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Comparison of pollen sampling with a Burkard Spore Trap and a Tauber Trap in a warm temperate climate

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Aerobiological data have been widely used by many scientists, including those that study modern flora as well as those wishing to reconstruct past vegetational associations. Burkard (Hirst-type) volumetric spore traps are widely used instruments for studying airborne pollen, while Tauber traps are typically used to analyze pollen deposition. The present study compared the pollen collected by these two methods in Tulsa, Oklahoma a warm temperate area with year-round pollen. There was a strong correlation between the pollen influx from the Tauber traps and cumulative sum of average daily airborne pollen concentrations recorded with the Burkard spore trap over the course of 12 months from 1 Feb 1997 through 1 Feb 1998. The correlation coefficient between all taxa over the 12 months was 0.914; while the correlation coefficient for the monthly totals was 0.972. The data showed that both methods reflected local anemophilous vegetation although variations occurred in the prevalence recorded by both samplers.

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Aerobiological data are widely used by members of the medical community to describe and predict atmospheric pollen and spore concentrations in an effort to help those sensitive to aeroallergens. Botanists, mycologists, plant pathologists and ecologists utilize aerobiological data to study factors influencing the reproductive biology of the present day flora and mycota and to study the dispersal and distribution of various taxa. These researchers believe that a volumetric instrument such as a Burkard-type spore trap is needed to accurately determine the composition of the atmosphere and that gravity devices are not adequate. Aerobiological data are also used by paleoecologist, geologists, and archeologists who want to understand the relationship between modern pollen deposition and modern plant communities as a guide to interpreting former plant communities using fossil pollen records. These scientists rely heavily on annual influx data from Tauber traps and sedimentary samples to provide an assessment of the atmospheric pollen rain, which serves as a modern analog to reconstruct paleoenvironments.

Burkard spore traps are widely used for sampling the bioaerosol composition of the atmosphere. These volumetric samplers are based on the Hirst spore trap (Hirst 1952, Gregory 1973). Air is drawn in at 10 liters/min and airborne particles are deposited on a sticky tape mounted on a drum. Analysis of the tape provides airborne concentrations of pollen and spores. Sampling efficiencies are generally reported to be high; however, particle size, wind velocity, and type of adhesive all affect sampling efficiency (Lacey & Venette 1995). Fægri & Iversen (1989) suggest that the effects of wind speed on the Burkard sampling efficiencies are not completely known. Data from various studies show conflicting results regarding trapping efficiencies, with one study showing efficiencies ranging from 62.4% to 93.8% over a range of wind speeds and another study finding greater than 90% efficiencies for the same spores at the same wind speeds (Hirst 1953, Lacey & Venette 1995). For unbiased particle collecting, flow velocity in the orifice of the sampler should equal prevailing wind speeds; however, in the natural environment, isokinetic conditions rarely persist for any length of time (Solomon et al. 1980). Sampling efficiencies also decrease for particles smaller than 5.0 μm (Willeke & Macher 1999); however, this is below the size range of all pollen and many spores. Generally speaking, Hirst-type spore traps provide a reliable assessment of both the air flora and air spora (Burge 1992).

Tauber traps are non-volumetric sedimentary samplers that rely on gravity to assess the composition of the atmosphere. This is the most widely used device for long-term studies of airborne pollen, especially in remote locations where electricity is not available. The trap consists of curved lid with a central hole approximately 5 cm in diameter. The aerodynamic lid, which is wider than the cylindrical jar beneath, escapes the turbulence that would be caused by the lip of the jar (Moore et al. 1991). Pollen is collected by this trap by processes that are analogous to the incorporation of pollen into sediments; therefore, facilitating the comparisons between present day and paleoenvironments (Hicks 1992).

Because the Tauber traps rely on gravity, it has been suggested that the deposition into these traps may not reflect true atmospheric composition but be biased toward the larger and heavier pollen types. Peck (1972) found this distortion in the pollen spectrum during tests in turbulent water, and Tauber (1974) also found that trapping efficiencies varied with wind speeds, "especially for large pollen grains." At wind speeds of 2 m/sec the trapping efficiencies of various test particles (ranging from 26 to 43 µm) were equal. However, at wind speeds below 2 m/sec trapping efficiencies varied positively with pollen size and above 2 m/sec trapping efficiencies were negatively related to pollen size.

Fægri & Iversen (1989) maintain that the use of Tauber traps has provided an understanding of pollen transport and deposition; however, they went on to state that the deposition in the traps was not "natural." Settling was only effective in the absence of wind, and generally occurred at night. However, Gregory (1973) asserted that the outdoor air is never calm and the effect of gravity is insignificant. Wind tunnel experiments have shown that sedimentation is negligible at wind speeds at or above 2 m/sec. Under normal atmospheric wind speeds, impaction and turbulent deposition may therefore be more important mechanisms for deposition.

Grosse-Brauckmann & Stix (1979) studied the relationship between yearly pollen deposition (Tauber influx) and airborne pollen counts (cumulative Burkard sum) at several sites in Germany. Although their data showed a great deal of variability between sites, they suggested that the ratio of deposition to airborne (Tauber to Burkard) levels depended primarily on settling velocity, which, in turn, depends on pollen size. As a result small pollen grains had lower ratios.

