature in Trieste averaged over the studied years (1990–2004).

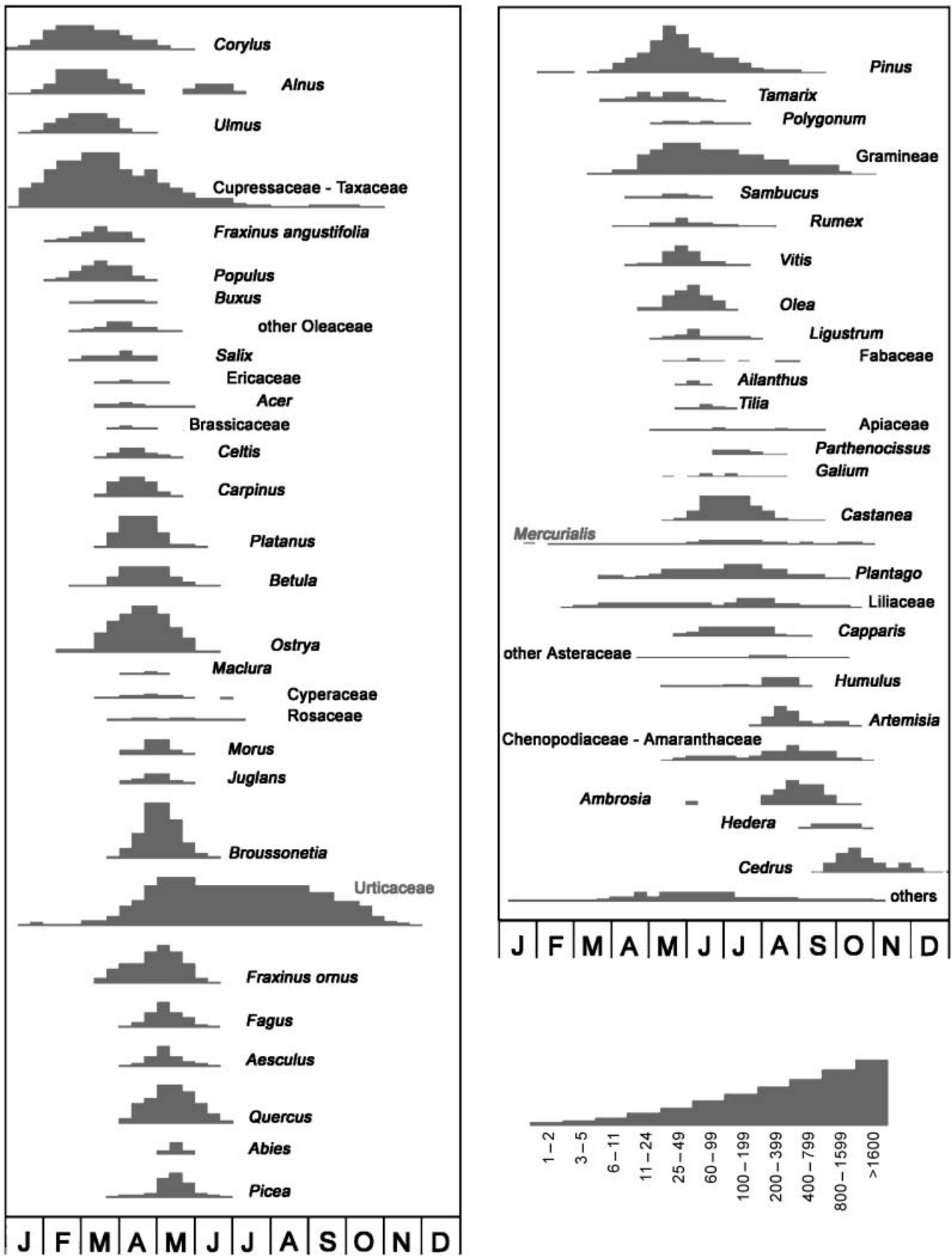


Figure 5. Pollen calendar of Trieste (1990–2004). The order of the taxa in the pollen calendar follows the maximum value of the 10-day pollen sum.

Table II. Aerobiological data for recorded pollen taxa in Trieste during the years 1990–2004. In brackets number of days from 1st January.

