

Comparative study of different methods for capturing airborne pollen, and effects of vegetation and meteorological variables

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Abstract The atmosphere of Mar del Plata city (Argentina) was monitored using three different pollen traps—Burkard, Rotorod, and Tauber—during a flowering season (mid-winter to springtime) in order to compare the diversity and amounts of pollen grains collected in each trap. Sixty three percent of taxa diversity was simultaneously recorded by all three apparatuses. The five most abundant types of pollen in the three traps were *Platanus*, *Ulmus*, *Quercus*, *Poaceae*, and *Fraxinus*. The Tauber trap contained the most pollen from taxa with the largest grains, and exclusively trapped ten pollen types with entomophilous characteristics. The amount of pollen in each trap and local/extra-local plant abundance were compared to elucidate the effect of the method used on the pollen–vegetation relationship. The correlation coefficients for total pollen were positive

and significant between all pairs of traps. The maximum peak was observed first in the Burkard trap, in agreement with an increase in temperature, but the general pattern in the three traps was similar, with a maximum in early spring. Opposite deviations from the mean value were observed for the Burkard and Tauber data; these deviations were associated negatively with wind speed and relative humidity, respectively. This paper discusses whether in some cases the pollen records could be used in an equivalent manner, although with some limitations.

Key words Plant-abundance representation · Volumetric and gravimetric pollen traps · Meteorological conditions

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1 Introduction

The concentration of pollen in the atmosphere is subject to variation with time because of the reproductive cycles of plants. Variation in pollen counts also depend on:

- 1 the distribution of vegetation and pollen dispersion according to air flow, which cause geographical variation of pollen abundance (Latorre and Bianchi 1997; Latorre 1999c; Latorre et al. 2001; Latorre and Caccavari 2006a); and
- 2 the sampling techniques used (Pedersen and Moseholm 1993).

Regarding the latter, different types of trap have been used in the last 50 years to study the pollen emitted to the atmosphere, but still no uniform criterion has been agreed.

There are two basic types of pollen sampler:

- 1 gravimetric traps which mainly collect the grains that fall by their own weight (Cundill 1998); and
- 2 volumetric traps that capture pollen grains and other particles directly from the atmosphere (Solomon and Mathews 1978).

The first type is used by phytogeographers and paleoecologists as a means of understanding the relationships between the actual pollen deposited and the communities present, and as a guide to interpreting fossil pollen assemblages. In this kind of trap, pollen grains are deposited by means of a process analogous to the incorporation of pollen into sediments. Thus these data can be used, in principle, as a modern analogue for reconstruction of paleo-environments (Hicks et al. 2001). The volumetric pollen trap is commonly employed in allergenic research, in order to warn sensitized patients when the allergens are detected. It is also used to study the factors affecting the reproductive rhythms of the flora and to analyse dispersion according to the geographical distribution of plants (Latorre 1999c; Levetin et al. 2000).

Many researchers believe that a volumetric instrument (Burkard or Rotorod) is a good tool for determining the composition of atmospheric pollen; its results should be more representative of regional vegetation (Gagnon and Comtois 1989). Also, traps exploiting the sedimentation process of capture (Tauber or Durham) would not be an adequate instruments for indicating regional sources because their results can over-represent local vegetation (O'Rourke 1990; Pérez et al. 2007), although location at ground level or use of one meter only could be reasons for this local over-representation.

Meteorological conditions can have an important effect on the differential capture of particles, depending on the type of trap used. The main factors are wind speed (O'Rourke 1990) and precipitation (Hall 1992), although the magnitude of the effect can depend on the size of the pollen grains. For example, at low wind speeds, larger grains are more likely to fall than smaller ones; for normal wind speeds, however, the capture efficiency of particles between

26 and 43 μm seems to be equal (Gregory 1973). On the other hand, Bhat and Rajasab (1989) found that volumetric and gravimetric traps are equally efficient for determination of the qualitative and relative contribution of the individual components of the total aeroflora.

Because of the great variety of results available, the purpose of this work was to elucidate how the sampling method can affect the pollen results obtained. The atmospheric conditions during capture of the pollen grains have also been evaluated. This work is focussed on a qualitative and quantitative comparison of data collected with three types of pollen trap, one gravimetric and the others volumetric. The final objective was to assess relative efficiency and representation of the nature of plant sources.

The possibility of using recent pollen grain values to provide a temporary scale for the recent past (Hicks 1974) is a topic which is being thoroughly investigated and developed by our research group. Thus, because the Tauber trap is used to monitor sedimentary deposition, we also tried to discover whether the abundance of plants with larger grains or the abundance of plants which are very near the trap are similar to the abundances obtained with a volumetric trap. The results could indicate whether interpretation of paleo-environmental data could underestimate the abundance of the taxa with small pollen grains and/or overestimate local vegetation. Finally, if the results from these two basic types of trap were similar, we could conclude that both records are comparable. In our work, information from volumetric traps which have been operating continuously for ten years in the Mar del Plata area (38°03' S 57°33' W) (Bianchi 1994; Latorre 1999c; Pérez 2000) could be used for general characterisation of the current pollen pattern which could then be compared with sedimentary pollen data from the Pampa grassland of Argentina (Majas et al. 1992; Pérez et al. 1996; Prieto 1996).

2 Materials and methods

The pollen content of the atmosphere at Mar del Plata (38°03' S; 57°33' W), a city in the Buenos Aires Province of Argentina, was analysed from mid-winter to the end of springtime (25 July to 15

November 1994). This period was chosen because the pollen concentrations are highest and the diversity of pollen types is greatest (Bianchi 1994). Three types of pollen trap were placed on the roof of the University building, at an approximate height of 20 m. The three traps were located 2 m apart to reduce variation related to the proximity of the pollen sources and so that their micro-environmental conditions were the same (Hall 1992).

The Burkard is a volumetric trap which works by suction (Hirst 1952), the Rotorod is a volumetric impact trap (Ogden and Raynor 1967), and the Tauber is a non-volumetric sedimentation trap (Tauber 1965). Burkard samples were analysed every 2 h, those from the Rotorod on a daily basis, and the Tauber trap was changed once a week. To make the data from the three traps comparable, calculation of pollen content was based on the longest period (i.e. weekly). For the Burkard and Rotorod traps the concentration is referred to a known volume of air, and standard counting methods are used. For the Burkard trap calculation is performed on the basis of 12 transversal transects at 200 $\times$ magnification; for the Rotorod calculation is based on two slender sticks that operate for 1 min every 9 min throughout the day, and analysis of the whole stick. The daily Rotorod and Burkard values were added to yield the final weekly data.