These findings raise questions about how well pollen influx values (as measured by Tauber traps) correlate with the airborne pollen spectrum (as measured by a Burkard spore trap). If Tauber traps parallel the deposition into sediments, some of these studies suggest that both may be biased toward larger pollen types. It would follow then that the interpretation of past biomes might underestimate the abundance of taxa with small pollen grains. The present study was undertaken to compare the pollen influx values from a Tauber Trap to the airborne pollen concentrations obtained from a Burkard spore trap in a warm temperate climate with atmospheric pollen present year-round.

METHODS AND MATERIALS

Study site

Aerobiological samples were collected on the roof of a building on The University of Tulsa campus, at 12 m above ground level. The campus is in a residential area approximately 5 km east of the downtown business section of Tulsa and approximately 8 km northwest of the geographic center of the city. Located in northeast Oklahoma (Fig. 1), Tulsa has a mild continental climate. Winters are short and mild; summers are typically long, hot, and frequently dry.

Ecologically, Tulsa is situated in a transition zone between the eastern deciduous forests and the tallgrass prairie. Although the grasslands are typical of western Oklahoma, the eastern portion of Tulsa lies in an extension of the prairie that dips down from Kansas to the north. Dominant anemophilous vegetation in the area includes *Quercus stellata, Q. marilandica, Juniperus virginiana*, and *Ulmus americana* along with *Ambrosia artemisiifolia, A. trifida, A. psilostachya*, and native grasses (Levetin & Buck 1980). In recent years, populations of *Juniperus virginiana* have been increasing within Oklahoma and this is reflected by significant increases in airborne *Juniperus* pollen (Levetin 1998).

Air sampling from The University of Tulsa has been on-going since 1980, with a Burkard spore trap in use since December 1986. Sampling data have shown that the airborne pollen season from local plants in the Tulsa area occurs from February through November. In December and January airborne pollen is present as well but is carried to the area by prevailing southerly winds from pollinating trees in southern Oklahoma and Texas. Samples for the present study were collected from 1 February 1997 to 1 February 1998.

Burkard samplers

A Burkard spore trap was set for seven day sampling onto Melinex tape which was coated with a thin film of Lubriseal (Thomas Scientific, Swedesboro, NJ) as previously described (Levetin 1991). Tapes were changed weekly, cut into seven daily segments, and mounted on microscope slides. Slides were stained with glycerin jelly containing basic fuchsin and examined microscopically at 400X using a single longitudinal traverse. Microscope counts (performed by CR) were converted into atmospheric concentrations and expressed as pollen grains/m^3. Daily concentrations were summed for cumulative monthly and yearly totals. Pollen sizes were determined by averaging the diameters of a minimum of 20 pollen grains for each pollen type measured.

Tauber traps

Tauber traps (Tauber 1974) were positioned approximately one meter from the Burkard sampler at the Study Site (Fig. 2). The Tauber trap (number 85) used in this study is identical to those from other studies in the south-central United States (Hall 1990, 1992); a one-eighth-inch (3.2 mm) metal wire mesh was placed under the aperture to keep out large insects, and the pollen-collecting jar beneath the Tauber top was installed dry without preservatives or adhesives. The Tauber trap was changed on the first day of each month, from February 1, 1997, to February 1, 1998. The jars were taken to the Palynology Laboratory, University of Texas at Austin, and processed by acetolysis techniques described elsewhere (Hall 1990, 1992, 1994). Pollen concentration in the Tauber jars was determined by adding a known spike of *Lycopodium* spores at the beginning of laboratory processing; one tablet (11,267±370 *Lycopodium* spores per tablet; batch 201890) was added to each month's jar. For statistical reasons, a fixed sum of 400 pollen grains was tabulated from each month's pollen accumulation (performed by SH) and influx values determined. These were expressed as pollen grains/cm^2.

Statistical analyses

Sampling data were entered into an Excel 5.0 spread sheet and analyzed with Statistica 5.0 software. For statistical analyses the Tauber influx values and cumulative Burkard concentrations were log transformed to normalize the data. Pearson correlation coefficients were determined between these transformed values for yearly and monthly data. Percent occurrences of all taxa were determined from the two sampling methods for both monthly and yearly data.

RESULTS

Pollen was collected by both sampling methods throughout the year (Tables I, II). The total annual pollen influx from the Tauber trap was 19,427 pollen grains/cm^2, and the cumulative sum of the average daily concentrations of the airborne pollen was 79,394. Lowest pollen levels were