Taxon	a						b	
	starting date of MPS	MPS length (days)	peak value (p/m ³)	date of peak-day	total sum	%	maximum total sum	year
<i>Abies</i>	7/5 (128)	12	7	18/5 (139)	20	0.04	284	1992
<i>Acer</i>	25/3 (84)	47	8	22/4 (112)	30	0.08	95	1991
<i>Aesculus</i>	24/4 (114)	44	30	2/5 (122)	122	0.26	257	1995
<i>Ailanthus</i>	15/5 (135)	26	5	7/6 (158)	14	0.03	81	2003
<i>Alnus</i>	16/2 (47)	101	81	26/3 (85)	632	1.33	1 215	1998
<i>Ambrosia</i>	7/8 (219)	40	72	27/8 (239)	360	0.78	908	2003
Apiaceae	25/5 (145)	109	4	5/7 (186)	24	0.05	46	2004
<i>Artemisia</i>	26/7 (207)	69	18	15/8 (227)	194	0.40	364	1997
<i>Betula</i>	29/3 (88)	49	38	19/4 (109)	297	0.65	636	1994
Brassicaceae	31/3 (90)	81	2	16/4 (107)	8	0.02	22	1992
<i>Broussonetia</i>	25/4 (115)	18	1381	30/4 (120)	7 515	15.82	11 844	2004
<i>Buxus</i>	9/3 (68)	39	6	28/3 (87)	19	0.03	71	2004
<i>Capparis</i>	12/6 (163)	63	15	5/7 (186)	137	0.30	446	2003
<i>Carpinus</i>	31/3 (90)	29	39	9/4 (99)	214	0.45	1 027	2004
<i>Castanea</i>	13/6 (164)	43	61	29/6 (180)	663	1.46	1 452	2004
<i>Cedrus</i>	28/9 (271)	51	103	9/10 (282)	351	0.76	1 123	2004
<i>Celtis</i>	3/4 (93)	28	13	14/4 (104)	55	0.12	255	2002
Chenopodiaceae-Amaranthaceae	5/6 (156)	127	13	22/8 (234)	183	0.40	313	2003
<i>Corylus</i>	6/2 (37)	59	79	3/3 (62)	700	1.39	1 796	1998
Cupressaceae-Taxaceae	18/2 (49)	65	1179	8/3 (67)	11 134	22.30	21 387	1998
Cyperaceae	28/3 (87)	82	5	2/5 (122)	31	0.07	55	1996
Ericaceae	21/3 (80)	66	3	9/4 (99)	15	0.03	42	1992
Fabaceae	30/5 (150)	80	4	16/6 (167)	18	0.04	71	2003
<i>Fagus</i>	22/4 (112)	39	48	4/5 (124)	246	0.50	1 161	1992
<i>Fraxinus angustifolia</i>	20/2 (51)	35	17	18/3 (77)	99	0.20	307	2004
<i>Fraxinus ornus</i>	12/4 (102)	39	195	3/5 (123)	1 448	2.96	4 427	1998
<i>Galium</i>	28/5 (148)	83	4	25/6 (176)	14	0.03	34	1996
Gramineae	4/5 (124)	107	93	24/5 (144)	1 741	3.79	2 453	1994
<i>Hedera</i>	14/9 (257)	32	9	27/9 (270)	42	0.08	109	2002
<i>Humulus</i>	26/6 (177)	64	12	8/8 (220)	82	0.18	182	2003
<i>Juglans</i>	14/4 (104)	32	12	23/4 (113)	61	0.13	105	1992
<i>Ligustrum</i>	16/5 (136)	58	14	11/6 (162)	51	0.11	131	1992
Liliaceae	28/3 (87)	176	12	24/7 (205)	163	0.34	282	1997
<i>Maclura</i>	24/4 (114)	14	3	25/4 (115)	8	0.02	43	2002
<i>Mercurialis</i>	23/3 (82)	174	8	30/6 (181)	76	0.15	152	1998
<i>Morus</i>	16/4 (106)	22	19	25/4 (115)	117	0.25	324	1993
<i>Olea</i>	22/5 (142)	24	106	2/6 (153)	365	0.73	1 578	1992
<i>Ostrya</i>	1/4 (91)	34	504	18/4 (108)	3 816	7.67	13 690	2004
other Asteraceae	19/4 (109)	159	5	28/6 (179)	36	0.08	77	1996
other Oleaceae	12/3 (71)	47	13	1/4 (91)	75	0.14	166	1992
<i>Parthenocissus</i>	1/7 (182)	35	10	11/7 (192)	32	0.07	80	1993
<i>Picea</i>	25/4 (115)	43	51	12/5 (132)	227	0.44	1 829	1992
<i>Pinus</i>	25/4 (115)	56	392	18/5 (138)	2 355	5.07	6 859	1998
<i>Plantago</i>	7/5 (127)	127	13	20/6 (171)	256	0.56	483	1996
<i>Platanus</i>	6/4 (96)	23	124	13/4 (103)	730	1.37	1 558	1996
<i>Polygonum</i>	8/5 (128)	97	4	16/6 (167)	20	0.05	46	1995
<i>Populus</i>	27/2 (58)	39	39	15/3 (74)	364	0.73	656	1999
<i>Quercus</i>	17/4 (107)	35	214	4/5 (124)	1 841	4.02	4 108	1993
Rosaceae	8/4 (98)	80	11	2/5 (119)	38	0.08	132	2004
<i>Rumex</i>	1/5 (121)	90	8	28/5 (148)	69	0.15	118	1996
<i>Salix</i>	13/3 (72)	39	12	1/4 (91)	72	0.15	159	1999
<i>Sambucus</i>	7/5 (127)	36	11	18/5 (138)	25	0.06	86	2004
<i>Tamarix</i>	12/4 (102)	58	16	10/5 (130)	102	0.23	207	2000
<i>Tilia</i>	28/5 (148)	57	4	19/6 (170)	17	0.04	42	2004
<i>Ulmus</i>	15/2 (46)	42	39	3/3 (62)	331	0.67	622	1999
Urticaceae	27/4 (117)	141	398	16/5 (136)	10 003	21.14	18 178	1996
<i>Vitis</i>	13/5 (133)	40	26	27/5 (147)	170	0.38	292	2003
Others					256	0.64	761	2003

