

Differences between airborne pollen and flowering phenology of urban trees with reference to production, dispersal and interannual climate variability

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Abstract

Annual totals of daily arboreal pollen concentrations were analysed in Mar del Plata (Argentina) during 1993 and 1994. Flowering patterns were associated with timing and intensity of pollen appearing in the air. Seasonal climatic parameters before the start of flowering and current weather conditions during dispersion were considered.

Flowering showed a regular pattern between years and it could be defined by cumulated pollen percentages. Arboreal pollen counts were higher in the first year and is probably due to 1) better climatic conditions connected with pollen productivity and 2) lower precipitation after pollen emission. *Betula* and *Q. ilex* showed an opposite behaviour that appears to be caused by a biennial fluctuating rhythm of pollen production.

1. Introduction

Airborne pollen concentration at any moment is influenced by factors related to production, discharge and deposition. Each of these sequential steps of the aerobiological pathway is linked to different biological events in association with atmospheric phenomena (Edmonds, 1979).

If we compare studies of the atmospheric variables effect on pollen dispersion, there often seems to be an apparent contradiction in the results found (Kawashima and Takahashi, 1995). Some researchers assume that a basic pattern of airborne pollen occurrence (cyclic or stable) due to plant source production exists. That pattern is, in some manner, independent of changing external conditions. Other authors assume that fluctuations are principally caused by meteorological factors (Spieksma and Tonkelaar, 1986). Therefore the problem requires consideration of the pollen productivity phenomenon separately from that of dispersion to access the suitable interpretation of the aerobiological process.

Pollen grain number and timing depends on the floral phenology of the emitting species. Phenology is a botanical science dealing with the effects of climate on seasonal flowering patterns (Bowers and Dimmitt, 1994). Moreover, meteorological conditions during the pollination period modify pollen concentration emitted into the atmosphere.

It is assumed that the number of trees in a city remains relatively constant year after year. If interannual differences in the arboreal pollen counts are found, that would be the result of other factors different from the abundance of plants. Endogenous or environmental factors could determine the interannual variability of arboreal pollen concentration that can be elucidated under an aerobiological approach.

In this preliminary study about production and dispersal recurring events, the concentration and seasonal variations of tree pollen types in the city of Mar del Plata are analysed. The pollen and flowering patterns between two consecutive years are compared. The temperature and precipitation influ-

ences are investigated as potential triggers of inter-annual variations and/or like potential modifiers of pollen-flowering relationship.

2. Materials and methods

Atmospheric pollen counts in Mar del Plata city (Argentina) (38°03 S; 57°33 W) were collected with a 7-day Burkard trap during the 1993–1994 period. The sampler is placed on the roof of the building of Universidad Nacional de Mar del Plata within the urban area. Daily means were achieved from 12 hourly transversal sweeps by day and expressed as number of pollen grains per cubic meter of air (O'Rourke, 1990). The airborne pollen spectrum of the city has been characterised in previous studies (Bianchi, 1994; Latorre and Pérez, 1997; Latorre and Bianchi, 1997). Only data from arboreal types (AP) are presented here. Cupressaceae was excluded because of the over-representation shown before by this spectrum (Latorre and Bianchi, 1997).

A vegetational census was performed to establish the composition and abundance of each arboreal species. All trees present in the streets and external gardens were included in the count. The area measured 1.5 km × 1.5 km with the pollen sampling point as its centre. Also, eight square areas of similar size (1.5 km × 1.5 km) scattered around the central area and in coincidence with a cardinal point were surveyed. At each sampling area, trees were registered on perpendicular transects 1.5 km long. The pairs of perpendicular transects were chosen randomly. Hence, it was defined local and extralocal vegetation (that of the census) and regional vegetation (that of the samples).

A quantitative survey of flowering was carried out twice a week on each arboreal species following the same local and extralocal individuals during the two years. The survey technique was described in Latorre (1997). Three main flowering phenophases were analysed: 1) start: when at least one of selected trees showed opened flowers, 2) maximum: when the mean percentage of opened flowers (exposed anthers with pollen) of all trees reached its highest value, and 3) end: when there were no opened flowers at any selected tree.

A specific study of pollen-flowering relationship was performed on the ten major taxa whose pollen counts were the highest (over 5% of AP pollen counts on at least one of the surveyed years). The genera included here were: *Fraxinus*, *Ulmus*, *Acer*, *Salix*,

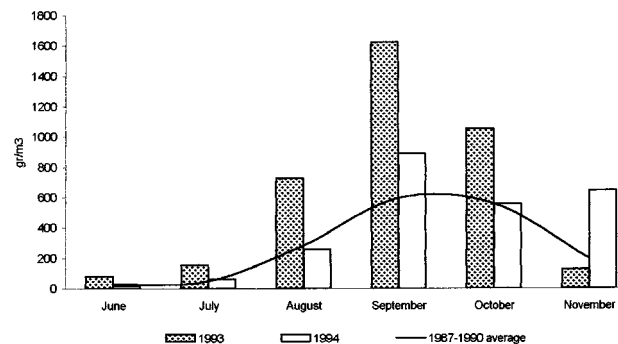


Figure 1. Monthly totals of daily mean concentration of arboreal pollen in 1993, 1994, and in a previous four-years airborne pollen survey.

