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A long-term study of winter and early spring tree pollen in the Tulsa, Oklahoma atmosphere

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Abstract

Since 1986 the atmosphere in Tulsa, Oklahoma has been monitored for airborne pollen and spores with a Burkard 7-day spore trap situated on the roof of a building at The University of Tulsa. The present study specifically examined the early spring tree pollen season for several local taxa and the occurrence of pre-season pollen during December and January. Knowledge of the local pollen season will help identify the presence of out-of-season pollen and possible long distance transport (LDT) events. Average daily concentrations of airborne pollen for species of *Betula*, *Quercus*, *Ulmus*, and Cupressaceae were determined for each year from 1987 to 1996. The data showed that during the early spring the precise pollination periods for these allergenic tree species are highly variable. There were considerable variations in start date, season length, peak concentration, date of peak, and cumulative season total. The start dates for *Ulmus*, *Betula*, and *Quercus* varied by 30 days or more, while the early spring Cupressaceae pollen showed the least variation in start date (only 23 days). More research is needed to understand the mechanisms which govern the onset and magnitude of pollen release. Although several reports have documented episodes of long distance transport (LDT) of pollen, the actual contribution of out-of-season or out-of-region pollen to local air spora is poorly known. The current study also re-examined the LDT of *Juniperus ashei* pollen in Oklahoma. *Juniperus* pollen appeared in the Tulsa atmosphere on 40% of the days in December and January with concentrations as high as 2400 pollen grains/m^3 of air; however, no local populations of *Juniperus* pollinate at this time of the year. High concentrations occurred on days with southerly winds suggesting that *Juniperus ashei* populations in southern Oklahoma and Texas were the pollen source. Since no local pollen is present in the Tulsa atmosphere in December and January, this example of LDT has been easy to document.

Keywords: *Juniperus*; *Ulmus*; *Betula*; *Quercus*; Long distance transport; Pollen season

1. Introduction

Oklahoma exhibits great floral diversity ranging from the deciduous forests in the east to the grasslands in the western half of the state. Prevailing southerly winds insure a mild climate within the region. Because of the climate and floral diversity, airborne pollen is present throughout much of the year. Over 80 species of trees that are recognized as allergenic occur in the state; the tree pollen season begins in winter and continues through May with other tree species pollinating in the fall (Levetin and Buck, 1980). In the early spring in Tulsa, the highest airborne tree pollen concentrations obtained from Burkard spore trap data are from species of *Quercus*, *Ulmus*, and *Juniperus* (Levetin, unpublished observations).

Airborne pollen grains of many tree species are widely recognized as triggers of allergic rhinitis and asthma with symptoms closely tied to the pollination period of local species (Gutman and Bush, 1993; Chang, 1993). Although several reports have documented episodes of long distance transport (LDT) of pollen, the actual contribution of out-of-season or out-

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of-region pollen to the severity of allergic disease is poorly known, especially in North America.

Studies by Ritchie and Lichti-Federovich (1967) and Christie and Ritchie (1969) provided evidence for the transport of *Populus*, *Ulmus*, *Corylus*, *Alnus* and *Salix* pollen to Churchill, Manitoba from a parkland area over 1000 km to the southwest during a 3 day period in May 1965. Peeters and Zoller (1988) found evidence of LDT of *Castanea sativa* pollen in Switzerland. Hall (1990) studied pollen deposition along a 320-km transect in the southern Rocky Mountains over a two year period using Tauber traps. He demonstrated that pollen dispersal was primarily related to the westerly air flow over the mountain crest and also to southerly and southwesterly summer winds. Hall suggested that 40–60% of the pollen collected at spruce-fir and grassland stations represented trees and shrubs not in the area, while in the pine-oak forest 20–40% of the pollen grains were from outside the vegetational area. Hjelmroos (1991, 1992) described the LDT of *Betula* pollen from southwestern Russia, the Baltic states, and Poland to both Sweden and Finland. Increased nasal and eye symptoms among Stockholm patients sensitive to *Betula* pollen were demonstrated during an episode of LDT that occurred 10 days before the local *Betula* flowering season (Hjelmroos, 1992). Similar data were recorded in the Umea region of northern Sweden (Wallin et al., 1991). Cambon et al. (1992) provided evidence for the LDT of three exotic pollen taxa originating at least 1000 km to the south of their southern Ontario sampling stations. Two of the pollen taxa are native to the West Indies and Mexico, while the third occurs in the southwest region of the U.S. Wind trajectory analysis for the time of the incursions corroborated these routes. Lindgren et al. (1995) described the LDT of *Pinus sylvestris* pollen suggesting that the pollen originated in central Sweden approximately 400 km south of Umea. They also speculated on the evolutionary significance of long distance dispersal in this taxon. Comtois and Mandrioli (1996) studied the concentration of airborne pollen and spores aboard a ship on the Adriatic Sea. They found that pollen levels and taxa corresponded to concentrations recorded on the Italian peninsula during the same time periods. The authors of these studies considered the presence of either out-of-season or out-of-region pollen as evidence for LDT. These same criteria are used in the present study.