the shortest MPS lengths (18, 14 and 12 days, respectively).

Cupressaceae-Taxaceae and Urticaceae were the most abundant pollen types: annual sums higher than 10 000 grains were found. The cumulative counts of each pollen type varied greatly over the years, and also the pollen peak values varied from year to year.

Arboreal taxa prevailed in the pollen spectrum of Trieste (Figure 6). Trees (69.63%) and shrubs (1.22%) constituted together most of the airborne pollen sum. Herbaceous taxa – herbs (6%) and weeds (23%) – contributed to a lesser extent. Such a composition broadly reflects the vegetation of this area, consisting both of natural woodlands around the town and anthropogenic coenoses inside.

Correlations with meteorological parameters

Pearson's correlation coefficients between the logarithmic standardized total daily pollen concentrations and the selected daily meteorological parameters were evaluated both during MPS and pre-peak period for the whole study period (1990–2004). In both cases negative correlations were found between the daily pollen content and rainfall, minimum humidity and mean weed speed (Table III a). Significant correlations were found between the daily pollen content and temperature; however, these correlations changed from negative during MPS to positive during pre-peak periods.

Pearson's correlation coefficients between the logarithmic daily pollen concentrations and the daily meteorological parameters were valuated only for the pre-peak period of each year. Significant positive correlations with the temperatures were confirmed for all years, whereas only few correlations with humidity, rainfall and wind speed were found (Table III b).