Populus, *Betula*, *Quercus*, *Platanus*, *Liquidambar* and *Juglans*. Two species of *Quercus* were examined separately (*Q. robur* and *Q. ilex*) because their flowering seasons do not overlap. The identification of these species by pollen morphology is possible.

Temperature data from the surveyed period was taken with the aid of an automatic meteorological station located near the pollen trap. Precipitation and statistical data from 1960–1980 period were obtained by the Servicio Meteorológico Nacional from Mar del Plata Aero meteorological station.

Basic statistics and non-parametric correlation (Spearman) were used to analyse the relationships (Sokal and Rohlf, 1979).

3. Results

3.1 General pattern of arboreal pollen

The atmospheric pollen recorded between June and November was chosen for the analysis because this period of year (winter–spring) showed the highest AP contribution. The ratio between 1993 AP concentrations and 1994 AP concentrations was 1.55, although a general pattern was observed in both years. Pollen counts increased in July and August due to *Ulmus* and *Fraxinus* blossoming periods. Most of arboreal species flowered in September and October. The AP peak is registered in these months, reaching 70% in 1993 and 60% in 1994 of total AP. Nevertheless, in 1994, the AP from September and October was 46% lower than the AP registered in the previous year. Few species were still in bloom during November, although in 1994, monthly concentrations were relatively higher. This temporal sequence of AP concentrations could

be compared with the arboreal pollen curve from 1987–1990 period (Figure 1).

3.2 Pollen contribution – atmospheric conditions

The highest AP concentrations were observed in 1993. The summer of 1993 was, on average, 1 °C warmer than the summer of 1994. Monthly mean temperatures in 1993 between January and April, were also higher than those from the last thirty years. Mean values in 1994 were similar to the statistical data. However, after the end of autumn, the temperatures in 1993 were, on average, 1 °C lower than the temperatures in 1994. Specifically, July 1993 was 0.92 °C colder than could be expected from the statistics. August temperature in 1993 was 0.33 °C hotter than in 1994 (Figure 2a).

Autumn of 1993 was rainy. In April and May of this year, precipitation was 146.62 mm higher than the thirty-years average. Precipitation during the months with the highest AP concentration (September and October) was, on the contrary, more abundant in 1994 and 94.22 mm higher than the statistics. Precipitation in September–October 1993 was 93.26 mm lower than the last thirty years. Anomalies in precipitation data were also registered for November. Precipitation was 63.5 mm higher than the statistical data during November 1993 and 57 mm below them for November 1994 (Figure 2b).

Pollen percentage from the ten taxa specially considered, reached 83.93% in 1993 and 82.46% in 1994, with respect to the total AP. Similarity between years was also observed analysing separate relative values from each taxon ($r_s = 0.74$, $p < 0.05$). *Platanus*, *Ulmus* and *Quercus* are the more abundant genera in both years (76.2% and 72.25%). *Fraxinus*, *Acer* and *Populus* fill the fourth, fifth and sixth place in the two year ranking. *Juglans*, *Liquidambar*, *Betula* and *Salix* have the lowest pollen contribution of the group (Figure 3). Major differences between years resulted when the two *Quercus* types were analysed separately. In 1993, *Q. ilex* was last in the order of contribution, whereas in 1994 it became the second taxon with higher pollen counts. The rest of the taxa only moved one or two places between years.

Whereas relative importance of each genus was equal between years, pollen concentration (absolute values) changed. In 1993, all the arboreal pollen types showed higher concentrations except for *Q. ilex* and *Betula* (Figure 4).

3.3 Pollen – flowering relationship

The pollination start of ten taxa was registered, on average, 3.55 days earlier in 1993 than in 1994. Only the start of *Fraxinus* and *Acer* pollen seasons showed a large difference of nearly 20 days between the two years. On the other hand, maximum and final stages in the first year were registered 2 and 3 days later, respectively, than the second year. Interannual differences of more than 1 week at the end of pollination were observed in *Fraxinus*, *Ulmus*, *Populus* and *Liquidambar*. On average, the 1993 pollination period was 17 days longer than in 1994. Only *Platanus* displayed a shorter pollination period in 1993 with a difference of 11 days between 1993 and 1994; that of *Q. ilex* was equal in both years (Table 1 and Figure 5).

The disagreement between the two years in regard to the three floral phenophases did not exceed 4.5 days on average. The duration of the flowering period was similar among 1993 and 1994 and the differences were not higher than 1 week, except for *Betula* and *Liquidambar* where the flowering period was nearly 10 days shorter in the first year (Figure 5). Main disagreements on seasonality were observed in *Juglans* and *Salix*; the flowering period was delayed 11 and 20 days in 1994 on each taxon, respectively (Table 1).