The occurrence of out-of-season *Juniperus* pollen in the Tulsa atmosphere has provided evidence of LDT in Oklahoma. During an earlier study it was found that, *Juniperus* pollen typically occurs in the Tulsa atmosphere on 30% of the days during December and January with concentrations as high as 700 pollen grains/m^3 of air (Levetin and Buck, 1986; Levetin, 1987). However, no local populations of *Juniperus* pollinate at this time of the year. *Juniperus ashei* (mountain cedar) does pollinate during these months, and large populations of this species occur in southern Oklahoma and Texas with the closest population approximately 320 km southwest of Tulsa. *Juniperus ashei* is a major winter allergen in Texas and is considered the most important allergenic species in the genus (Wodehouse, 1971; Levetin and Buck, 1986). Several Tulsa area allergists skin test and treat for mountain cedar sensitivity (Levetin and Buck, 1986). During December and January high concentrations of *Juniperus* pollen in Tulsa occurred on days with southerly or southwesterly winds suggesting that *Juniperus ashei* populations were the source of this pre-season pollen. Since no other pollen is present in the Tulsa atmosphere in December and January, this example of LDT was easy to document. At other times of the year in Tulsa, the abundance of local pollen may obscure additional evidence of LDT.

One goal of the present study was to re-examine the LDT of *Juniperus ashei* pollen in Oklahoma. A second goal was to determine the pollen season start dates for the major tree taxa in the Tulsa area. Precise knowledge of the local pollen season will help identify the presence of out-of-season and out-of-region pollen. This study specifically examined the pollen seasons for species of *Betula*, *Quercus*, *Ulmus*, and the family Cupressaceae from 1987 to 1996. It is anticipated that these preliminary data will aid future studies focus on long distance transport.

2. Materials and methods

Since December 1986, the atmospheric pollen content in Tulsa has been monitored with a Burkard spore trap situated on a roof of a building at The University of Tulsa approximately 12 m above ground. The Burkard trap was set for seven day sampling onto melenex tape coated with a thin film of Lubriseal (Thomas Scientific, Swedesboro, NJ). The tapes were changed weekly and cut into one day segments which were mounted onto microscope slides. Slides were stained with glycerin-jelly containing basic fuchsin and examined microscopically. Microscope counts were converted into atmospheric concentrations and expressed as pollen grains per cubic meter of air. Data from 1980–1986 presented in Table 1 are derived from an earlier study using Rotorod samplers (Levetin and Buck, 1986).

Meteorological data were supplied by the NOAA weather station in Tulsa which is approximately 6 km northeast of the sampling station.

The beginning of the main pollen season for a particular taxon was defined as the date when the cumulative total pollen reached 5% of the season total.

Table 1
Variation in the spring *Juniperus*/Cupressaceae pollen season in Tulsa, Oklahoma

Year	Start date[a]	End date[a]	Season length (days)	Peak concern (pollen grains/m^3)	Date of peak	Season total
1987	41	74	34	523	43	3335
1988	52	71	20	655	67	1708
1989	61	91	31	1057	71	2888
1990	38	81	44	1115	57	3607
1991	42	78	37	442	64	3533
1992	45	75	31	1156	51	3629
1993	39	100	62	1248	67	4823
1994	39	80	42	1311	62	4971
1995	50	77	28	1485	75	7316
1996	40	67	28	2027	53	6238
Mean	44	79	36	1102	61	4205

[a] Days from January 1.

3. Results

3.1. Local pollen taxa

In early spring the Tulsa atmosphere was dominated by *Ulmus*, *Juniperus*/Cupressaceae, *Betula*, and *Quercus* pollen. The mean daily concentrations for the 10-year period were determined (Figs. 1–4), and the cumulative season totals calculated for each year from the sum of the average daily concentrations. Season start dates were defined as 5% of the cumulative season total, and the end date was defined at the 95% level. For all taxa examined, the pollen data showed considerable variations from year-to-year (Tables 1–4).