With the Tauber trap the number of grains obtained depends on the area of sedimentation. A foreign marker (*Lycopodium*) was added in order to calculate the absolute value within a sample. The counting technique applied was proposed by Bianchi and D'Antoni (1986). Briefly, to establish an acceptable pollen sum, i.e. to obtain a result that accurately represents the system analysed, "intervals of recount" were established, using a quantity of *Lycopodium* (e.g. 10 *Lycopodium* spores) as a unit of measure. In each recount interval the number of grains per taxon and the number of individual taxa determined were counted. To ensure the recount gave a valid result for the presence of significant taxa, a curve of "minimum area" according to Muller-Dambois and Ellenberg (1974), was drawn. The graph shows the intervals of the recount on the x-axis and the new taxa in each of the intervals on the y-axis. This curve increases rapidly at the beginning of the recount, and a "plateau" is reached when the increase in the area swept is not accompanied by a

significant increase in the number of taxa. The size of each recount unit is adjusted for each sample, because the pollen content of the samples is very variable. The final number of pollen grains counted per sample was never lower than 200 pollen grains (Nöetinger et al. 1994).

We used percentage data to compare pollen traps. The percentages enable general characterisation of the pollen patterns because the relative values are stable throughout the years (Latorre 1999c). Each percentage value for one type of trap was calculated independently but percentage values always refer to the same specified time period (the week). The beginning of the pollination period was set in the week when at least 1% of the total pollen concentration of the taxon was recorded.

The vegetation and the flowering data were obtained by Latorre (1997, 1999b, c) and the methods used are briefly described below.

The number of trees present in the streets, in the private external gardens, and in the public parks, was counted in an area of 2.25 km² with the pollen traps as the geographical central point. This area includes the local/extra-local vegetation (Prentice 1985) that is the main source of the pollen collected (Halwagay 1988).

The herbaceous plant species present were characterised monthly and the state of flowering was found to be seasonal. The first survey was in late June, the second in mid-September, and the third in November (Latorre 1999c). To compare flowering with the presence of pollen, only data from the second survey were used because this was the period when the concentration of pollen in the air was highest. Information about flowering species was grouped in taxonomic categories of family, according to pollen categories. The area covered by the herbaceous survey surrounds the pollen sampling point. The area comprised land adjacent to the pollen samplers and was bordered by railway lines. The study area was no further than 800 m from the pollen sampling point because that is the distance proposed by Moseholm et al. (1987) in which pollen from low-altitude sources, for example grasses and herbs, are mostly dispersed. Within this area six sub-areas with a length of 100 m and a width of approximately 20 m were selected. Sub-areas 1 and 2 were located to the northeast of the pollen samplers, the third to the east, the fourth to the south, and the fifth and sixth to the

southwest. In each sub-area, plots of 1 m × 1 m were set at random and from each individual plot the relative abundance of flowering plants in relation to the total plants was estimated. The following conversion scale derived from that proposed by Braun Blanquet (1972) was used:

- 1 1/5 × 100,
- 2 2/5 × 100,
- 3 3/5 × 100,
- 4 4/5 × 100, and
- 5 5/5 × 100.

The mean value derived from all the plots analysed per area was the datum used for comparison with pollen value.

Temperature, relative humidity and wind-speed data were measured by means of a weather station installed next to the traps; precipitation data were provided by the Servicio Meteorológico Nacional. Spearman rank correlations were used to compare the effectiveness of capture by each pollen trap and to identify the type of sampler that better reflects plant abundance. In addition, the correlation between the weekly percentage of total pollen (arboreal and non-arboreal) and the meteorological variables was calculated (Sokal and Rohlf 1979).

3 Results

3.1 Pollen pattern characteristics

Seventy-five types of pollen were identified; 47 were found in all three traps (common taxa). More pollen from 41% of these common taxa was found in the Tauber trap; most of these pollen grains (73%) were larger than 30 µm, with those of greater size being *Araucaria* and the Mimosoideae type. The highest diversity (65 pollen types) was also recorded for the Tauber trap; ten pollen types were only found in this trap (exclusive taxa). Nevertheless, these exclusive pollen types were present as very low proportions (smaller than 0.2%), with the exception of Solanaceae (0.9%) (Table 1).

Seventy-six percent of the pollen types did not reach 1% of total pollen throughout the analysed period. *Platanus*, *Ulmus*, *Quercus*, *Poaceae*, and *Fraxinus* were the most abundant taxa, and accounted for 62%, 67%, and 56% of the total pollen in

Table 1 Pollen types (taxa) with a contribution to the Mar del Plata spectrum below 1% (period July–November 1994)

TAXA	Burkard	Rotorod	Tauber
Aesculus	×	×	×
Alnus	×	×	×
Alternanthera			⊗
Ambrosia/Xanthium	×	×	
Apiaceae	×	×	×
Araucaria	×	×	×
Artemisia	×	×	×
Asteraceae Asteroideae	×	×	×
Asteraceae Cichorioideae			⊗
Brassicaceae	×	×	×
Caprifoliaceae			⊗
Carya	×	×	
Caryophyllaceae	×	×	×
Citrus	×		×
Corrigiola			⊗
Corylus	×	×	×
Cucurbitaceae	⊗		
Dodonea	×	×	×
Echium	×	×	×
Ephedra	×	×	×
Euphorbiaceae	×	×	×
Gomphrea		⊗	
Gynkgo	×	×	×
Indeterminate	×	×	×
Lamiaceae	×	×	×
Lauraceae	×	×	
Ligustrum	⊗		
Liquidambar	×	×	×
Liriodendron			⊗
Malvaceae			⊗
Mimosoideae	×	×	×
Monocotyledoneae	×	×	×
Myoporum	×	×	×
Myriophyllum	×		×
Nothofagus	×	×	×
Olea	×	×	×
Plantago	×	×	×
Primula			⊗
Prosopis	×	×	×
Proteaceae	×		×
Prunus	×	×	×
Ricinus	×	×	×
Rosaceae	×	×	×

Table 1 continued

TAXA	Burkard	Rotorod	Tauber
Rumex	×	×	×
Rutaceae	×		×
Salix	×	×	×
Saxifragaceae			⊗
Schinus	×	×	×
Solanaceae			⊗
Fagus type		⊗	
Tsuga type		⊗	
Tilia			⊗
Triglochin	×		×
Typha	×		×
Verbenaceae		×	×
Viburnum	×		×
Viola		⊗	

A cross indicates that the taxon is present; a encircled cross indicates that it is exclusive

the Burkard, Rotorod, and Tauber traps, respectively (Fig. 1).

The total relative values of each pollen type were highly correlated between traps. The percentage deviations from the general average obtained from the mean value for the three traps and for the 47 common taxa were similar for the Burkard and Rotorod but opposite to those for the Tauber (Table 2). The largest differences between Tauber pollen percentages and values obtained in the other traps were for *Ulmus* and *Platanus*. The first pollen type was most abundant in the Tauber trap; the second was least abundant in the same trap (Fig. 2a).

Correlations between the abundance of arboreal taxa in local/extra-local vegetation and in the three traps were positive and significant; the highest coefficient was that for the Rotorod trap, followed in decreasing order by the Burkard and Tauber traps (Table 3). *Platanus*, *Ulmus*, *Quercus*, and *Celtis* were the taxa with the highest pollen percentages in the three traps relative to the percentage of vegetation. They were not within the 95% confidence interval for estimating pollen abundance according to plant abundance (Fig. 2a).