The pollen grains in the air were registered before the flowering period started (on average 3 and 2 days of difference in 1993 and 1994, respectively). The differences between pollen and flowering starts were longer than 10 days only in *Acer* and *Liquidambar* in 1993 and in *Fraxinus* and *Platanus* in 1994. Pollen recordings were preceded by flowering in both years only for *Ulmus*, *Salix*, *Q. ilex* and *Juglans*. On the contrary, maximum pollen and flowering phases did not generally show any differences. Only in the case of *Betula* and *Q. robur* during 1994 did the differences between maximum phases exceeded one week. The highest differences were observed between the two variables in the final stage. The pollen season ended, on average, 20 and 18 days after flowering in 1993 and 1994, respectively. *Ulmus* showed the more important difference between these phenophases, with 73 days in 1993 and 55 days in 1994. In 1994, *Liquidambar* was the taxon with a pollen season that finished before the flowering ended; the time lag was 13 days (Table 1 and Figure 6).

For both flowering and pollen season, the ascendant phase was defined from the start until the maximum. Ascendant phase of both phenomena

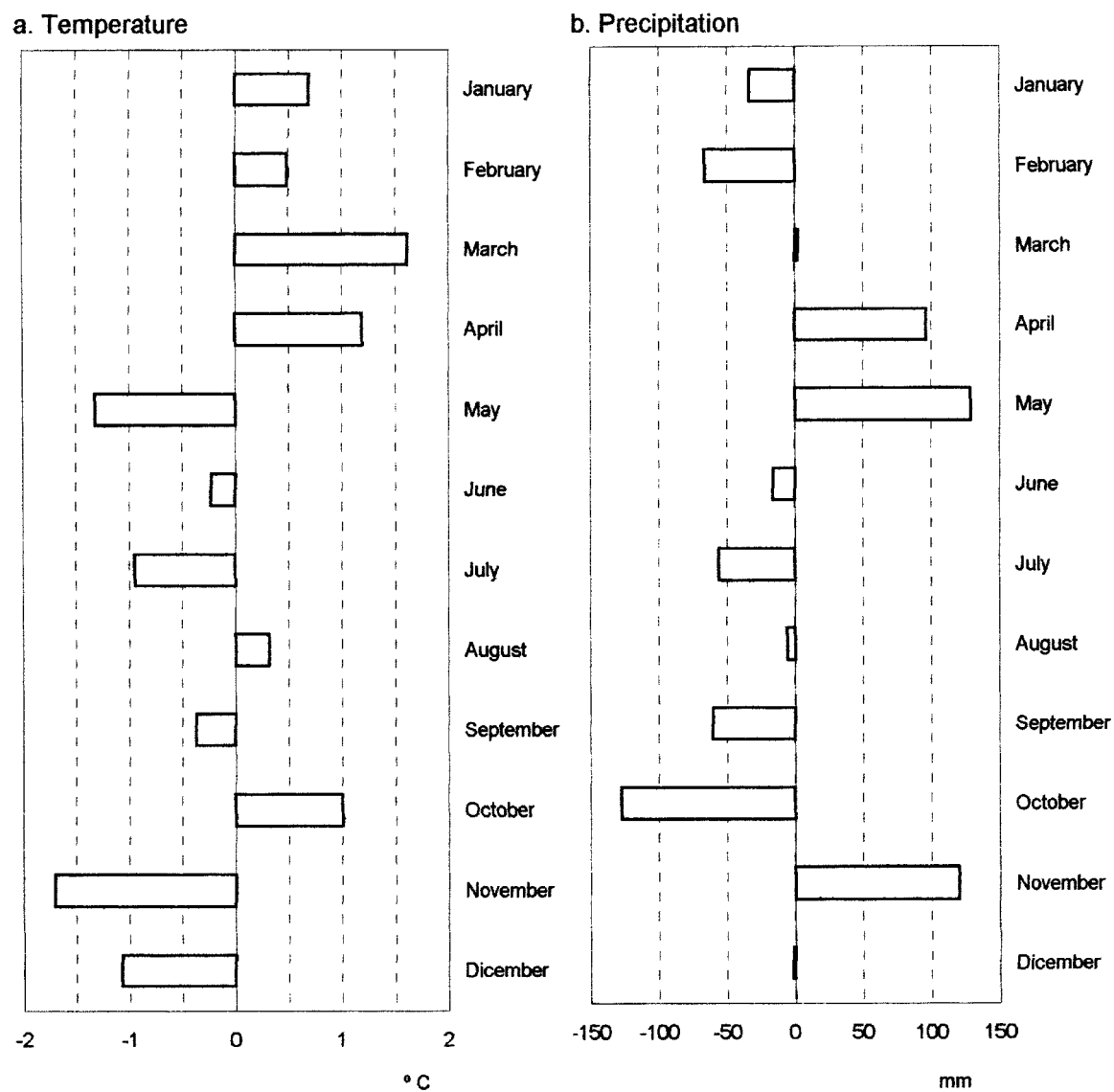
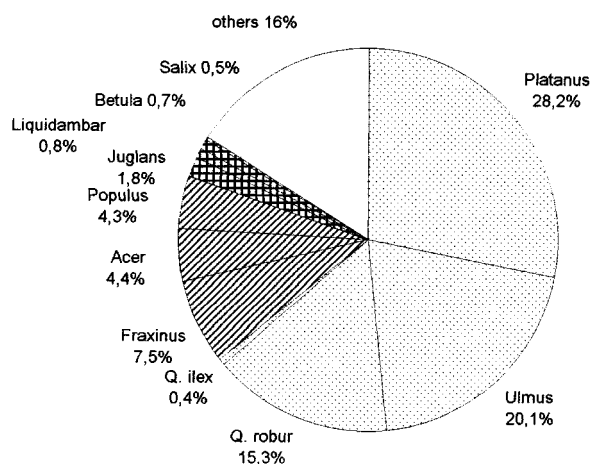