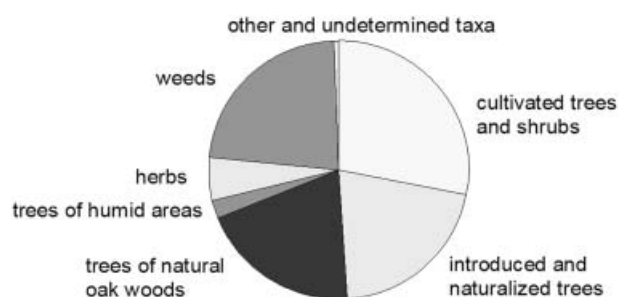


Figure 6. Airborne pollen spectrum in Trieste (1990–2004): percentage of different groups of plants. Predominant taxa are: Cupressaceae-Taxaceae and *Platanus* in the group 'cultivated trees and shrubs'; *Broussonetia* and *Pinus* in 'introduced and naturalized trees'; *Ostrya*, *Quercus*, *Fraxinus*, *Castanea* and *Corylus* in 'trees of natural oak woods'; *Alnus* in 'trees of humid areas'; Gramineae in 'herbs', and Urticaceae in 'weeds'.

Pearson's correlation coefficients between the logarithmic standardized daily pollen of the eight main taxa and the daily meteorological parameters were valuated both on their MPS and on pre-peak period. In both cases negative correlations were found between the daily pollen counts of these taxa and rainfall and humidity (Table IV). For all these taxa, significant positive correlations were found between the daily pollen counts and temperatures during pre-peak period; also during MPS the correlations were positive except for Urticaceae, *Pinus* and Gramineae. The correlations with wind speed were more often negative.

With reference to the total annual pollen sums, no relationships were found with meteorological parameters except for *Ostrya* and *Pinus*. *Ostrya* annual pollen sum was correlated with relative and minimum humidity ($r=0.619$, $p=0.018$; $r=0.680$, $p=0.007$) and total rainfall of the previous summer ($r=-0.615$, $p=0.025$); *Pinus* annual pollen sum was correlated with the number of the days with a mean temperature $<5^{\circ}\text{C}$ ($r=0.578$, $p=0.039$).

Discussion

The mean annual total (48 082 pollen grains) recorded in Trieste between 1990 and 2004 was higher than the mean annual total found in other European sites, like Cagliari (Ballero & Maxia, 2003) and several Spanish sites (Candau Fernandez-Mensaque et al., 1998; Recio et al., 1998; Rodríguez et al., 1998; Munuera Giner et al., 2002; Rodríguez-Rajo et al., 2003). This difference is probably due to the close proximity of natural vegetation to the town of Trieste. On average, two peaks of total daily pollen counts are recognizable in Trieste, the former in late February–mid March, mainly due to Cupressaceae-Taxaceae, the latter between April and May, due to full blooming of a high variety of spring taxa.

Seasonally, the pollen concentration was the highest in spring, when 64% of the annual sum was recorded, and the lowest in autumn (2% of the annual sum). During winter and summer the amount of airborne pollen collected was relatively low (19% and 15% of the annual sum, respectively).

A high variety of pollen types was recorded, especially during spring and summer months. Grains of thermophilous taxa (*Cupressus*, *Olea*, *Vitis*, *Quercus*, *Ostrya*, *Fraxinus ornus*, *Ligustrum*) coexist in the air of the town with mesophilous taxa (*Carpinus*, *Castanea*, *Tilia*, *Fagus*, *Fraxinus angustifolia*, *Abies*) and more microtherm ones (*Picea*, *Betula*). Pollen amounts of these taxa sometime increase because of the grains brought over by the dominant winds. The Sirocco wind carries thermophilous taxa

Table III. (a) Pearson's correlation coefficients between logarithmic standardized daily total pollen counts and daily meteorological variables both for the MPS and pre-peak period in the whole period (1990–2004). (b) Pearson's correlation coefficients between logarithmic daily total pollen counts and daily meteorological variables for pre-peak period in each year. No correlations are reported for 1997 because of missing values and for 1991 because of only 1 degree of freedom.