For herbaceous taxa, the correlations between the abundance of flowering plants during the period of sampling and the abundance of pollen were significant for the Burkard and Rotorod traps only and non-significant but positive for the Tauber (Table 3). The

highest percentage of pollen was from the Poaceae, the smallest from the Apiaceae. Both types of pollen were not within the 95% confidence interval with regard to the value expected according to the abundance of plants in the vegetation near the traps. For Urticaceae in the Tauber trap there was an important difference compared with the other traps and with regard to the abundance of vegetation, with percentages pollen that exceed the percentage of flowering plants (Fig. 2b).

3.2 Total pollen pattern and its relationship with meteorological variables

The same general patterns were observed for total pollen variations in the three traps in the months studied (Fig. 3a). The temperature throughout this period increased gradually, in accordance with the season (late winter and spring); the frequent precipitation totalled 297 mm during the period (Fig. 3b). The relative humidity was, in general, high ($79.5 \pm 5\%$) and the average wind speed was 9.33 ± 2 km/h but varied throughout the period (Fig. 3c).

The maximum amount of pollen in the Burkard trap coincided with the maximum floral phenophase of the arboreal anemophilous community. Both maxima were recorded in the third week of September when the temperature increased by more than 4°C compared with the previous week, and with the wind speed and, despite the high relative humidity, rainfall of 42.5 mm. The largest numbers of pollen grains in the Rotorod and Tauber traps were recorded one week later, when the highest wind speed of the period occurred.

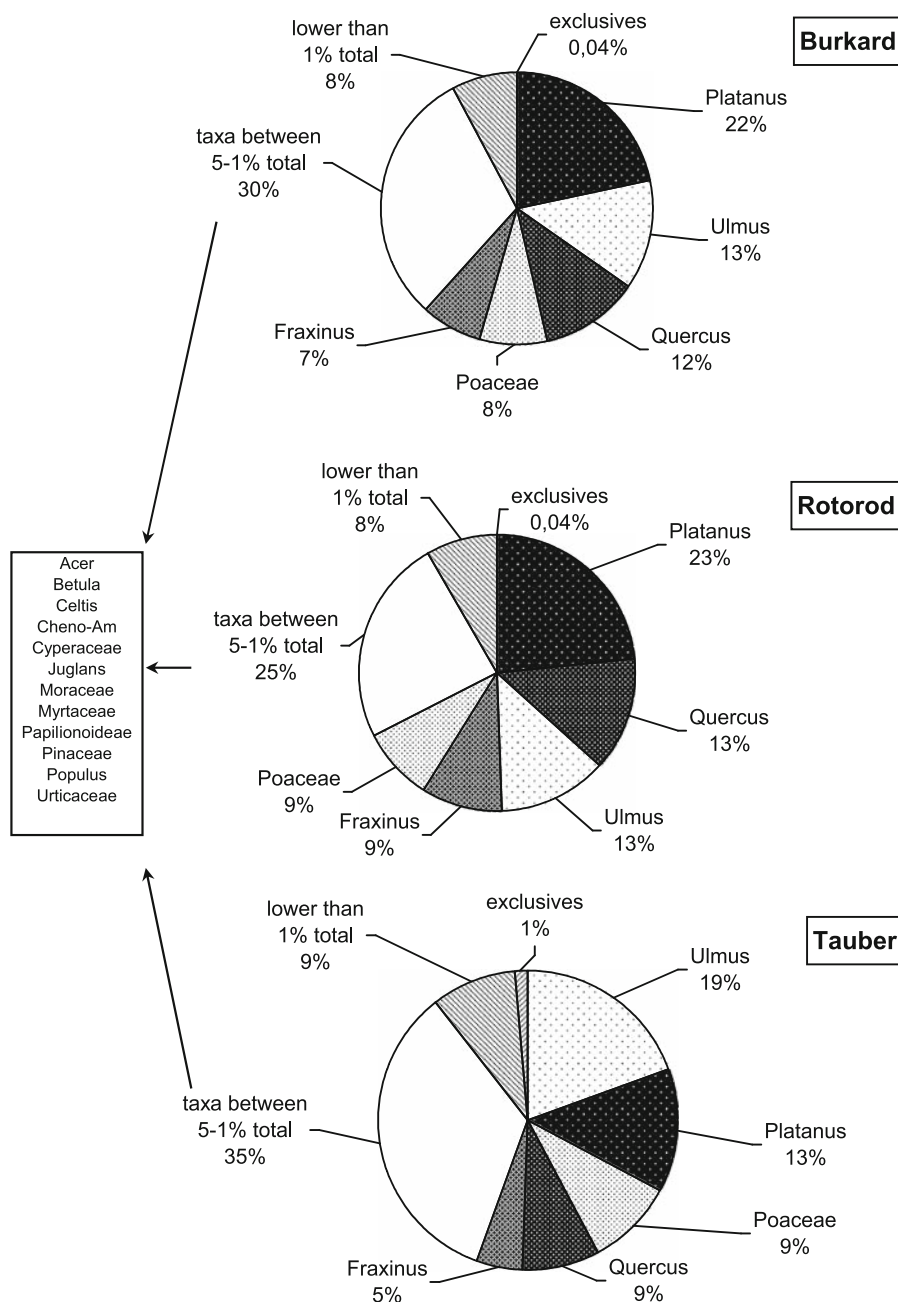
During the first three weeks of October the pollen content of the three traps decreased gradually. The maximum number of arboreal anemophilous species in flower was recorded during the first two weeks of October and started to decrease in the third week. Also in October an increasing number of arboreal entomophilous species and more than 50% of the herbaceous plants were in bloom. Considering the floral phenological development of the 25 most abundant arboreal anemophilous species, regarded as a “community” (Latorre 1997), the decline of the phenophase was recorded during October whereas its maximum coincided with the Burkard maximum pollen counts (third week of September). Simultaneously, a

progressive increase in temperature occurred. During the second week of October precipitation was the most abundant for the period (133.10 mm). The atmospheric pollen decrease of this period was not only related to precipitation but also to the low wind speed.

There was a positive correlation among the weekly data for total pollen in the traps; this means that if an

increase in the Burkard weekly amount occurred, it also occurred in the Rotorod and Tauber traps. The weekly amount of pollen also correlated positively with the weekly average temperature for all the traps, so an increase in pollen count coincided with an increase in temperature and a decrease in pollen count was significantly related to a decrease in temperature during the period, irrespective of the type