Juniperus/Cupressaceae pollen was primarily found in the Tulsa atmosphere in February and March (Fig. 1). The earliest main season start date took place on 7 February 1990 and the latest start date was on 2 March

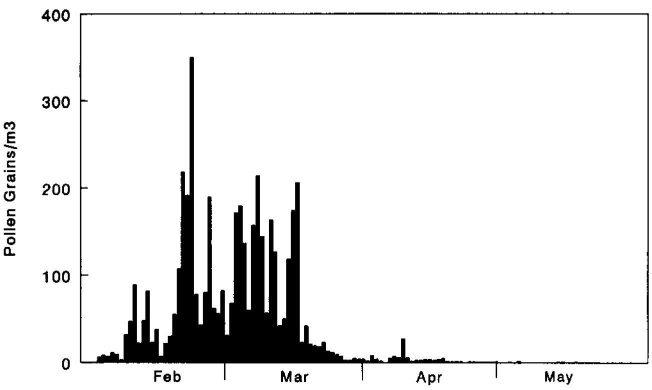

Fig. 1. Mean daily concentration of airborne *Juniperus*/Cupressaceae pollen in Tulsa, Oklahoma, 1987–1996.

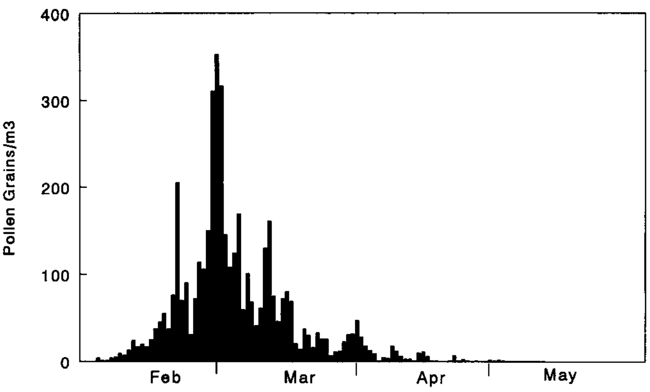

Fig. 2. Mean daily concentration of airborne *Ulmus* pollen in Tulsa, Oklahoma, 1987–1996.

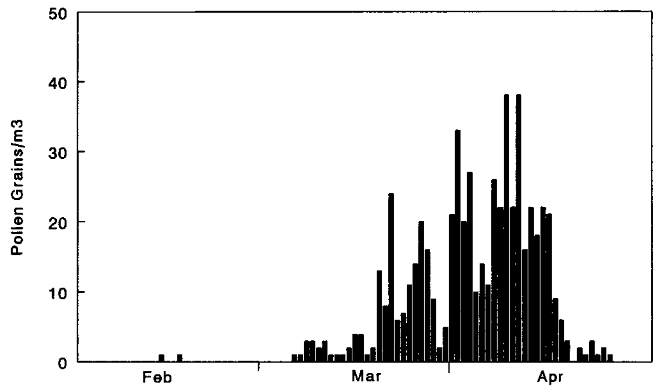

Fig. 3. Mean daily concentration of airborne *Betula* pollen in Tulsa, Oklahoma, 1987–1996.

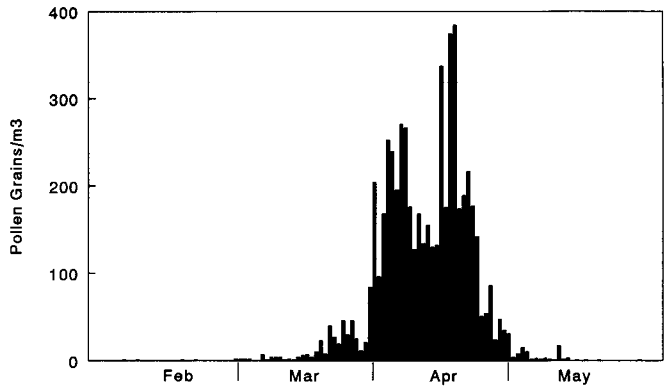

Fig. 4. Mean daily concentration of airborne *Quercus* pollen in Tulsa, Oklahoma, 1987–1996.