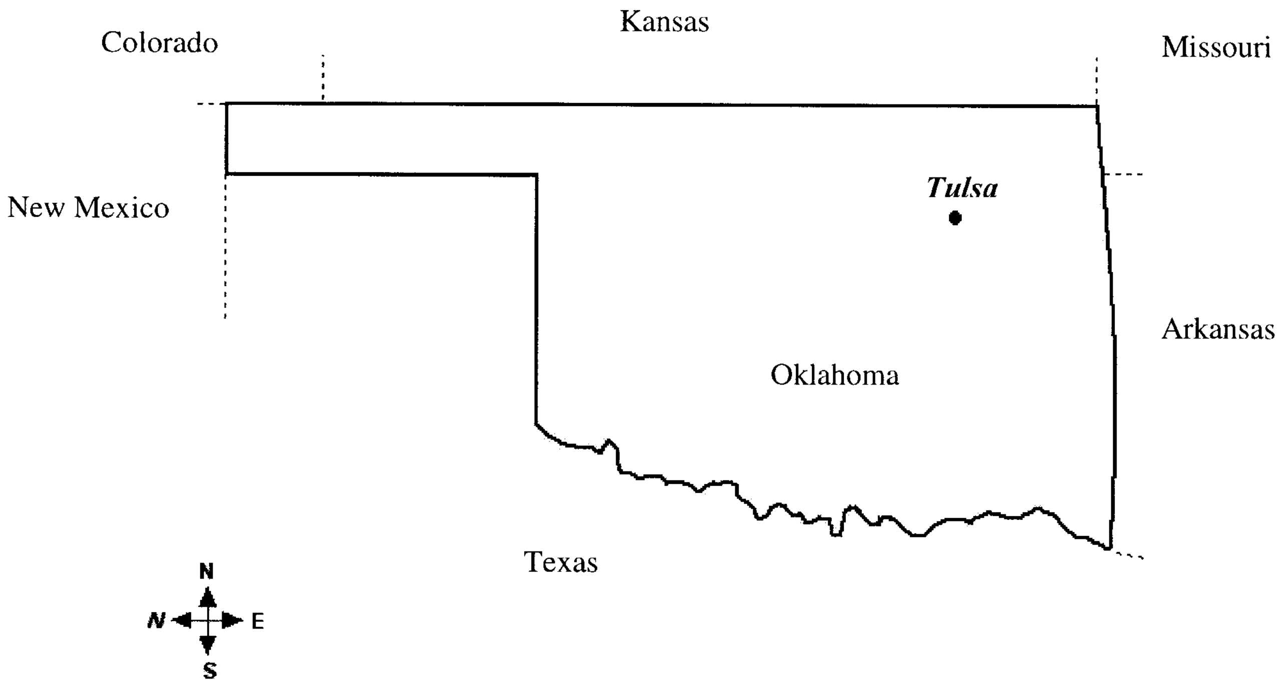

Fig. 1. Study site map.

Fig. 2. Sampling Site on the roof of Oliphant Hall at The University of Tulsa with the Burkard Spore Trap on the right and three Tauber traps on the left.

registered in November and December, with the highest levels occurring in March and April when the atmosphere was dominated by *Quercus* pollen (Tables I, II). Both methods recorded over 50% of the yearly pollen during these months (Fig. 3); however, the Tauber trap registered the highest influx in March (33% of the yearly total) whereas the Burkard registered the highest monthly cumulative sum in April (33% of the yearly total).

Thirty-five pollen taxa were registered by each sampler; however, it should be noted that both samplers recorded pollen taxa not collected by the other instrument (Tables I, II). Although most of these independent registrations were at low levels, two taxa were collected in notable concentrations. The cumulative yearly sum of *Rumex* pollen counted from the Burkard sampler was 428; this taxon was not identified from the Tauber traps. Likewise the influx values of pollen of Apiaceae was 112 grains/cm^2, but none was recorded in the Burkard trap.

Tauber pollen influx data and cumulative Burkard pollen sums showed significant correlation. Log-transformed yearly totals of all taxa registered by both samplers showed significant correlation ($r=0.9143$; $p<0.0001$). Similar results occurred with the log-transformed monthly totals ($r=0.9715$; $p<0.0001$). These relationships are illustrated in Figs. 4 & 5.

The most abundant taxa during the year were *Quercus, Ambrosia, Juniperus* and *Ulmus* although the rankings of *Juniperus* and *Ulmus* were transposed by the two sampling methods (Table III). Together these four taxa accounted for 63% of the Tauber influx and 58% of the cumulative Burkard pollen sum. The percent occurrence of these four taxa and others differed with the two sampling methods. This variability is further reflected in the ratios shown in Table III, where a ratio of 1.0 would indicate perfect agreement between the percent occurrence of a pollen type in the Burkard and Tauber values. The ratios found in this study ranged from 0.32 for *Morus* to 27.22 for *Corylus*. Values less than 1.0 indicate greater occurrence of cumulative Burkard sum and greater than 1.0 indicate greater occurrence of the Tauber influx. Ratios for *Liquidamber* (with low occurrence by both methods) and *Juniperus* (with high occurrence by both methods) showed near equality with 0.98 and 0.92, respectively. When the ratios of the prevailing taxa (those that represent 1.0% or more of the yearly total) are examined, seven taxa had ratios above 1.0 and seven had ratios below 1.0. Of these 14 taxa, the lowest ratios were found for taxa with small pollen: *Morus* 0.32, *Platanus* 0.39, and *Ambrosia* 0.77 (Table III), and there was a significant correlation