Fig. 1 Pollen composition in each trap



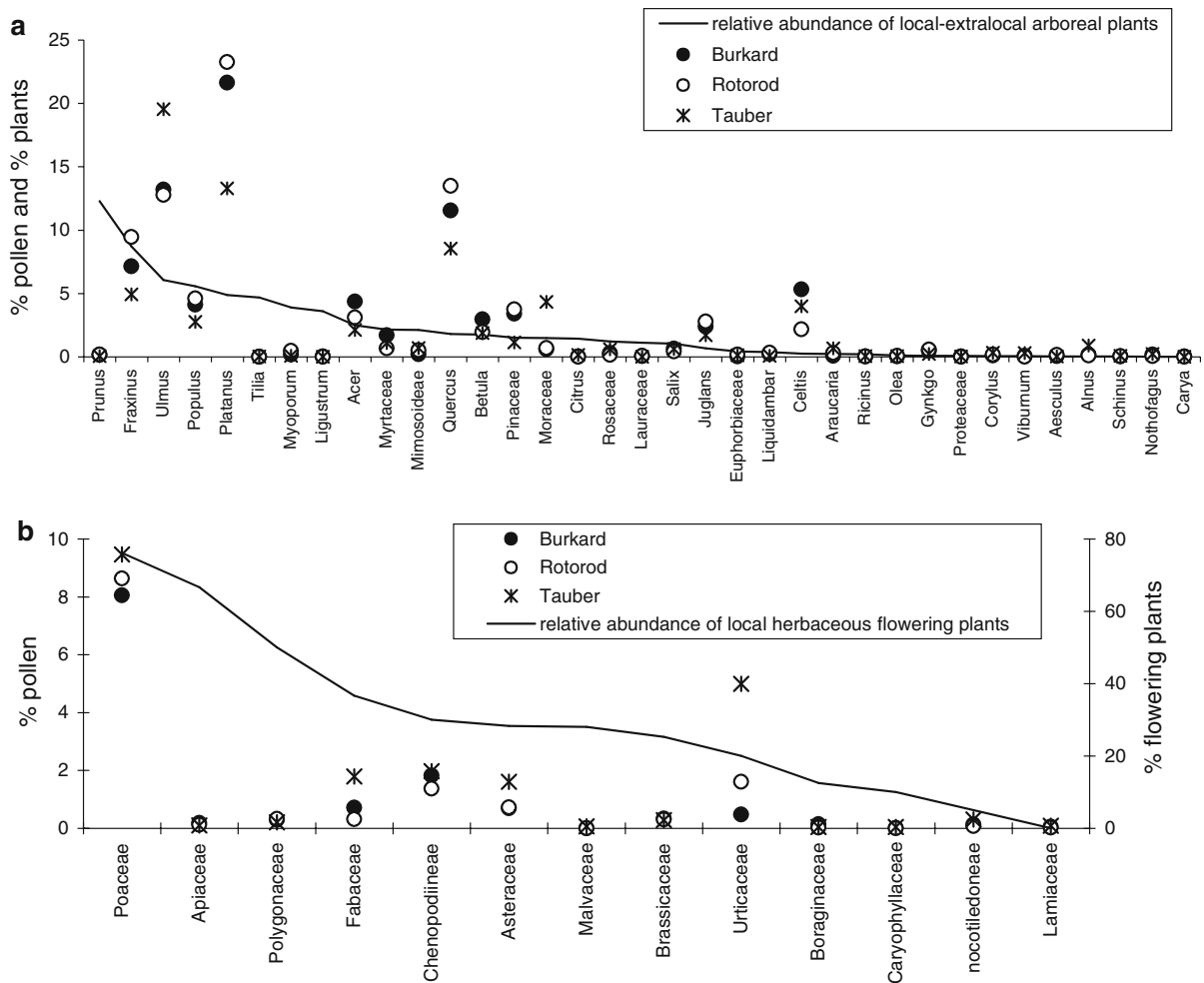


Fig. 2 Individual percentage values for each trap: (**a**, arboreal pollen types; **b**, non-arboreal pollen types) and percentage values for the abundance of plants in the surrounding vegetation

Table 2 Rank correlation coefficients between pairs of traps

	Taxa	Standard deviation
Burkard–Rotorod	0.90***	0.16
Rotorod–Tauber	0.85***	−0.76***
Tauber–Burkard	0.86***	−0.62***

Data correlated were percentage values of total pollen from each trap, for total pollen of common taxa ($n = 47$), and standard deviation from the mean value obtained from the average value for the three traps

*** $p < 0.001$

of trap. The percentage deviations from the average pollen values indicate particular variations in each trap that could be linked to atmospheric variables that affect capture differently, depending on the method

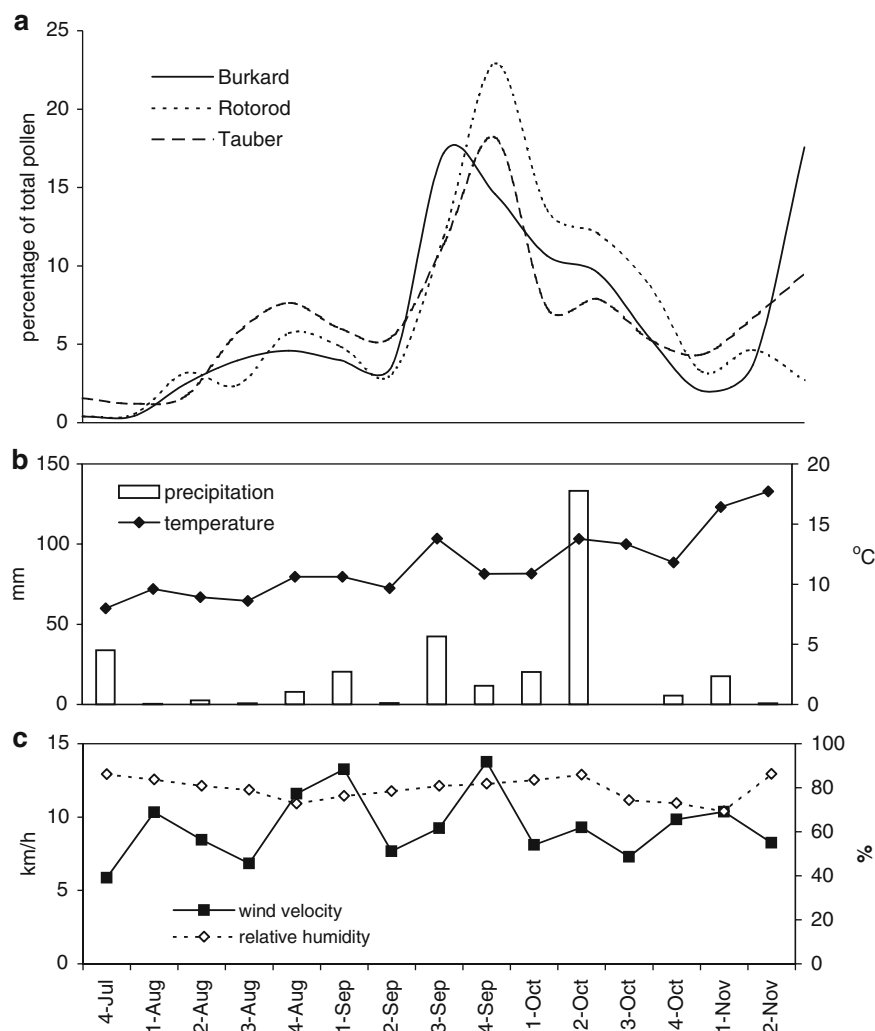
used. There was a negative correlation between differences between the Burkard and Tauber data; if in one week the Burkard trap recorded more pollen than the mean, the Tauber recorded less pollen than the mean; this negative correlation was significant.