a	Years	d.f.	T _{mean}	T _{min}	T _{max}	H _{rel}	H _{min}	H _{max}	R	W
MPS	'90–'04	2267	−0.147 ***	−0.152 ***	−0.122 ***	−0.024	−0.053 *	−0.001	−0.135 ***	−0.047 *
pre-peak	'90–'04	735	0.586 ***	0.536 ***	0.596 ***	−0.020	−0.073 *	0.043	−0.159 ***	−0.083 *
b	Year	d.f.	T _{mean}	T _{min}	T _{max}	H _{rel}	H _{min}	H _{max}	R	W
pre-peak	1991	31	0.616 ***	0.500 **	0.675 ***	−0.170	−0.273	−0.006	−0.189	−0.125
	1992	59	0.478 ***	0.428 **	0.470 ***	−0.136	−0.165	−0.044	−0.176	0.053
	1993	48	0.802 ***	0.739 ***	0.801 ***	0.207	0.085	0.282	−0.239	−0.284 *
	1994	81	0.642 ***	0.615 ***	0.651 ***	0.057	−0.060	0.242 *	−0.250 *	−0.082
	1995	72	0.617 ***	0.580 ***	0.601 ***	−0.014	−0.015	−0.086	−0.057	0.099
	1996	12	0.748 **	0.693 *	0.460	0.572	0.562	0.641 *	0.059	−0.519
	1998	86	0.753 ***	0.743 ***	0.727 ***	0.115	0.015	0.194	−0.141	−0.065
	1999	68	0.491 ***	0.432 ***	0.526 ***	−0.021	−0.055	0.084	−0.179	−0.094
	2000	54	0.565 ***	0.457 **	0.639 ***	−0.212	−0.378 **	−0.094 *	−0.265	−0.179
	2001	78	0.318 **	0.266 *	0.347 **	0.015	−0.037	0.078	−0.047	0.021
	2002	54	0.406 **	0.385 **	0.365 **	−0.039	−0.081	−0.063	−0.275 *	−0.156
	2003	53	0.590 ***	0.578 ***	0.603 ***	0.144	0.129	0.211	−0.162	−0.148
	2004	38	0.600 ***	0.422 **	0.657 ***	−0.421 **	−0.378 *	−0.323 *	−0.420 **	0.049

T_{mean} mean daily temperature, T_{min} minimum daily temperature, T_{max} maximum daily temperature, H_{rel} relative humidity, H_{min} minimum humidity, H_{max} maximum humidity, R daily rainfall, W mean wind speed, d.f. degrees of freedom. Level of significance: * p < 0.05; ** p < 0.01, ***p < 0.001

from the Istrian region, while the Bora wind carries mesophilous taxa from the Karst, from Slovenian forests and from regions further away. The long-distance transport to the area of Trieste by the Bora was especially evident in 1992; in this year, exceptionally high annual totals of *Abies*, *Fagus* and *Picea* were found notwithstanding the scarceness of these trees in the area.

On the basis of the annual total mean for each pollen type, the most common types in the air of Trieste, in decreasing order, are: Cupressaceae-Taxaceae, Urticaceae, *Broussonetia*, *Ostrya*, *Pinus*, *Quercus*, Gramineae and *Fraxinus*.

Almost a half of total pollen content comes from trees and shrubs introduced either for reforestation (*Pinus*) and other economic reasons (*Broussonetia*, *Olea*, *Vitis*) or for ornamental purposes, such as *Aesculus*, *Betula*, Cupressaceae (*Chamaecyparis*, *Cupressus*, *Thuja*), Pinaceae (*Abies*, *Cedrus*, *Larix*, *Picea*), *Platanus*, *Taxus*. One fifth of the total pollen content comes from natural woodlands, above all from thermophilous oak woods surrounding the town (mainly *Quercus*, *Ostrya* and *Fraxinus ornus*), whereas airborne pollen grains of *Alnus*, *Fraxinus angustifolia* and *Salix* are scarce in Trieste, because the lack of streams and other humid areas. Herbaceous taxa make up one quarter of total airborne pollen count, the highest concentrations being recorded for Gramineae and Urticaceae. Yearly pollen sums for these taxa, as also for *Artemisia*, were very high in the first years of the

considered period, while they decreased after the year 2000 due to better management of the ruderal flora of the town. Although rather scarce in the air of Trieste (on average 0.78%), the highly allergenic ragweed (*Ambrosia*) appears to have increased over the years (2.36% in 2003). This might be due to the increasing trade relations with Eastern European countries, where ragweed which was first found in 1863 (Járai-Komlódi & Juhász, 1993) in Hungary, has spread throughout the central and central-south Europe since the second world war (D'Amato, 2001; Makra et al., 2005).