Table I. *Tauber monthly pollen influx values at Tulsa (grains/cm²).*

Taxa	Feb-97	Mar-97	Apr-97	May-97	Jun-97	Jul-97	Aug-97	Sep-97	Oct-97	Nov-97	Dec-97	Jan-98	Yearly Influx
Acer	103	226	12	0	2	0	0	0	0	0	0	7	349
Alnus	0	0	0	0	0	0	0	0	0	0	0	3	3
Ambrosia	11	32	0	3	3	5	225	2391	167	36	16	12	2901
Apiaceae	0	0	0	0	101	5	4	0	0	0.4	0.5	1	112
Artemisia	0	0	12	0	3	1	20	0	7	1	1	1	44
Asteraceae	0	0	0	3	8	5	6	33	39	16	3.5	1	116
Betula	0	97	94	6	0	0	0	0	0	0	0	0	196
Brassicaceae	0	0	0	0	7	0	0	0	0	0	0	0	7
Carpinus	0	0	0	0	0	0	0	0	0	1	0	0	1
Carya	0	0	70	318	30	1	0	0	1	3	0.5	2	425
Cedrus	0	0	0	0	0	1	0	0	0	14	2	0	17
Celtis	0	1160	397	29	5	1	0	0	0	0.4	0	1	1593
Chenopod/Amaranth.	6	0	0	11	2	27	112	60	18	6	1	1	244
Corylus	0	145	0	0	0	1	0	0	0	0	0	0	146
Cyperaceae	0	0	12	17	0	2	0	0	0	0	0	0	31
Ephedra	0	0	0	3	0	0	0	0	0	0	0	0	3
Fern spore	0	0	0	0	0	1	0	0	0	0	0	0	1
Fraxinus	0	306	269	9	0	1	0	0	0	0	0	0	584
Juglans	0	0	12	49	8	1	0	0	0	1	0.3	1	71
Juniperus	711	806	23	3	3	1	0	0	77	37	12	115	1787
Liquidambar	0	64	35	0	2	0	0	0	0	1	0	0	102
Morus	0	145	257	40	3	0	0	0	0	0	0	1	446
Picea	0	0	0	0	0	0	1	0	0	0	0	0	1
Pinus	6	97	164	112	61	20	9	0	0	3	2	5	477
Plantago	0	0	0	0	3	3	0	0	0	0	0	0	6
Platanus	0	97	456	6	5	0	0	0	0	0	0	0	563
Poaceae	0	0	12	249	159	106	73	99	19	11	2	1	732
Populus	0	81	23	6	0	1	0	0	0	0	0	1	112
Prosopis	0	0	0	0	0	0	0	0	1	0	0	0	1
Quercus	0	1950	2595	163	40	7	3	0	3	7	6	5	4778
Salix	0	0	35	11	2	0	0	0	0	0	0	1	49
Tilia	0	0	0	0	12	0	0	0	0	0	0	0	12
Typha	0	0	0	0	2	2	0	0	0	0	0	0	4
Ulmus	1399	1224	12	0	2	2	82	0	2	3	1	41	2767
Urtica	0	0	0	32	0	3	11	0	0	0	0	0	46
Indeterminant	6	0	23	20	10	7	4	7	2	3	2	2	86
Unknown A	0	0	0	0	174	0	0	0	0	0	0	0	174
Other unknowns	52	16	164	57	17	41	23	60	1	3	5	5	442
Monthly Influx	2293	6445	4676	1146	664	243	573	2650	335	147	54	201	19427

between pollen size and the percent occurrence ratio (Spearman correlation coefficient, $r=0.65$, $p<0.05$).

When the percent occurrence of all taxa registered by both methods is examined for the whole year there was a strong correlation ($r=0.919$; $p<0.0001$); however, when the percent occurrences for individual months are examined, differences are apparent. The prevalence of all taxa with a 2% or greater occurrence is shown in Fig. 6. The percent occurrences for the Tauber influx data are shown on the left side of each graph and the cumulative Burkard pollen occurrence on the right. Taxa below 2% were added together and included with unknown and indeterminate pollen types in the category called other. The closest agreement between methods occurred in September when *Ambrosia* pollen represented 90% of both the Tauber and Burkard values. In February, the percent occurrence of *Ulmus* in the Tauber values was 18% greater than the Burkard values, while the *Juniperus* Tauber influx was 23% less than the Burkard occurrence. In April there was a 14% difference in *Quercus* levels, a 10% difference in *Morus* levels and a 9% difference in *Platanus* levels. During May there were 9% differences in both *Carya* and *Quercus,* and 14% difference in *Morus.* The percent occurrence of the Burkard Poaceae pollen was 36% greater than the Tauber influx in June and 27% greater in July. As noted above, Apiaceae pollen was only registered in the Tauber trap and was 15% of the June total. Data from August showed a 16% and 14% difference in *Ambrosia* and Chenopodiaceae/Amaranthaceae levels, respectively. Airborne *Ambrosia* levels were 10% greater than influx in October and *Juniperus* 8% lower. By contrast Burkard *Juniperus* levels were 25% higher in November, 15% greater in December and 11% greater in January than the corresponding Tauber influx values.

DISCUSSION

Air samples from both devices showed an air flora that reflected local anemophilous vegetation (Levetin & Buck

Table II. *Burkard cumulative monthly sums of pollen concentrations in Tulsa atmosphere.*