Figure 2. Differences in monthly mean temperatures (a) and in monthly totals of precipitation (b) between 1993 and 1994. Positive values indicate higher data in 1993.

1993



1994

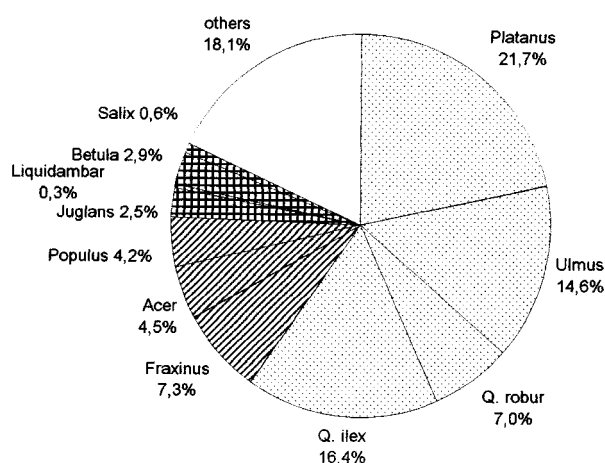


Figure 3. Pollen percentages of each taxon during to the total six-month period in 1993 and 1994. Daily mean concentration ranking: 1061–354 gr/m^3 (dots), 281–109 gr/m^3 (lines) and 69–5 gr/m^3 (squares).

showed the same duration each year. Its average was 20 days in 1993 and 26 days in 1994, except for *Ulmus* with both ascendant phases longer (about 40 and 50 days each year). Flowering descendant phase was defined from maximum up to the end and it was longer than the flowering ascendant phase. It lasted, on average, 20 days in 1993 and 23 days in 1994. However, pollen descendant phase was two times longer than the flowering descendant phase. On average, both lasted 51 and 44 days each year. *Q. ilex* and *Liquidambar* pollen descendant phases were

the exception to the rule because in those taxa the ascendant phase equals the descendant phase. Variation coefficients were similar to all variables (pollen and flowering ascendant and descendant phases of all the taxa together) and reached 45%, on average. Two-years average of flowering ascendant phase was 2 days longer than the descendant phase; but pollen ascendant phase was 24 days shorter than the descendant phase.

When flowering started in 1993, the cumulative pollen percentage in the air was higher than in 1994. The Spearman rank correlation coefficients between cumulative percentages each year before flowering started for the taxa analysed, were not significant (Figure 7a). This coefficient was significant when we compared pollen achieved at the moment of the maximum and the final stages of flowering (Figures 7b and 7c). The amount of each pollen type registered before flowers had opened was 1.17% of the total. When the species reached its flowering maximum, pollen was, on average, 59.66% and when the flowering ended, the pollen collected reached 95.65% of total (Table 2). Variation coefficient of cumulated percentages towards flowering end phases was the lowest (6.5% on average).

4. Discussion

4.1 General pattern

Between the end of winter and the start of spring, the main atmospheric arboreal pollen sources in Mar del Plata area are in bloom. This pattern is regularly followed year after year (Bianchi, 1992; Latorre, 1993; Latorre and Pérez, 1997). The highest number of these species flowering is registered in September and it coincides with the highest recording of monthly airborne pollen. October is the second month with high AP counts.