Table 3 Rank correlation coefficient between individual pollen percentages from each trap and plant source percentages (34 genera or families of trees and 13 families of herbaceous plants)

	Arboreal vegetation	Herbaceous vegetation
Burkard	0.454**	0.637*
Rotorod	0.52***	0.575*
Tauber	0.401*	0.454 ns

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; ns: not significant

Fig. 3 Amounts (%) of total pollen collected with each trap (**a**), precipitation and temperature data (**b**), and wind velocity and relative humidity data (**c**) for every week during the study period



Deviations for the Burkard trap correlated negatively with wind speed and positively with relative humidity; in contrast, those for the Tauber trap were negatively correlated with the relative humidity (Table 4).

3.3 Taxa with more than 5% of the total pollen

The *Platanus* pollination pattern (Fig. 4a) had a unique peak in all three traps; in the Burkard, however, the maximum was reached one week before that in the others. Maximum pollen values in the Rotorod and Tauber traps and maximum floral phenophases of *Platanus* trees in the surrounding vegetation were observed simultaneously (between 16 September and 1st October). The start of the

pollination period was detected simultaneously in the three traps and coincided with the start of flowering period (14 September).

Fraxinus pollen (Fig. 4b) was collected throughout the period studied; one, two or three peaks of high values were observed depending on the pollen trap. Although in the urban vegetation there are three species that bloom successively: *F. excelsior*, *F. americana*, and *F. excelsior* var. *aurea*, the greatest percentage of this pollen type in the three traps was in agreement with the flowering period of *F. americana* (early September–mid of October). The flowering of *F. excelsior* began before the atmospheric monitoring started.

Celtis pollen reached 5% of total counts in the Burkard trap only; in the Tauber it was 4% and in the

Table 4 Rank correlation coefficients of weekly total pollen percentages and their standard deviations from the mean: between traps and with the meteorological variables

		Total pollen	Standard deviation
Burkard	Rotorod	0.68**	−0.36
Rotorod	Tauber	0.68**	−0.44
Tauber	Burkard	0.90***	−0.53*
Burkard	Temperature	0.66**	0.07
	Wind velocity	0.15	−0.52*
	Relative humidity	0.17	0.63*
	Precipitation	0.19	0.03
Rotorod	Temperature	0.51(*)	0.04
	Wind velocity	0.42	0.33
	Relative humidity	−0.18	−0.04
	Precipitation	0.44	0.13
Tauber	Temperature	0.62*	−0.37
	Wind velocity	0.37	0.14
	Relative humidity	0.06	−0.54*
	Precipitation	0.41	−0.26

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; (*) $p = 0.05$

Rotorod only 2%. There are two species that bloom successively; one (*C. australis*) is present in the local urban vegetation and the other (*C. tala*) is part of the natural vegetation forming small forests outside the city. The start of *Celtis* pollination period in the three traps (Fig. 4c) and the start of the *C. australis* flowering period were recorded simultaneously (14 September). The contribution of *C. australis* pollen to the Burkard trap was relatively low with a maximum of 6% of total *Celtis* pollen. In contrast, the *C. australis* pollen peaks in the Rotorod and Tauber were higher—27% and 19% of *Celtis* pollen, respectively. Seventy three percent of *Celtis* pollen caught by the Burkard trap could be attributed to *C. tala*; in the Rotorod and Tauber traps this contribution was lower (26% and 39%, respectively). The *C. tala* flowering period extended beyond the period studied.

Two *Quercus* species are present in the surrounding vegetation; their flowering periods are different. The *Q. robur* pollination period (Fig. 4d) started a week earlier in the Burkard trap and coincided with the beginning of its flowering period (14 September). Nevertheless, maximum and end of the pollination

period were simultaneously observed in all three traps; these events also coincided with *Q. robur* maximum floral phenophase (28 September and 21 October, respectively). In contrast, the *Q. ilex* flowering period started at the beginning of November with the maximum phase on 14 November; the floral phenophase ended in December. Only the Burkard and Tauber traps recorded a high proportion of pollen grains from these species (Fig. 4d).

The beginning of the *Ulmus* pollination period (Fig. 4e) was detected earlier in the Burkard and Tauber traps, in the same week as the *U. pumila* average flowering phenophase started (24 July). Two species are mainly represented in urban vegetation: *U. pumila* and *U. procera*. Maximum pollen counts were recorded at the same time in the three traps, but one week after the maximum flowering phase of both species had occurred. Relative amount of pollen during the week of maximum flowering was higher in the Burkard and Tauber traps.

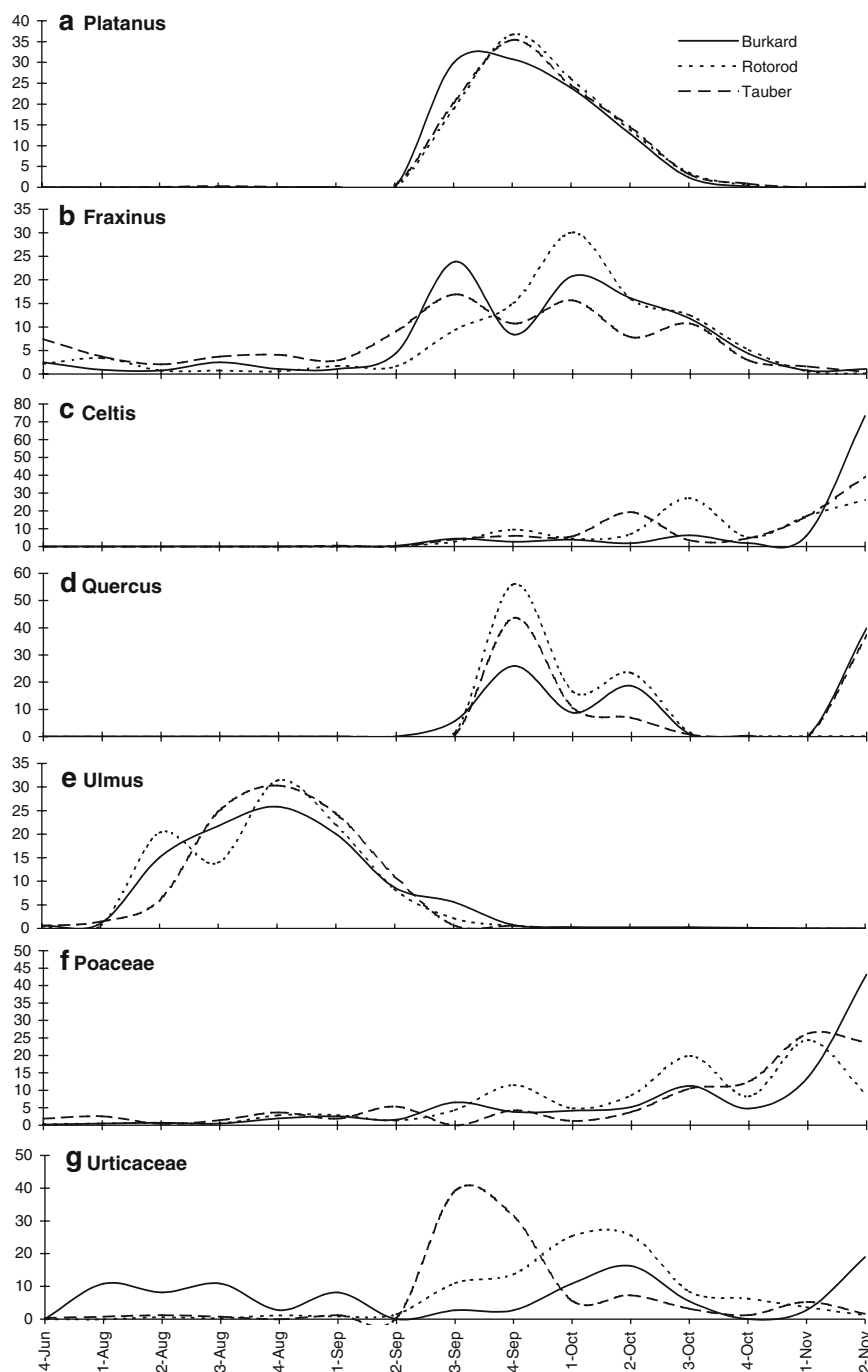
Poaceae pollen (Fig. 4f) arises from different species in the vegetation; the amount of this type of pollen becomes important in October. Poaceae pollen dominates the atmospheric spectrum between November and December (Latorre 1999c), thus the period analyzed in this work did not include the whole pollination period.