Taxa	Feb-97	Mar-97	Apr-97	May-97	Jun-97	Jul-97	Aug-97	Sep-97	Oct-97	Nov-97	Dec-97	Jan-98	Yearly Sum
Acer	171	53	13	2	0	0	0	0	0	0	0	4	243
Alnus	7	0	0	4	0	0	0	0	0	0	0	7	18
Ambrosia	2	15	4	2	0	4	1191	12 838	1278	118	15	18	15 486
Artemisia	0	0	0	0	0	0	9	63	22	0	0	2	96
Asteraceae	0	0	0	7	70	26	26	225	192	26	9	2	583
Betula	0	750	433	9	2	0	0	4	0	0	0	0	1198
Cannabis/Humulus	0	0	0	0	0	0	11	0	0	0	0	0	11
Carpinus	0	9	0	0	0	0	0	0	0	0	0	0	9
Carya	0	0	125	1062	42	0	2	7	0	0	0	2	1239
Celtis	0	2251	1837	9	0	0	0	0	0	0	0	0	4097
Chenop./Amaranth.	0	11	0	4	11	76	122	247	55	7	0	0	533
Cornus	0	0	2	0	0	0	0	0	0	0	0	0	2
Corylus	0	13	4	4	0	0	0	0	0	0	0	0	22
Cyperaceae	0	22	85	74	13	17	4	2	4	0	0	0	223
Fagus	0	2	0	0	0	0	0	0	0	0	0	0	2
Fraxinus	0	977	1646	70	0	0	0	0	0	0	0	0	2693
Juglans	0	0	59	319	13	0	0	0	0	0	0	0	391
Juniperus	4296	2629	61	17	0	7	0	2	321	212	22	430	7998
Liquidambar	0	109	319	0	0	0	0	0	0	0	0	0	428
Morus	0	474	4172	1016	85	7	35	2	0	0	0	2	5793
Picea	0	0	0	2	2	2	0	0	0	0	0	0	7
Pinus	11	208	754	181	52	28	0	0	4	4	2	0	1246
Plantago	0	2	61	35	26	28	7	2	0	0	0	0	161
Platanus	0	996	4910	33	0	0	0	0	0	0	0	0	5939
Poaceae	9	0	42	1276	1345	784	343	553	162	33	4	2	4552
Populus	0	620	90	4	0	0	0	0	0	0	0	0	714
Prunus	0	0	4	0	0	0	0	0	0	0	0	0	4
Quercus	7	4247	10 968	315	42	2	0	0	0	0	0	0	15 580
Rumex	0	0	46	323	59	0	0	0	0	0	0	0	428
Salix	0	59	262	109	2	0	0	0	0	0	0	0	433
Tilia	0	0	2	0	9	0	0	0	0	0	0	0	11
Typha	0	0	0	0	26	0	0	0	0	0	0	0	26
Ulmus	3372	2905	11	0	2	0	170	61	33	2	2	153	6712
Urtica	0	39	0	2	4	20	81	15	0	0	0	0	162
Xanthium	0	0	0	0	0	2	4	13	0	0	0	0	20
Indeterminate	0	0	350	155	76	13	13	37	26	7	4	7	688
Unknown a	0	0	22	20	17	0	81	39	0	0	0	0	179
Unknown b	0	0	4	415	201	0	0	9	0	0	0	0	629
Unknown c	0	0	17	17	11	90	2	2	2	0	0	0	142
Other unknown	13	208	170	262	122	11	31	37	20	4	0	2	881
Total	7887	16 601	26 475	5750	2234	1119	2132	14 159	2119	413	59	632	79 580

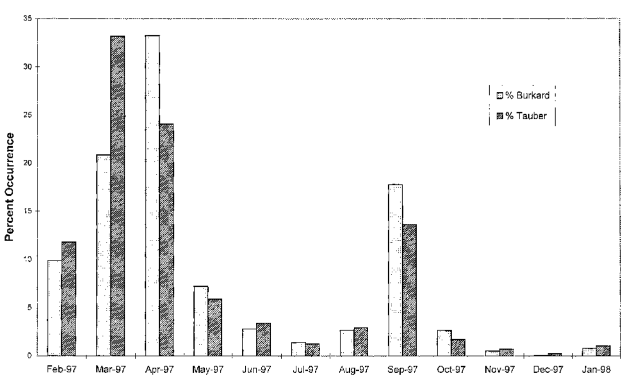

Fig. 3. Percent Occurrence of Total Yearly Pollen by Month for Each Pollen Trap.

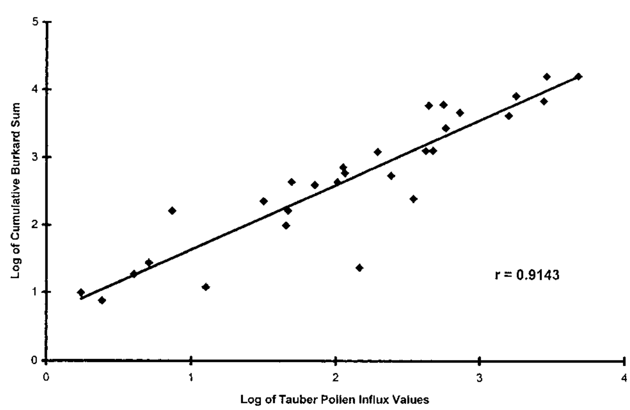

Fig. 4. Correlation of Burkard Cumulative Yearly Sums with Yearly Tauber Influx Values for Individual Taxa.

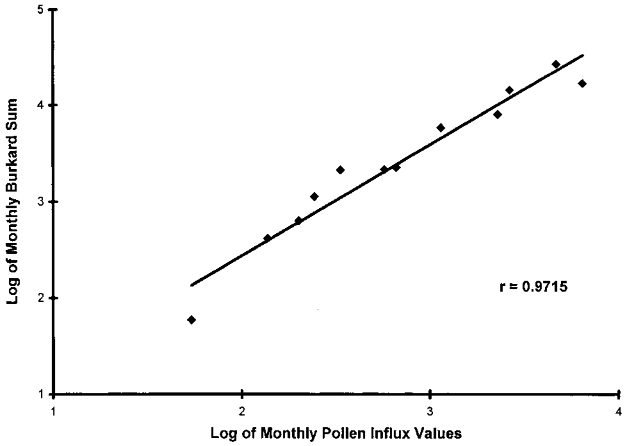

Fig. 5. Correlation of monthly Burkard Sums with Monthly Tauber Influx Values for All Pollen.