4.2 Pollen contribution – atmospheric conditions

Each particular taxon produced similar relative pollen amounts in the two years analysed in comparison with previous atmospheric surveys (Latorre and Bianchi, 1997; Latorre and Pérez, 1997). The predominant pollen types are *Platanus*, *Ulmus* and *Quercus*. The contributions of those taxa to the total pollen sums are similar each year. Information about local pollen sources facilitated the identification of airborne pollen to species level. *Quercus* contribution as genus was stable from one year to the next, but great differences

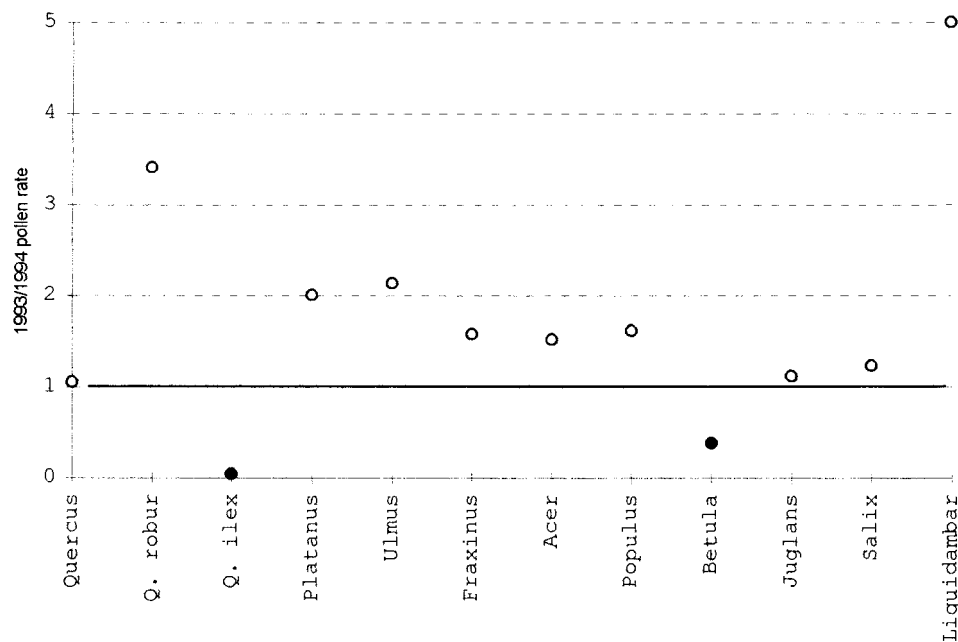


Figure 4. Ratio between the 1993 concentration and the 1994 concentration for each taxon. Values greater than the unit indicate larger pollen concentration data in 1993.

were found between pollen types from both species present in the vegetation.

The arboreal pollen in 1993 showed absolute values higher than those from 1994. The observed interannual differences can be explained by seasonal climatic factors that precede the flowering period. Temperature is one of the principal factors controlling this phenomenon (Caramiello et al. 1990, 1994; Emberlin et al., 1993). The influence of temperature as a controlling factor of intensity of pollination is higher during the summer, when trees produce and accumulate the major amount of photosynthates that will be available to reproduction in spring (Cadman et al., 1994). Towards the end of the summer, pollen grains start to form in anthers (Emberlin et al., 1990). The warm summer of 1993 could have been responsible for greater pollen productivity of trees that year.

Arboreal species with a winter-spring flowering pattern have a cold requirement related to dormancy period (Frenguelli et al., 1991; Emberlin et al., 1993). After a dormancy period, the accumulation of heat above a threshold is required to start the pollen shedding (Seeley et al., 1997; Frenguelli et al., 1992). Temperatures from previous months, until anthesis starts, were lower in 1993 compared to those registered in 1994. In August (month immediately before the arboreal species flowering period) temper-

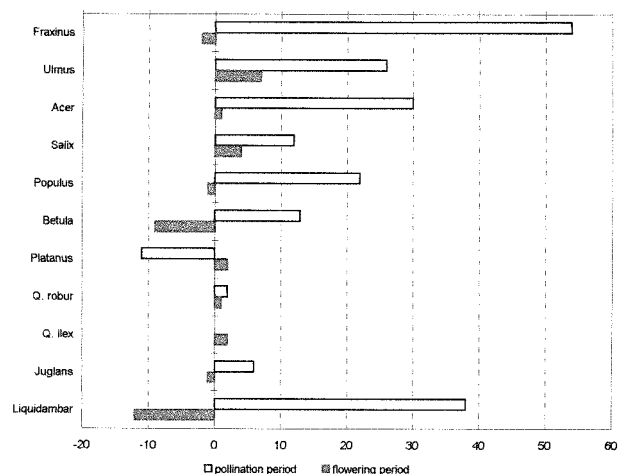


Figure 5. Differences (in days) between 1993 and 1994 for the flowering period and for the airborne pollen presence in the air period of each taxon. Negative values indicate less days in 1993 than in 1994.

atures were slightly higher in 1993. These facts should be indicating better conditions for pollen discharge on the first sampling year.

Precipitation would be another factor influencing the high productivity of trees (Caramiello et al., 1994). In Mediterranean ecosystems, water availability plays an important role in determining phenological devel-

Table 1. Dates of pollen and flowering principal phases: start and end, for the different taxa analysed in 1993 and 1994. The months with higher pollen concentration are shown.