Urticaceae pollen (Fig. 4g) reached 5% of total pollen only in the Tauber trap; in this trap the pollen pattern had a single peak of high values in the second fortnight of September (70% of total Urticaceae pollen). In the Rotorod trap 50% of Urticaceae pollen was recorded in the first fortnight of October. In contrast, weekly differences between Urticaceae pollen levels for the Burkard trap were smaller than for the other traps.

4 Discussion

The same great atmospheric pollen diversity observed previously in Mar del Plata, especially in springtime from Burkard records (Latorre 1999a; Latorre and Bianchi 1997), is reflected in the results from the three types of sampler studied here. Nevertheless, only five pollen types (*Platanus*, *Ulmus*, *Quercus*, *Poaceae*, and *Fraxinus*) account for more than half of the total pollen, in agreement with previous results for the same place (Latorre 1993; Latorre

Fig. 4 Pollen curves from taxa with a contribution >5% of the total pollen in each pollen trap. The *X-axis* shows the weeks and the *Y-axis* the pollen percentages



and Pérez 1997). Sixty three percent of pollen types were observed simultaneously in the three traps and for half of these the values were greater in the Tauber trap. The exclusive pollen types came mainly from zoophilous plants and the largest number of these was collected by the Tauber trap, but in relatively small

proportions. The greater size and the thicker walls of entomophilous grains (Faegri and van der Pijl 1979), which facilitate sedimentation by gravity, could be part of the reason for this important presence in the Tauber trap. The relatively large amount of Urticaceae found in the Tauber trap seems to be an

exception. Although it would be expected that differences between traps are primarily because of differences in the capturing method, they may, in part, be because of the size of the surface area of deposition/impact, and not the counting procedure; this last possibility should be taken into consideration. It is not plausible to achieve equality in the three counting methods; equivalence between them, only, is expected. Because the Tauber trap records a great diversity of pollen, in addition to economic issues and ease of installation, it could be suitable for bio-geographic studies in which results could be well correlated with the composition of the vegetation in the study area, especially in relation to the arboreal taxa, although it should not be forgotten that Tauber is also suitable for study of herbaceous vegetation. Smaller proportions of exclusive (or entomophilous) types were recorded by the Burkard trap. An analogous example appears in Belmonte et al. (2000), where a Burkard trap is compared with a Cour trap. A greater proportion of small grains was found in the Burkard, and a minor proportion of grains of greater size.

The Burkard and Rotorod traps are more similar to each other than they are to the Tauber trap in relation to the total individual values, although no significant difference was observed between each pair of traps. According to Gagnon and Comtois (1992) and Solomon et al. (1980), the Burkard and Rotorod traps are also the most similar samplers, and both are different from the trap that collects by sedimentation (in those instances a Durham trap, 1946). Here the differences from the gravimetric trap are mainly because of its greater relative collection of *Ulmus* pollen and its minor uptake of *Platanus* type. Again, the relative size of the grains may be important (*Ulmus*: 28 μm and *Platanus*: 17 μm).

The association between the Tauber trap and the abundance of flowering herbaceous plants was not significant, but was positive. In general, the greater discrepancies between non-arboreal pollen and herbaceous vegetation for the three traps clearly correspond to completely entomophilous taxa (e.g. Apiaceae, Boraginaceae), and this is different from the relationship of other taxa with species with different types of pollination (e.g. Asteraceae, Monocotyledoneae), or from the completely anemophilous taxa (e.g. Poaceae). Even though abundance of the local and extra-local arboreal vegetation was represented by the three traps,

the best relationships were observed for the Rotorod and then for the Burkard. The abundance of *Platanus*, *Ulmus*, *Quercus*, and *Celtis* vegetation was overestimated not only by the Burkard (Latorre 1999b) but also by the Rotorod and Tauber traps. This is mainly because of anemophily, high pollen productivity, and the proximity of the sources (Latorre et al. 2001).

The total pollen pattern is almost similar for the three traps, with maxima in the spring. Nevertheless, in the Burkard trap maximum pollen was recorded one week previously, in agreement with an important increase in temperature.

Values of weekly total pollen were better related for the Burkard and Tauber samplers; they also had a significant and positive association with temperature. Gagnon and Comtois (1992) observed that these two traps were most similar in comparison with the Rotorod. The concentration increase with increasing temperature could be related to the floral opening rhythm of the emitting plants. Nevertheless, the deviations from the general average for the Burkard and Tauber traps were in opposite directions. Because the samplers were in the same place, the only external factors that could account for the relatively different results were atmosphere conditions in relation to the type of pollen captured (O'Rourke 1989). For the Burkard trap the greater deviations occurred at lower wind speed. When high temperature causes anthesis, high speed wind releases the pollen grains from the exposed anthers to the atmosphere. The grains are continuously collected by this sampler and the particles are captured in the direction in which the wind blows. Variations of pollen concentration in the Burkard trap seem to be independent of relative humidity and precipitation, at least if these are not extremely high. One explanation could be that the other pollen traps (specially the Tauber) are more sensitive to relative humidity. In relation to this, greater deviations are observed for the Tauber when the relative humidity is lower. A high relative humidity is associated, in general, with greater precipitation (so pollen is washed from the atmosphere; Hall 1992), or with low wind speeds. These weather conditions are favourable for deposition by gravity. Also the effect could be related to hydration of the pollen grains; the sedimentation speed could vary substantially with greater volume. According to Gagnon and Comtois (1992), these meteorological variables (wind speed and precipitation) better

explain the variations between volumetric and gravimetric traps. On the other hand, the results from the Rotorod are most constant throughout time and do not seem to be as affected by the meteorological conditions as the others, at least by the variables considered.