Table 2
Variation in the annual *Ulmus* pollen season in Tulsa, Oklahoma

Year	Start date[a]	End date[a]	Season length (days)	Peak concern (pollen grains/m^3)	Date of peak	Season total
1987	41	76	36	1348	43	4789
1988	52	84	33	819	57	3815
1989	63	97	35	271	71	934
1990	35	68	34	510	43	5764
1991	43	67	25	889	51	4309
1992	33	68	36	450	47	3612
1993	39	81	42	315	40	2471
1994	47	72	26	816	63	4996
1995	36	97	62	788	52	5567
1996	49	64	16	1451	53	5665
Mean	44	77	34	766	52	4192

[a] Days from January 1.

1989 (Table 1). Although there was a 23-day range in the start date, during seven of the years the pollen season began during the second week of February. The mean start date for the 10 years was 13 February. The season ranged from 20 to 61 days and the peak concentrations generally occurred in late February or early March.

Ulmus pollen also was present in the Tulsa atmosphere in February and March (Fig. 2). Start dates varied over a 30-day period with the earliest on 2 February in 1990 to the latest on 4 March in 1989 (Table 2). During six of the years, pollination began during the first or second week of February. The mean start date was 13 February. The peak concentration generally occurred in mid-February, and the season varied from 15 to 62 days. It should be noted that on five of the years *Ulmus* pollen was recorded in the atmosphere during the last week of January.

The *Betula* pollen season generally developed in March and April with relatively low concentrations compared to the other taxa (Fig. 3). There was a 33-day difference in the start date for *Betula* pollen release during the 10 years of this study ranging from 8 March in 1992 to 10 April in 1996 (Table 3). In nine of the years, pollen release began in March and during six of those years the season began during the third week of March. The mean start date was 23 March. The season length varied from 9 to 34 days and the peak concentration occurred in late March or early April. The earliest *Betula* pollen was recorded on 12 February 1987 which was several weeks before the onset of the pollen season.

The main part of the pollination season for *Quercus* species was generally found in April (Fig. 4). There was a 35 day range in start date during the study period with the earliest on 9 March 1992 and the latest on 13 April in both 1993 and 1996 (Table 4). The mean start date was 29 March and for five seasons, pollination began during the last week of March. The peak concentrations generally were from early to mid-April, and season length ranged from 16 to 49 days. The earliest *Quercus* pollen was recorded on 1 February 1992, with other early February registrations in 1990 and 1991.

In addition to the differences in the timing of pollen release, there were also variations in peak concentration and cumulative season total. The magnitude of the

Table 3
Variation in the annual *Betula* pollen season in Tulsa, Oklahoma

Year	Start date[a]	End date[a]	Season length (days)	Peak concern (pollen grains/m^3)	Date of peak	Season total
1987	74	102	29	209	81	570
1988	83	100	18	198	94	692
1989	84	107	24	192	105	769
1990	79	107	29	117	104	542
1991	82	95	14	179	85	594
1992	67	98	32	57	80	466
1993	86	111	26	159	99	564
1994	70	103	34	101	81	357
1995	81	98	18	113	92	425
1996	100	108	9	260	102	877
Mean	81	103	23	159	92	586

[a] Days from January 1.

Table 4
Variation in the annual *Quercus* pollen season in Tulsa, Oklahoma

Year	Start date[a]	End date[a]	Season length (days)	Peak concern (pollen grains/m^3)	Date of peak	Season total
1987	75	108	34	186	82	1312
1988	92	113	22	903	98	6954
1989	92	112	21	723	106	4849
1990	90	124	35	525	112	3088
1991	90	105	16	1420	95	8862
1992	67	115	49	257	99	2180
1993	102	120	19	1477	108	9003
1994	82	109	28	1045	91	7656
1995	85	106	22	604	99	4554
1996	102	118	17	2225	110	10 271
Mean	88	113	26	937	100	5873

[a] Days from January 1.

peak varied extensively. For example, the 1996 *Quercus* peak of 2225 pollen grains/m^3 was 12 times greater than that during 1987 (Table 4), the year with the lowest peak. Although the interannual variation for cumulative total pollen was great for all taxa, *Quercus* showed the greatest variation. The 1996 seasonal total of airborne oak pollen at 10271 was 7.8 times greater than the year with the lowest cumulative total. Overall, the general trend showed a slight increase in pollen levels over the past ten years for both *Quercus* and *Ulmus* pollen and a statistically significant increase for *Juniperus*/ Cupressaceae pollen ($r^2 = 0.7779$; $p < 0.001$).