Taxon	Flowering		Pollen		Month
	Start	End	Start	End	
Fraxinus ^a	1993 6/30	11/12	6/26	11/8	Sep–Oct
	1994 7/7	11/21	6/8	12/14	Sep–Oct
Ulmus ^a	1993 7/3	9/8	7/7	11/20	Aug
	1994 7/7	9/5	7/12	10/30	Aug
Acer	1993 8/26	10/12	8/9	11/20	Sep
	1994 9/2	10/18	9/2	11/14	Sep
Salix ^a	1993 8/12	10/22	8/24	11/10	Sep
	1994 9/1	11/7	9/3	11/8	Sep
Populus ^a	1993 8/31	10/12	8/25	11/25	Sep
	1994 9/1	10/14	8/27	11/5	Sep
Betula	1993 9/8	10/26	8/31	11/4	Oct
	1994 9/5	11/1	9/6	10/28	Sep–Oct
Platanus	1993 9/16	10/21	9/11	11/23	Sep
	1994 9/15	10/18	9/2	11/25	Sep
Q. robur	1993 9/13	10/18	9/8	11/23	Sep–Oct
	1994 9/14	10/18	9/15	11/28	Sep–Oct
Q. ilex	1993 10/29	11/30	11/1	11/23	Nov
	1994 10/31	11/30	11/8	11/30	Nov
Juglans	1993 9/8	10/29	9/25	11/23	Oct
	1994 9/19	11/10	10/1	11/23	Oct
Liquidambar	1993 9/27	10/18	9/4	11/7	Oct
	1994 9/21	10/24	9/15	10/11	Oct

^a Includes different species

opment (Spano and Cesaraccio, 1998). Higher autumn precipitation was registered in 1993, however, this atmospheric variable could not be determinant in Mar del Plata city because of the lack of water deficit described for this region (Burgos and Vidal, 1951). On the other hand, precipitation is very important during the period in which grains remain airborne (on pollen dispersion stage). It is independent of the climate where the species live (Emberlin et al., 1993; El-Ghazaly et al., 1993). In the city of Mar del Plata, it was observed that rain in the months where most arboreal species are in bloom was higher in 1994. This year had the lowest airborne pollen counts. On November 1994, a lower rain amount and higher pollen concentration, compared to the same month in the previous year, occurred. This high number of pollen grains is imputable only to *Q. ilex* (see below).

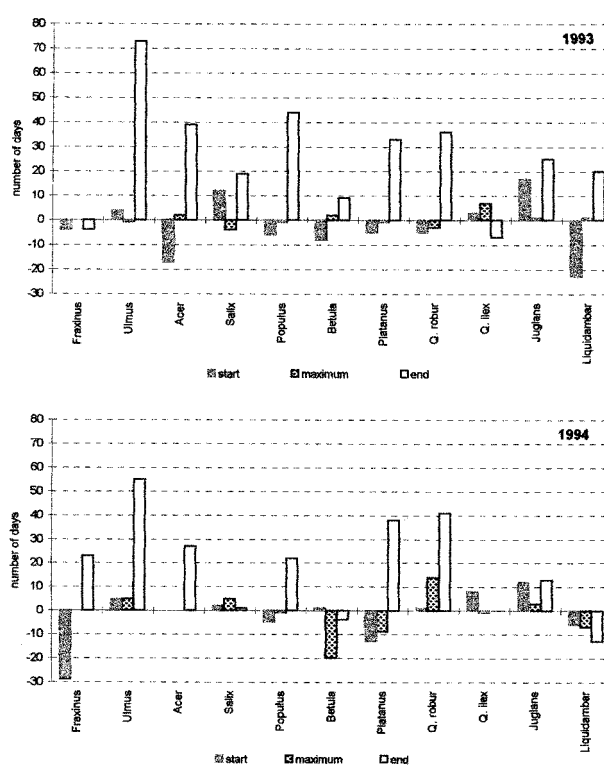


Figure 6. Differences (in days) between pollen and flowering periods for each phase in 1993 and 1994. Positive values indicate that flowering phases precede the corresponding pollen phase; negative values indicate the opposite relationship.

Table 2. Cumulative pollen percentages achieved at the start, maximum and end of the flowering period in 1993 and 1994.

	Start		Maximum		End	
	1993	1994	1993	1994	1993	1994
Mean	1.62	0.71	56.04	63.28	95.04	96.27
Standard deviation	2.44	1.75	25.60	31.69	5.9	6.58
Number of taxa	11	11	10	10	11	11

Except for *Q. ilex* and *Betula*, pollen amounts in the air of all the taxa considered were higher in 1993. The 1993 lower concentration of *Q. ilex* could be, in part, the result of depression effect of abundant precipitation registered during its pollination month (November). But the great differences in concentrations between years were so large that they cannot be attributed only to washout in the first year (14.18 gr/m³ in 1993 and 386.96 gr/m³ in 1994). In both years, predominant winds did not come from the place where *Q. ilex* trees are most abundant. Therefore, this atmo-