The pollen calendar of Trieste differs from the calendars of North and central Europe (Spiexsma, 1991) mainly because of the occurrence of the wide variety of taxa. The general pattern of airborne pollen concentration in Northern Italy (Spiexsma, 1991) is confirmed in Trieste, even if some taxa (Cupressaceae-Taxaceae, *Olea* and *Quercus*) show more similar values to those recorded in Central Italy (Spiexsma, 1991).

Total daily pollen concentrations in Trieste show always negative correlations with rainfall and humidity (Table III a), as found in Cartagena (Moreno-Grau et al., 1998; Angosto et al., 2005), Braga (Ribeiro et al., 2003) and Sydney (Stennet & Beggs, 2004). Unlike other studies (Ribeiro et al., 2003; Stennet & Beggs, 2004; Angosto et al., 2005), total daily pollen concentrations show negative correlations with wind speed and temperatures (Table III a). In Trieste, the strong local winds (Bora and

Table IV. Pearson's correlation coefficients between logarithmic standardized daily total pollen counts and daily meteorological variables both for the MPS and pre-peak period in the whole period (1990–2004) for the eight main taxa.

Taxon		d.f.	T _{mean}	T _{min}	T _{max}	H _{rel}	H _{min}	H _{max}	R	W
Cupressaceae	MPS	890	0.194 ***	0.182 ***	0.201 ***	0.103 **	0.056	0.159 ***	−0.091 **	−0.124 ***
	pre-peak	251	0.734 ***	0.682 ***	0.717 ***	0.154 *	0.071	0.257 ***	−0.010	−0.151 *
Urticaceae	MPS	1885	−0.029	−0.031	−0.012	−0.027	−0.038	−0.083 ***	−0.169 ***	−0.184 ***
	pre-peak	295	0.228 ***	0.190 **	0.247 ***	−0.107	−0.082	−0.123 *	−0.247 ***	−0.196 **
<i>Broussonetia</i>	MPS	244	0.531 ***	0.487 ***	0.549 ***	−0.094	−0.132 *	−0.083	−0.185 **	−0.097
	pre-peak	101	0.642 ***	0.596 ***	0.631 ***	−0.252 *	−0.225 *	−0.259 **	−0.267 **	−0.239 *
<i>Ostrya</i>	MPS	466	0.306 ***	0.244 ***	0.328 ***	−0.303 ***	−0.309 ***	−0.247 ***	−0.260 ***	0.099 *
	pre-peak	253	0.503 ***	0.415 ***	0.510 ***	−0.186 **	−0.236 ***	−0.116	−0.228 ***	0.014
<i>Pinus</i>	MPS	763	−0.032	−0.064	0.034	−0.332 ***	−0.321 ***	−0.259 ***	−0.153 ***	0.208 ***
	pre-peak	331	0.494 ***	0.443 ***	0.498 ***	−0.482 ***	−0.452 ***	−0.418 ***	−0.235 ***	0.263 ***
<i>Quercus</i>	MPS	476	0.323 ***	0.278 ***	0.353 ***	−0.273 ***	−0.266 ***	−0.218 ***	−0.170 ***	0.101 *
	pre-peak	250	0.596 ***	0.546 ***	0.583 ***	−0.294 ***	−0.278 ***	−0.237 ***	−0.211 **	−0.058
Gramineae	MPS	1412	−0.174 ***	−0.179 ***	−0.160 ***	−0.071 **	−0.049	−0.077 **	−0.087 **	−0.019
	pre-peak	308	0.399 ***	0.335 ***	0.363 ***	−0.116 *	−0.111	−0.106	−0.123 *	−0.113 *
<i>Fraxinus</i>	MPS	783	0.548 ***	0.425 ***	0.504 ***	0.559 ***	−0.257 ***	−0.271 ***	−0.171 ***	−0.130 ***
	pre-peak	566	0.563 ***	0.511 ***	0.572 ***	−0.193 ***	−0.214 ***	−0.129 **	−0.130 **	−0.011