The pollen types present every week of the period in all three traps are from taxa represented in the vegetation by species which have different blooming requirements, for example Poaceae, Asteraceae, Myrtaceae, *Fraxinus*, and Pinaceae. This is consistent with the multispecific origin of each taxon (Trigo et al. 1996)—Poaceae: *Bromus unioloides*, *Hordeum* sp., *Lolium multiflorum*, *Briza subaristata*, *Stipa papposa*, *Poa* spp.; Asteraceae: *Aster squamatus*, *Bidens laevis*, *Calendula arvensis*, *Conyza serrana*, *Crisanthemum* sp, *Galinsoga parviflora*, *Matricaria chamomilla*, *Picris echioides*, *Senecio mikanioides*, *Senecio pinnatus*, *Sonchus asper*; Myrtaceae: *Callistemon lanceolatus*; *Eucalyptus camaldulensis*, *E. cinerea*, *E. globulus*, *E. siredoxylon*, *E. tereticornis*, *Luma apiculata*; *Fraxinus*: *Fraxinus americana*, *F. excelsior*, *F. excelsior* var. *aurea*, *F. ornus*; Pinaceae: *Abies* sp., *Cedrus atlantica*, *C. deodara*, *Picea glauca*, *Pinus* spp., *Pseudotsuga mentziessi* (Latorre 1999c). On the other hand, only for a small number of pollen types was the maximum concentration recorded by the three traps in the same week; this is another significant difference between the traps. Nevertheless, particularly for *Fraxinus*, a large number of pollen peaks was recorded, irrespective of the trap used, because of the high intraspecific variability and the high variation within each tree in respect of the flowering phases (Latorre and Bianchi 1998).

The Burkard was the most efficient sampler, detecting the low individual concentrations of taxa (i.e. before the increase to the maximum) that indicate the beginning of the initial floral phenophases of the plants (*Q. robur*, *Platanus*, *Ulmus* and *Q. ilex*; the last two with Tauber data also). The Burkard also recorded pollen of regional origin (*Platanus* in part and *Celtis tala*) and local pollen (*Q. ilex* and *C. australis*) earlier than the other traps (Latorre and Bianchi 1997; Latorre et al. 2001). The greater sensitivity of the Burkard record makes it more suitable for studies in which it is important to detect low concentrations, for example, in allergy

studies and medicine and when the objective is to observe the dynamics of flowering.

Outside cities, and with the intention of studying the composition of the natural vegetation, pollen monitoring with volumetric samplers could be difficult to perform, because these apparatuses require particular installation and maintenance guidelines, and secure conditions to avoid vandalism. In natural places the Tauber trap could fit this purpose better (Latorre and Caccavari 2006b). This is also true because the Tauber trap seems to record the highest pollen diversity (especially because it records entomophilous types) and because quantitative differences are not so important.

5 Conclusions

- *Platanus*, *Ulmus*, *Quercus*, *Fraxinus* and Poaceae totalled more than 50% of pollen collected in the three traps. These arboreal genera correspond to the most abundant trees planted in the city and the grasses are the most abundant anemophilous herbaceous plants present in the terrain and parks.
- Tauber registered high diversity and a high proportion of entomophilous pollen types. Thus, the Tauber is an important tool for biogeographic characterization of a region, also taking into account the low cost and easy installation.
- The Burkard trap record the anthesis progress of different taxa more accurately, especially for the anemophilous types. High pollen concentrations were related to the increase in temperature. The Burkard trap also enabled more sensitive detection of pollen present at low concentrations, a fundamental aspect of allergy medicine.
- The Burkard and Rotorod traps resulted in similar representation of pollen abundance with regard to individual plant abundance.
- The Burkard and Tauber traps gave similar results for weekly total pollen levels, although deviations were in opposite directions, probably because of different effects of wind speed and relative humidity.
- Results from the Burkard, Rotorod, and Tauber traps all reflected a similar qualitative and relative pollen spectrum but each has particular utility in different research areas. Although it would be very interesting to compare absolute data in some

way, results from the Burkard and Rotorod traps are for a known volume of air within which the particles are contained whereas those for the Tauber are for an area of deposition, so this kind of comparison is not possible.

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References

- Belmonte, J., Canela, M., & Guàrdia, R. A. (2000). Comparison between pollen data obtained by Hirst and Cour sampling methods. *Aerobiologia*, 16, 177–185. doi: [10.1023/A:1007628214350](https://doi.org/10.1023/A:1007628214350).
- Bhat, M. M., & Rajasab, A. H. (1989). Efficiency of vertical cylinder spore trap and seven day volumetric Burkard spore trap in monitoring airborne pollen and fungal spore. *Grana*, 28, 147–153.
- Bianchi, M. M. (1994). *El muestreo aerobiológico en Mar del Plata. Aportes de una nueva metodología al análisis de polen. Su aplicación en el diagnóstico de la polinosis. Monograf. 10*. Buenos Aires: Acad. Nac. Cs. Ex., Fís. y Nat.
- Bianchi, M. M., & H. L. D'Antoni (1986). *Deposición del Polen Actual en los alrededores de Sierra de Los Padres (Pcia de Bs As)*. Actas del IV Congreso Argentino de Paleontología y Bioestratigrafía, Mendoza, Noviembre 1986, pp. 16–27.
- Braun-Blanquet, J. (1972). *Plant sociology. The study of plant communities* (p. 439). New York: Hafner Pub. Co., INC.
- Cundill, P. (1998). A comparison of results from two designs of sedimentation pollen trap. *Grana*, 37, 49–52.
- Durham, O. C. (1946). The volumetric incidence of airborne allergens. IV. A proposed standard method of gravity sampling counting and volumetric interpolation of results. *The Journal of Allergy and Clinical Immunology*, 17, 79–86.
- Faegri, K., & van der Pijl, L. (1979). *The principles of pollination ecology* (p. 244). Pergamon Press: London.
- Gagnon, L., & Comtois, P. (1989). Urban aeropalynology: Is one sampling station representative of the pollen rain? In P. Comtois (Ed.), *Aerobiology health environment, A symposium* (pp. 43–54). Montréal: Université de Montréal Press.
- Gagnon, L., & Comtois, P. (1992). Peut-on comparer les résultats de différents types de capteurs polliniques? *Grana*, 31, 125–130.
- Gregory, P. H. (1973). *The microbiology of the atmosphere*. New York: Halstead press.
- Hall, S. A. (1992). Comparative pollen influx at a nine-array in the grad prairie of Northern Texas. *The Texas Journal of Science*, 44(4), 469–474.
- Halwagy, M. H. (1988). Concentration of airborne pollen at three sites in Kuwait. *Grana*, 27, 53–62.
- Hicks, S. (1974). A method of using modern pollen rain values to provide a time-scale for pollen diagrams from peat deposits. *Memoranda soc. Fauna Flora Fennica*, 49, 21–33.
- Hicks, Sh., Tinsley, H., Huusko, A., Jensen, Ch., Hättstrand, M., Gewreasimides, A., et al. (2001). Some comments on spatial variation in arboreal pollen deposition: First record from the Pollen Monitoring Programme (PMP). *Review of Palaeobotany and Palynology*, 117, 183–194. doi: [10.1016/S0034-6667\(01\)00086-0](https://doi.org/10.1016/S0034-6667(01)00086-0).
- Hirst, J. M. (1952). An automatic volumetric spore trap. *The Annals of Applied Biology*, 39, 257–265. doi: [10.1111/j.1744-7348.1952.tb00904.x](https://doi.org/10.1111/j.1744-7348.1952.tb00904.x).
- Latorre, F. (1993). *Relación entre la concentración de polen en la atmósfera y la vegetación arbórea de la ciudad de Mar del Plata*. Degree Thesis, Universidad Nacional de Mar del Plata, p. 74.
- Latorre, F. (1997). Comparison between phenological and aerobiological patterns of some arboreal species of Mar del Plata (Argentina). *Aerobiologia*, 13, 49–59.
- Latorre, F. (1999a). Differences between airborne pollen and flowering phenology of urban trees with reference to production, dispersal and interannual climate. *Aerobiologia*, 15, 131–141. doi: [10.1023/A:1007523316024](https://doi.org/10.1023/A:1007523316024).
- Latorre, F. (1999b). Variaciones interanuales del polen en la atmósfera de Mar del Plata en relación a la fenología floral. Caso especial *Quercus* (Fagaceae). *Publicación Especial Ameghiniana*, 6, 81–84.
- Latorre, F. (1999c). *El polen atmosférico como indicador de la vegetación y de su fenología floral*. Doctoral Thesis, Universidad de Buenos Aires, p. 244.
- Latorre, F., & Bianchi, M. M. (1997). Relación entre la concentración polínica atmosférica y la vegetación arbórea de Mar del Plata (Argentina). *Polen*, 8, 43–59.
- Latorre, F., & Bianchi, M. M. (1998). Relationships between flowering development of *Ulmus pumila* and *Fraxinus excelsior* and their airborne pollen. *Grana*, 37, 233–238.
- Latorre, F., & Caccavari, M. A. (2006a). *Comparación aerobiológica de un ambiente natural (Parque Nacional Pre-Delta) y un ambiente urbano (Diamante)*. Paper presented at the IX Jornadas de Ciencias Naturales del Litoral y Reunión Argentina de Ciencias Naturales, Paraná, p. 78.
- Latorre, F., & Caccavari, M. A. (2006b). Deposición polínica anual en el Parque Nacional Pre-Delta (Entre Ríos, Argentina). *Revista del Museo Argentino Ciencias Naturales, n.s.*, 8(2), 195–200.
- Latorre, F., & Pérez, C. F. (1997). One year of airborne pollen sampling in Mar del Plata (Argentina). *Grana*, 36, 49–53.
- Latorre, F., Romero, E. J., & Mancini, M. V. (2001). Representatividad de la vegetación en el espectro de polen atmosférico de la ciudad de Mar del Plata (Argentina). *Publicación Especial Ameghiniana*, 8, 119–124.
- Levetin, E., Rogers, C. A., & Hall, S. A. (2000). Comparison of pollen sampling with a Burkard spore trap and a Tauber trap in a warm temperate climate. *Grana*, 39, 294–302. doi: [10.1080/00173130052504333](https://doi.org/10.1080/00173130052504333).
- Majas, F. D., Noetinger, M., & Romero, E. J. (1992). Airborne pollen and spores monitoring in Buenos Aires city: a