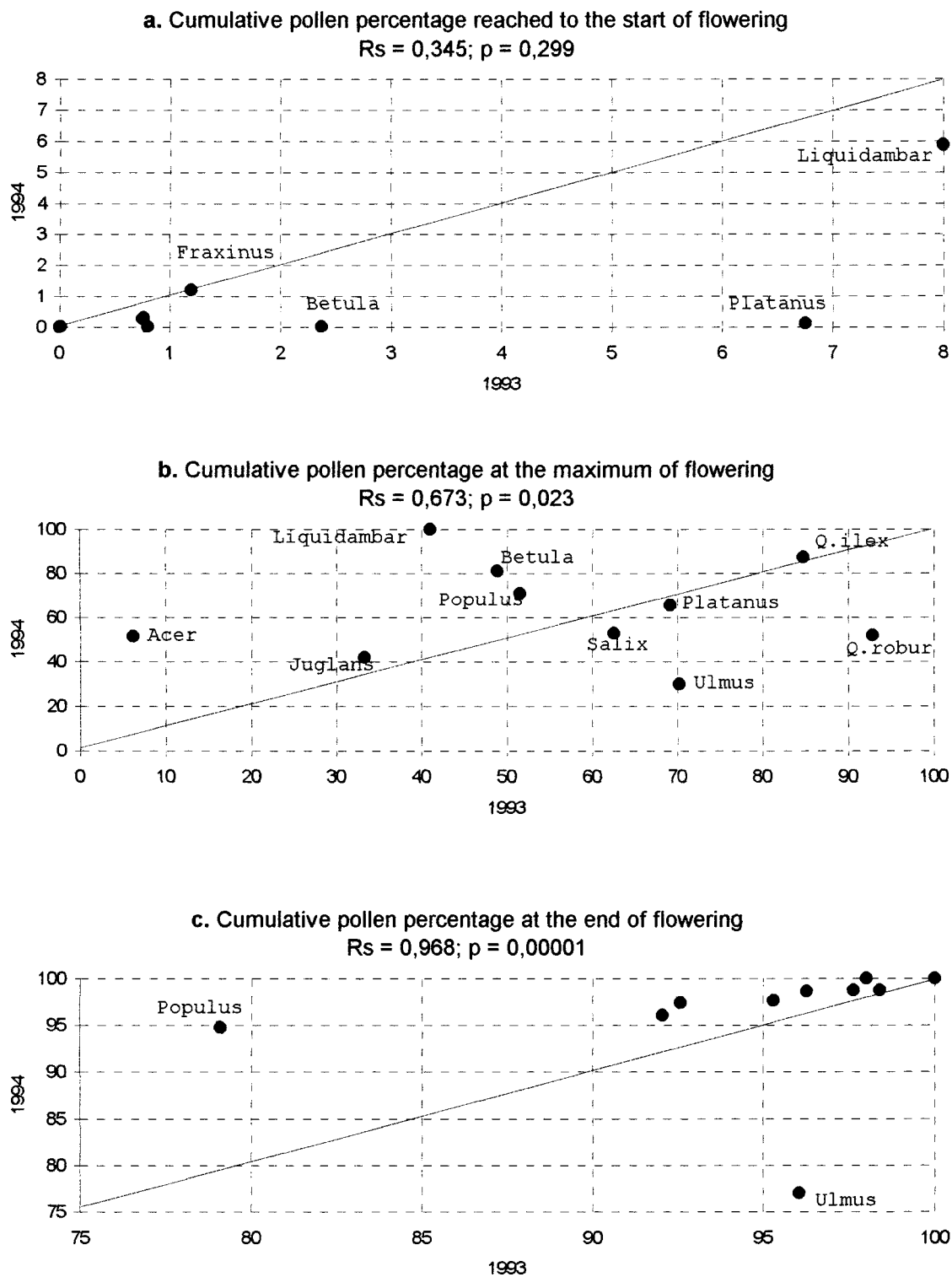


Figure 7. Cumulative pollen percentage achieved at each floral phenophase for each taxon. Spearman rank correlation coefficients are shown.

spheric variable did not seem to influence the different *Q. ilex* concentrations registered (Latorre, in press).

Factors other than climatic-meteorological controls seem to determine differential features observed in *Betula* and *Q. ilex*. A plausible explanation would be a biannual reproductive rhythm of both taxa. It was shown that physiological factors inherent to plant genetic constitution could be more important than ecological and/or meteorological influences (Madrigal Jiménez, 1997). The data presented here are not sufficient to establish definite conclusions. But this alternate pattern of two-years variability in concentrations was observed in both *Betula* and *Quercus* (Jäger et al., 1991; Emberlin et al., 1990, 1993; Nilsson and Persson, 1981). It was also found in other taxa like *Ulmus* (El-Ghazaly et al., 1993) and *Celtis* (Cadman et al., 1994). As support to this hypothesis, Spieksma et al. (1995) found that a basic rhythm of *Betula* pollen showed a tendency to synchrony along years among five cities geographically and climatically different. Nevertheless, this rhythm is not absolute and interruptions can occur as well as shifts of phase.