1980). The dominant taxa by both methods were *Quercus, Ambrosia, Juniperus*, and *Ulmus*. There are 26 species of *Quercus* native to Oklahoma (Levetin & Buck 1980), and most of these are widely distributed in the eastern half of the state. Although *Quercus* was the most abundant pollen type during 1997 and also in 1996, the levels during these years were two to three times higher than the 10-year average of *Quercus* pollen (Levetin 1998). During other years, *Ambrosia* pollen was the dominant member of the air flora.

Oklahoma also supports large populations of *Juniperus virginiana* along with smaller populations of *J. ashei, J. monosperma, J. pinchotii,* and *J. scopulorum.* The range expansion of *J. virginiana* and *J. ashei* has been well documented (Snook 1985, Engle et al. 1997) and the population increase has been paralleled by increasing pollen levels in the atmosphere (Levetin 1998). The data presented here from 1997 show a continuation of this trend. Only *J. virginiana* occurs naturally in the Tulsa area, although other cedars are used widely as ornamentals. Both *J. virginiana* and the ornamentals pollinate in the spring and are responsible for airborne *Juniperus* pollen in February, March and April. The *Juniperus* pollen in the atmosphere from October through January arises from long distance transport of *J. pinchotii* and *J. ashei* pollen from populations in southern Oklahoma and Texas (Levetin & Buck 1986, Levetin 1998, Rogers & Levetin 1998).

Even though Dutch elm disease has taken a heavy toll on the population of *Ulmus americana*, *Ulmus* pollen is still a major component of the air flora. It should be noted that there has been no decrease in the levels of airborne *Ulmus* pollen from Tulsa despite the loss of many trees on campus near the sampler (Levetin 1998).

Thriving populations of four *Ambrosia* species are also present in Oklahoma: *A. artemisiifolia, A. trifida*, and *A. psilostachya*, occur throughout the state and are abundant in the Tulsa area. *Ambrosia bidentata* however is not as common nor as widely distributed (Buck & Levetin 1982). *Ambrosia* pollen has frequently been the dominant taxon identified from the Tulsa atmosphere. Although data show decreasing levels in the Tulsa atmosphere during the past few years, this may reflect habitat elimination due to reduction in construction activity (Levetin et al. 1998). Other pollen taxa registered in the samplers also reflect local vegetation, especially *Celtis, Morus*, and *Platanus,* which are well represented in the area.

Table III. *Percent occurrence of pollen taxa from Tauber and Burkard samplers.*

Taxa	% of Total Tauber*	% of Total Burkard**	Ratio
Quercus (30 μm)***	24.59	19.58	1.26
Ambrosia (20 μm)	14.93	19.46	0.77
Ulmus (28 μm)	14.24	8.43	1.69
Juniperus (22 μm)	9.20	10.05	0.92
Celtis (28μm)	8.20	5.15	1.59
Poaceae (30 μm)	3.77	5.72	0.66
Fraxinus (21μm)	3.01	3.38	0.89
Platanus (17 μm)	2.90	7.46	0.39
Pinus (75 μm)	2.46	1.57	1.57
Morus (15 μm)	2.30	7.28	0.32
Carya (41 μm)	2.19	1.56	1.41
Acer (31 μm)	1.79	0.31	5.88
Chenopod/Amaranth. (24μm)	1.25	0.67	1.87
Betula (21 μm)	1.01	1.51	0.67
Corylus	0.75	0.03	27.22
Asteraceae	0.59	0.73	0.81
Populus	0.58	0.90	0.64
Apiaceae	0.58	N.R.****	
Liquidambar	0.53	0.54	0.98
Juglans	0.36	0.49	0.74
Salix	0.25	0.54	0.46
Urtica	0.24	0.20	1.17
Artemisia	0.23	0.12	1.89
Cyperaceae	0.16	0.28	0.56
Cedrus	0.09	N.R.	
Tilia	0.06	0.01	4.34
Brassicaceae	0.03	N.R.	
Plantago	0.03	0.20	0.16
Typha	0.02	0.03	0.64
Alnus	0.02	0.02	0.71
Ephedra	0.01	N.R.	
Picea	0.01	0.01	0.90
Prosopis	<0.01	N.R.	
Carpinus	<0.01	0.01	
Fern spore	<0.01	N.R.	
Cannabis/Humulus	N.R.	0.01	
Cornus	N.R.	<0.01	
Fagus	N.R.	<0.01	
Prunus	N.R.	0.01	
Rumex	N.R.	0.54	
Xanthium	N.R.	0.02	
Others	3.62	3.17	1.14

*Percent occurrence of total yearly influx.
**Percent occurrence of cumulative yearly sum of average daily concentrations.
***Average pollen size used in statistical analysis for taxa with prevalence greater than 1%.
****N.R. = not registered.