- preliminary report. Part I. Trees and shrubs (AP). *Aerobiologia*, 8, 285–296. doi:[10.1007/BF02071637](https://doi.org/10.1007/BF02071637).
- Moseholm, L., Weeke, R. E., & Peterson, B. N. (1987). Forecast off pollen concentration of Poaceae (Grasses) in the air by Time Series Analysis. *Pollen et Spores*, 29(2–3), 305–322.
- Müller-Dombois, D., & Ellenberg, H. (1974). *Aims and methods of vegetation ecology* (p. 547). New York: Wiley.
- Nöetinger, M., Romero, E. J., & Majas, F. D. (1994). Airborne pollen and spores monitoring in Buenos Aires city: A preliminary report. Part II. Herbs, weeds (NAP) and spores. General discussion. *Aerobiologia*, 10, 129–139. doi:[10.1007/BF02459227](https://doi.org/10.1007/BF02459227)
- Ogden, E. C., & Raynor, G. S. (1967). A new sampler for airborne pollen: The Rotoslide. *Journal of Allergy*, 40, 1–11.
- O'Rourke, M. K. (1989). Relationships between airborne pollen concentrations and weather parameters in the arid environment. In P. Comtois (Ed.), *Aerobiology health environment, A symposium*. Montréal: Université de Montréal Press.
- O'Rourke, M. K. (1990). Comparative pollen calendars from Tucson, Arizona: Durham vs. Burkard samplers. *Aerobiologia*, 6, 136–140. doi:[10.1007/BF02539105](https://doi.org/10.1007/BF02539105).
- Pedersen, B. V., & Moseholm, L. (1993). Precision of the daily pollen count. Identifying sources of variation using variance component models. *Aerobiologia*, 9, 15–26. doi:[10.1007/BF02311366](https://doi.org/10.1007/BF02311366).
- Pérez, C. F. (2000). *Caracterización de la nube polínica y determinantes meteorológicos de la dispersión del sistema urbano-rural de Mar del Plata*. Doctoral Thesis, Universidad Nacional de Mar del Plata, p. 144.
- Pérez, C. F., Stutz, S. M., Latorre, F., & Pastorino, S. (1996). *Patrones de dispersión-depositación polínica en el área de las lagunas Mar Chiquita y Los Hinojales, Pcia. De Buenos Aires. Resultados preliminares*. Paper presented at the XXV Jornadas Argentinas de Botánica, Mendoza, p. 229.
- Pérez, C. F., Stutz, S., Latorre, F., & Pastorino, S. (2007). Depósito polínico en la laguna de Mar Chiquita Buenos Aires. *Boletín de la Sociedad Argentina de Botánica*, 42(2), 125.
- Prentice, C. (1985). Pollen representation, source area and basis size: unified theory of pollen analysis. *Quaternary Research*, 23, 76–86.
- Prieto, A. R. (1996). Late quaternary vegetational and climatic change in the Pampa grassland of Argentina. *Quaternary Research*, 45, 73–88. doi:[10.1006/qres.1996.0007](https://doi.org/10.1006/qres.1996.0007).
- Sokal, R. R., & Rohlf, F. J. (1979). *Biometría. Principios y métodos estadísticos en la investigación biológica*. Madrid: H. Blume.
- Solomon, W. R., & Mathews, K. P. (1978). Aerobiology and inhalant allergens. In E. Addleton, Ch. Reed, & E. Ellis (Eds.), *Allergy principles and practice*. Missouri: The C. Mosby Co.
- Solomon, W. R., Burge, H. A., Boise, J. R., & Becker, M. (1980). Comparative particle recoveries by the retracting Rotorod, Rotoslide and Burkard spore trap sampling in a compact array. *International Journal of Biometeorology*, 24, 107–116.
- Tauber, H. (1965). Differential pollen dispersion and the interpretation of pollen diagrams. *Geological Survey of Denmark, 2nd. sec.*, 89, 34–41.
- Trigo, M. M., Cabezudo, B., Recio, M., & Toro, F. J. (1996). Annual, daily and diurnal variation of Urticaceae airborne pollen in Málaga (Spain). *Aerobiologia*, 12, 85–90.