4.3 Relationship pollen – flowering

The duration of the pollen season of each taxon was longer in 1993 than in 1994, however, flowering season duration did not show important differences between years. Only the tree flowering periods seemed to be constant. The main differences between pollen season and opened flowers season were registered in the final phase. Pollen grains were registered, on average, 19 days after flowering had ended. Airborne pollen did not indicate exactly the flowering period length. Specifically, it did not show the final stage of flowering in a direct and explicit way.

A longer pollen period in 1993 could be related to better atmospheric conditions for dispersal (lower rain than in 1994). The emitted pollen remains in the air after flowering ends, although the amount of grains in the atmosphere is very low (O'Rourke, 1990). Another possibility is that plant sources are far away (Hjelmroos and van Hage-Hamsten, 1993; Mandrioli et al., 1980). Downtown vegetation can flower 1–2 weeks before the rest of city due to hot island effect (Emberlin, 1990; Caramiello et al., 1994). In Mar del Plata, temperature differences between urban – suburban areas are nearly 2 °C (Pérez, pers. com.). A relatively great amount of pollen after flowering ended was registered only in *Populus* the first year and in *Ulmus* the second year. In all cases, the origin of

these pollen grains is secondary (refloated or carried on from medium – long distance range) and it does not correspond to local – extralocal plant flowerings.

Many methods using aerobiological data were proposed (Hänninen, 1984; Sarvas, 1972) to determine the start and the final stages of flowering seasons. This is an important goal in ecological and genetics studies. Hänninen method (1984) is based on the statistical analysis of many years and is founded on theoretical hypothesis, but without empirical support by phenological observations. Flowering period could be defined with the aid of airborne pollen data and in agreement with pollen cumulated percentages until each floral phenophase. According to the results presented here, flowering periods would extend from the day where 1% of total pollen is reached, until the day where it has accumulated 96% of pollen emitted by the taxon. This technique of defining the season avoids distortions by incidental occurrences through localised trees not surveyed with abnormal flowering at the start, and resuspension at the end. Flowering maximum coincides, on average, with 60% of total pollen. A flowering period defined in this way, resembles different definitions about the principal pollen season (Nilsson and Persson, 1981; Lejoly-Gabriel, 1978; Emberlin et al., 1993, 1997). But here, it is based on the detailed observations of floral phenology and not only on aerobiological data.

The pollen percentages achieved at the moment of the maximum and the final flowering phases were similar between years and between taxa. On the contrary, cumulated pollen percentages until opened flowers were detected were variable between years due to some particular taxa. Data used here are not enough to allow a more precise estimation of the start of flowering. There are taxa whose variability concerning the flower opening is not uniform within or between individuals and it is larger than other species (Latorre and Bianchi, in press). Perhaps the start of flowering must be fitted particularly to each taxon (like in Hänninen, 1984) and/or by other means like daily temperature sums or cumulated heat units (Bowers and Dimmitt, 1994; Larsson, 1993). At this moment, studies are conducted to account for thermal requirements in the forecast of the start of pollination.

5. Conclusions

The seasonality of flowering trees is reflected by the airborne pollen spectrum. The pattern of tree

blooming, between the end of autumn and start of spring, is regularly observed every year.

Relative data are useful to describe a general characterisation of the aeroflora of a region because they maintain stable. On the contrary, absolute data show interannual variations in the final concentration reached by each taxon.

A joining effect of climatic and meteorological factors that determine and modify, respectively, the amount of pollen grains in the air exists. Greater concentration in 1993, compared to that found in 1994, would be the result of 1) favourable conditions before flowering started that would produce a higher pollen productivity, and 2) favourable meteorological conditions to airborne pollen dispersion during the flowering period. This second point is the centre of further studies.

In *Betula* (*B. pendula*) and *Q. ilex*, endogenous rhythms of flowering (genetic-physiologic) determine a biannual cycle that is independent of climatic conditions, and it seems to be the reason for the interannual variations observed. This pattern can be counteracted or increased by climatic conditions, but such effects can only be observed if several years are studied.

Flowering pattern is regular and constant year after year, but not the pollen pattern, specially in the final phase. Atmospheric characteristics must be considered to detect resuspension effects.

Flowering period, defined by means of the pollen data and based on phenological observations, comprises the period from the day when 1% of total annual pollen is registered until the day when 96% is reached.

To elucidate the way that the constraint factors act on the interannual pollen variability, a detailed investigation analysing separately the principal aerobiological steps (production and emission-dispersion) is required. The weather conditions before flowering constrain the pollen productivity. The triggering conditions for the bloom are subject to the yearly climatic variation. Phenological studies are potentially a powerful tool for monitoring the biotic response to climate change. Nevertheless, there could exist an endogenous rhythm in certain arboreal species that result from cyclic patterns in pollen production. The instantaneous effect of actual weather situation (meteorological conditions) during the period for which the pollen grains remain airborne does not influence at all the process of pollen production and flowering. It takes place after the pollen emission and during the dispersion aerobiological step.

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