Although there were differences in the relative abundance of various taxa using the two sampling methods, the Tauber pollen levels were significantly related to the cumulative Burkard pollen sums (Figs. 4 & 5) based on correlations of the yearly totals of individual taxa ($r = 0.9143$) and monthly totals of all taxa ($r = 0.9715$). There was also a significant

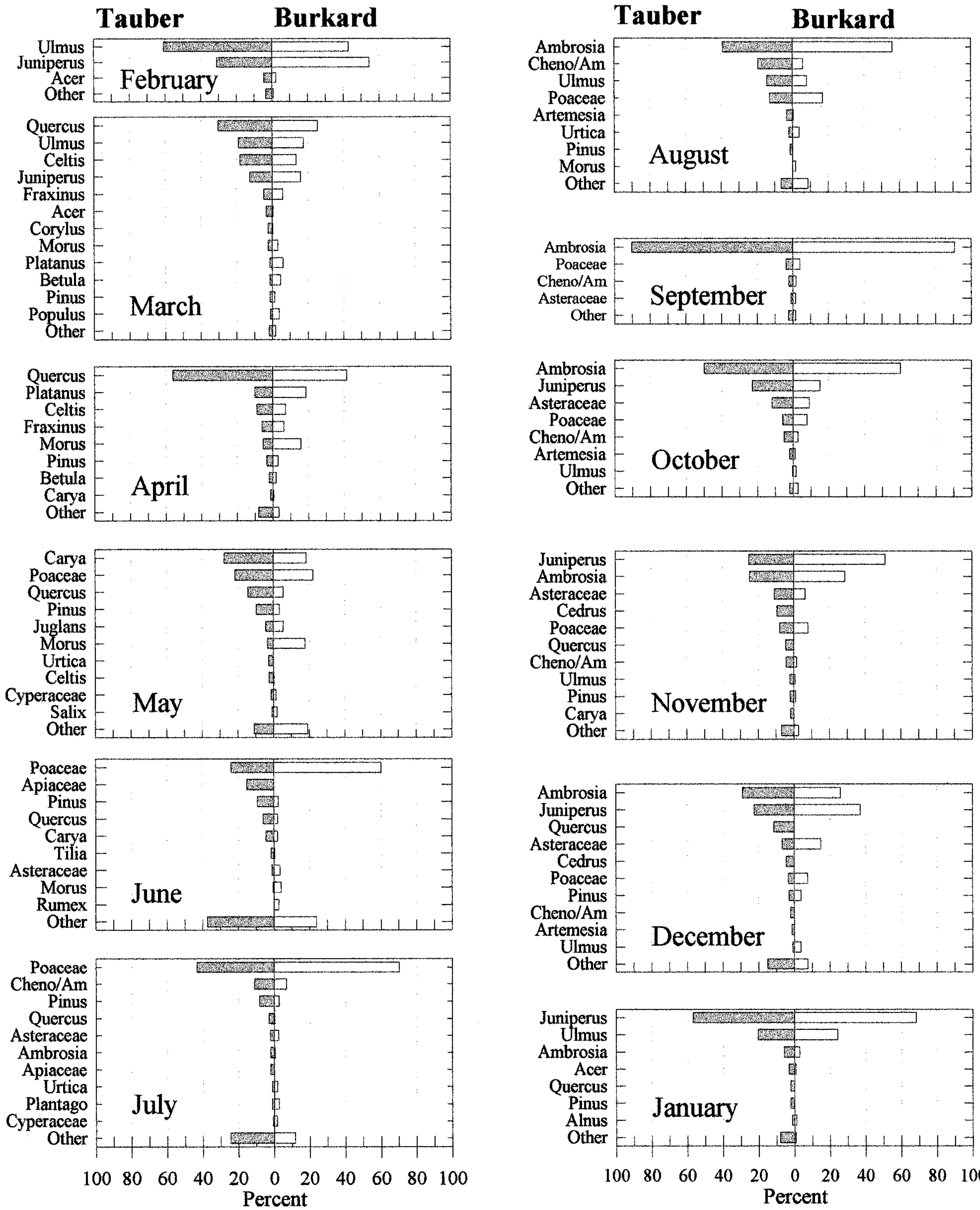

Fig. 6. Comparison of Monthly Percent Occurrence of Pollen Taxa from Tauber and Burkard Traps.

correlation between the percent occurrences of pollen taxa for the whole year (r=0.919). O'Rourke (1986) showed similar correlations between the two methods during a study of the atmospheric pollen rain in the arid southwest.

Even though the yearly data showed significant correlation between the two sampling methods, there were some notable differences in the prevalence of individual taxa by month. When two or more pollen taxa were co-dominant, the taxon with the larger pollen grain sometimes had a higher percent occurrence in the Tauber trap. For example, in February (Fig. 6) differences in prevalence between *Ulmus* (approximately 30 µm) and *Juniperus* (approximately 22 µm) may be due to the larger size (and therefore greater settling velocity) of *Ulmus* pollen. A similar explanation may account for the percent differences during April with *Quercus* pollen (approximately 34 µm) and both *Platanus* (17 µm) and *Morus* (15 µm) pollen.