3.2. *Juniperus ashei* pollen

Over the past 16 winters, *Juniperus* pollen was identified from the Tulsa atmosphere on 40% of the days in December and January (Table 5). The data from December 1980 to January 1986 were from samples collected with a Rotorod sampler, while for the remaining years, samples were collected with the Burkard spore trap. The 2-month mean concentrations of *Juniperus* pollen for this season (December and January) were generally low, ranging from 0.07 to 67.7 pollen grains/m^3. However during each season there were several days with high atmospheric concentrations. Winds were from the south or southwest on days with high levels of *Juniperus* pollen (Fig. 5). During the 16 winters there were 31 days with atmospheric concentrations above 100 pollen grains/m^3; this includes eight days with levels above 500 pollen grains/m^3 and 3 days above 1000 pollen grains/m^3. The majority of these days, 24 out of 31, occurred in January. The peak concentrations recorded each year varied from a low of two pollen grains/m^3 on 10 December 1983 to the highest which was on 13 January 1996 at 2411 pollen grains/m^3 (Fig. 6).

Table 5
Atmospheric *Juniperus* pollen in Tulsa, Oklahoma during December and January

Winter	Number of days with *Juniperus* pollen	Peak concentration (pollen grains/m^3)	Date of peak	Mean concentration for December and January (pollen grains/m^3)
1980–81[a]	36	549	24 Jan	14.9
1981–82[a]	37	350	5 Jan	7.6
1982–83[a]	23	689	22 Dec	13.6
1983–84[a]	7	2	10 Dec	0.07
1984–85[a]	22	35	23 Dec	2.0
1985–86[a]	38	698	15 Jan	24.6
1986–87	24	149	13 Jan	6.6
1987–88	12	175	28 Jan	9.0
1988–89	29	546	6 Jan	18.0
1989–90	28	257	22 Jan	10.4
1990–91	20	333	28 Jan	11.4
1991–92	20	158	16 Dec	9.7
1992–93	14	802	29 Dec	27.2
1993–94	31	2027	26 Dec	67.7
1994–95	30	947	11 Jan	29.1
1995–96	29	2411	13 Jan	61.5

[a] Data collected with a Rotorod sampler from 1980–86.

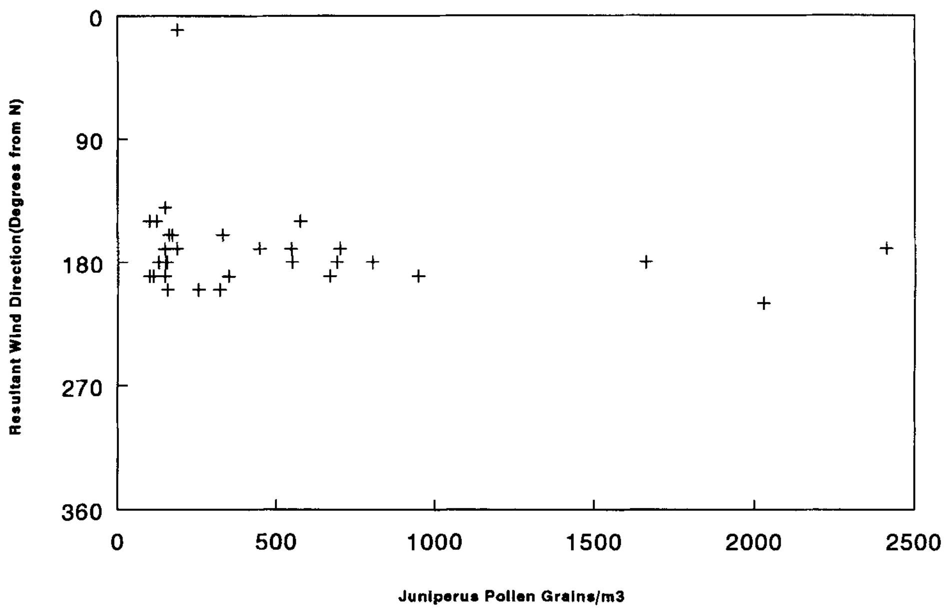

Fig. 5. Resultant wind direction on days during December and January (1980–1996) when airborne *Juniperus* pollen levels in Tulsa, Oklahoma exceeded 100 pollen grains/m^3. The one outlier reflects a sampling day when there were 12 h during which the winds were from the south (180–190°); however, the 24-h sampling period and meteorological day were not synchronized. Meteorogical data were supplied by the NOAA weather station in Tulsa.