T_{mean} mean daily temperature, T_{min} minimum daily temperature, T_{max} maximum daily temperature, H_{rel} relative humidity, H_{min} minimum humidity, H_{max} maximum humidity, R daily rainfall, W mean wind speed, d.f. degrees of freedom. Level of significance: * p < 0.05; ** p < 0.01, *** p < 0.001

Sirocco) have a dilution impact in pollen concentration, as already found for Poaceae in León (Valencia-Barrera et al., 2001). The negative correlations with temperatures during MPS may be explained by the biological rhythm of the vegetation in Trieste. It overrides the influence of temperature after the peak, so even if the temperature increases in summer, pollen release decreases because the pollen production of the main taxa has been exhausted (see Figure 4). Positive significant correlations with temperatures have been always found only in pre-peak period (Table III a).

Analysing the eight main taxa (Table IV), correlations between daily pollen counts and rainfall and humidity are usually negative both on MPS and pre-peak period according to the results of other studies. As regards the temperatures, the same correlations found for total daily pollen are confirmed for the taxa having a longer MPS (Urticaceae, *Pinus* and Gramineae) unlike other studies (Moseholm et al., 1987; Bricchi et al., 1992; Galán et al., 1995; González Minero et al., 1998; Iglesias Fernandez et al., 1998; Jato et al., 2002; Sánchez Mesa et al., 2003; Rodríguez-Rajo et al., 2003, 2004; Stennet & Beggs, 2004). The other main taxa with short MPS show positive correlation with temperatures both on MPS and pre-peak period, as reported in the literature (Moreno-Grau et al., 2000; Aira et al., 2001; Jato et al., 2002; Rodríguez-Rajo et al., 2003, 2004). Except from *Ostrya* and *Pinus*, the annual pollen productivity appears usually not to be influenced by meteorological parameters. Drought in the previous summer stimulates pollen production of *Ostrya*, as has been demonstrated for *Betula* (Rasmussen, 2002) and *Quercus* (Corden & Millington, 1999). The exceptional pollen production of *Ostrya* verified in 2004, following the abnormal hot and dry summer of 2003, reinforces the negative correlation between *Ostrya* annual sum and summer rainfall of the preceding year. Negative correlation between the annual sum of *Pinus* and the number of days preceding flowering with mean temperature $<5^{\circ}\text{C}$ suggests that *Pinus* productivity is limited when winter is very severe, as previously suggested for some thermophilic species of *Pinus* (like *P. halepensis* and others), less tolerant to low winter temperatures (Frenguelli et al., 2002).

Conclusions

The most important aerobiological features of the pollen calendar of Trieste are:

1. The high airborne pollen content: the average yearly total is 48 082 pollen grains, a third of which is collected in May;

2. The predominance of arboreal taxa (mainly cultivated and ornamental) and the abundance of weeds;
3. The vast variety of pollen taxa (123 identified taxa), with Cupressaceae-Taxaceae and Urticaceae as main taxa, followed by *Broussonetia*, *Ostrya*, *Pinus*, *Quercus*, Gramineae and *Fraxinus ornus*;
4. The richness of both mesophilous and thermophilous pollen taxa, reflecting the complexity of flora and vegetation in this zone, considered as "crossroads" of species.

The pollen composition in the air of Trieste reflects both ornamental and ruderal flora of the town. The natural vegetation surrounding the urban area and the vegetation growing on Karst plateau influences the pollen spectrum, as well as the small cultivated belt of vineyards and olive groves in the outskirts. The airborne pollen composition of the town is often also affected by the nearby Slovenian forests; moreover, total yearly pollen counts and pollen season lengths can be influenced also by a long-range pollen transport.

Total daily pollen concentrations in Trieste are positively correlated with temperatures only in pre-peak period. The same behaviour is found for Urticaceae, *Pinus* and Gramineae. Other main taxa display positive correlations with temperatures both in main pollen season and in pre-peak period. Rainfall and humidity almost always show negative correlations with pollen counts.

Annual pollen sums are not correlated with meteorological parameters except for *Ostrya* and *Pinus*. The yearly pollen concentration of *Ostrya* is negatively correlated with total rainfall of the previous summer and the yearly *Pinus* pollen concentration is negatively correlated with the number of the days having mean temperature $<5^{\circ}\text{C}$.

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