Grosse-Brauckmann and Stix (1979) suggested that the ratio of pollen influx (Tauber) to airborne pollen (Burkard) concentrations should theoretically depend on the settling velocity when all meteorological influences are ignored. However, in the natural world it is not possible to eliminate the meteorological factors. In their study of the relationship between pollen influx and airborne concentrations, they found little correlation between these values from different locations in Germany for a single pollen type. This may be analogous to the differences in *Ambrosia* pollen seen in the current study. The percent occurrence of cumulative Burkard *Ambrosia* pollen was greater than Tauber influx in August and October but the percents were equal in September. Grosse-Brauckmann and Stix (1979) also showed no close correlations with the settling velocities, but smaller pollen did have lower ratios of Tauber influx to airborne Burkard levels. In the present study smaller pollen taxa had lower ratios and there was also a significant correlation between pollen size and the ratio of Tauber to Burkard percents.

Average pollen size is the major factor determining settling velocity; however, investigators have found that settling velocities of a single pollen type were highly variable. Di Giovanni et al. (1995) suggest that size variations among pollen grains from the same plant or from different plants in the population as well as differences in moisture content of the grains may explain the variation. They also found significant differences between the settling velocities determined experimentally and those values calculated using Stoke's Law. Jackson & Lyford (1999) reviewed several studies that found deposition varied substantially between wet and dry pollen grains. Both density and volume changes were dependent upon relative humidity in a variety of pollen taxa.

Although pollen size and settling velocity are important parameters for pollen deposition, wind tunnel experiments have shown that sedimentation is negligible at wind speeds at or above 2 m/sec (Gregory 1973). Tulsa is characterized by a mild continental climate that is subject to rapid changes in temperature. Prevailing surface winds are from the south and occasionally violent storms with high winds occur during spring and early summer. Wind speeds typically average 4 to 5 m/sec, and higher wind speeds are common. Wind speeds below 2m/sec occurred less than 15% of the time (NOAA 1997). As a result, it is possible that settling velocity, and therefore pollen size, played only a minor role in deposition at this site.

Pollen size differences also cannot explain other variance observed in this study. *Rumex* pollen occurred in the Burkard samples in April, May and June, but was absent from the Tauber samples. Although Poaceae pollen makes up only a minor component of the yearly air flora (3.77% of Tauber total and 5.72% of Burkard total) there were major differences in the prevalence during June and July. Burkard occurrence was greater than Tauber occurrence during both months. Registration of Apiaceae pollen in the June Tauber trap and the presence of a large number of an unknown pollen type (Table I) suggest a possible insect incursion, which resulted in the introduction of non-anemophilous types. Without these pollen types, the percent occurrence of Poaceae pollen would have been higher in June. The reasons for the difference in this prevalence during July are not clear, nor are the reasons for the differences in *Ambrosia* levels in August and October. Possibly meteorological conditions affected the deposition differently each month. Fægri & Iversen (1989) indicate that there is no constant relationship between different sampling methods because of variable meteorological conditions.

Rainfall is one of the meteorological factors that could have influenced deposition of pollen in the Tauber traps. Several studies have shown that raindrops scavenge pollen grains from the atmosphere (McDonald, 1962; Norris-Hill and Emberlin, 1993). Pollen-laden raindrops could easily collect in the Tauber jars used in this study since the traps lacked a rain-shield. Tauber (1974) indicated that "unroofed" samplers will collect pollen washed out by rain as well as airborne pollen. This may explain some of the differences in monthly prevalence obtained by the two methods.

Other sources of variance include the natural variability in the atmosphere, the variability due to analyzing only a subsample of the pollen collection, and the variability due to two different individuals involved in identifying and counting pollen. The atmospheric variability has been examined in previous studies. An experimental array of nine Tauber traps, located approximately six meters apart, produced a mean annual influx with a standard deviation of 10.5% (Hall 1992). Intrasampler variance was also cited in a study by Solomon et al. (1980). They found small but consistent differences between the recoveries of 4 adjacent rotorod samplers and also between the recoveries of 3 adjacent rotoslide samplers. The intrasampler variance could have reflected minor differences in the functioning of the samplers or the innate variability of atmospheric bioaerosols. Pedersen and Moseholm (1993) examined sources of variance in daily pollen counts. They used two Burkard traps positioned side-by-side on the roof of a building in Copenhagen. Three experienced pollen counters analyzed the samples from both traps. They analyzed the data for four pollen types and found 12 to 31% of the variance was due to what they called day-trap interaction. This included minor difference in the functioning of the two samplers as well as meteorologically dependent variations. This would include the natural variability of atmospheric components. Pedersen and Moseholm also found that 2 to 13% of the variance was attributed to difference among pollen counters. Several studies have shown that increased precision in pollen analysis could be achieved by increasing the amount of the pollen sample analyzed (Käpylä & Penttinen 1981, Pedersen & Moseholm 1993, Sterling et al. 1999, Comtois et al. 1999). It is possible that all of these factors contributed to differences in the monthly prevalence seen in the present study.

CONCLUSION

The present study compared the cumulative airborne pollen levels measured by a Burkard Spore Trap with pollen influx values measured by a Tauber Trap. The data showed that there were significant correlations between Burkard and Tauber values, even though Burkard traps are generally used for daily pollen counts and Tauber traps are used for long-term studies. During some months there were differences in the prevalence recorded by both methods and pollen size may have been one of the factors that was responsible for the variation.

Overall, this study confirmed that data from both methods reflect local anemophilous vegetation, and are equally effective at estimating the regional pollen prevalence over yearly time scales.

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