4. Discussion

The pollen season start dates for *Ulmus*, *Betula*, and *Quercus* varied by 30 days or more, while *Juniperus*/Cupressaceae pollen showed the least variation in start date (23 days). Although various criteria are in use for defining the start date (Pathirane, 1975; Lejoly-Gabriel and Leuschner, 1983; Persson and Nilsson, 1984; Andersen, 1991), the 5% level was chosen for this study due to the relatively low airborne *Betula* pollen concentrations. Early registrations of this pollen brought the percentage above 1% one to two weeks before the main pollen season.

Similar fluctuations were seen in season length, peak concentration, date of peak, and cumulative season total. The shortest season length was nine days during 1996 for *Betula* pollen and the longest was 62 days for *Ulmus* in 1995. Up to 31 days variation was seen in the date of the peak concentration for each taxon. The magnitude of the peak also varied extensively. Overall, the general trend showed a slight increase in pollen levels over the past ten years for both *Quercus* and

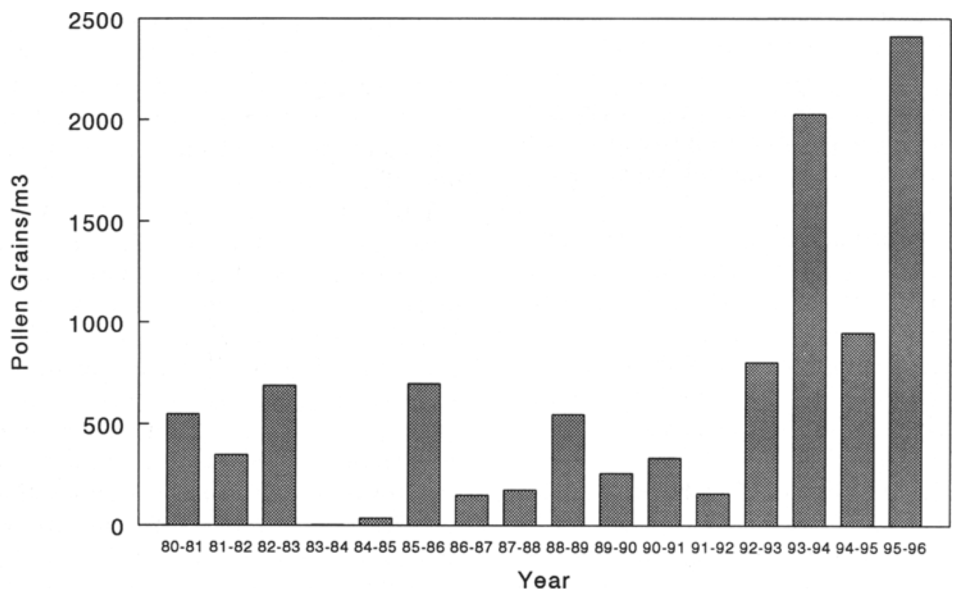

Fig. 6. Peak *Juniperus ashei* concentrations in the Tulsa, Oklahoma atmosphere for December–January, 1980–1996.

Ulmus pollen and a statistically significant increase for *Juniperus*/Cupressaceae pollen.

Similar variations in pollen seasons were shown by Andersen (1991) who reported that the beginning of the pollen season in Denmark for *Alnus* varied by 93 days from 30 December to 1 April, for *Ulmus* by 70 days from 21 February to 2 May, and for *Betula* by 37 days from 2 April to 9 May. Spieksma et al. (1995) described the variation in seasonal *Betula* pollen totals and start dates at several European cities. They found that there was a 27-day range in the start date in Vienna, a 37-day range in Basel and London, a 46-day range in Stockholm, and a 47-day range in the start date in Leiden. Seasonal totals showed an equivalent degree of variability.

Knowledge of the pollen season is of significant value in the prophylactic treatment of seasonal rhinitis and asthma. In addition, the identification of pre-season or out-of-season pollen requires precise knowledge of the local pollen seasons. For certain taxa such as *Ambrosia* spp. , the pollination period is well-defined and consistent from year to year. Although high concentrations of tree pollen are well known in the spring atmosphere, the precise pollination periods are not entirely defined. The timing of the pollen season is variable, with the pollen release in temperate zone trees a function of two temperature factors (Frenguelli et al., 1991). The first is a variable chilling requirement to end dormancy; the length of the chilling period may be species-specific. After dormancy ends, plants require an accumulation of heat units above a threshold temperature (Boyer, 1973; Solomon, 1979; Frenguelli et al., 1991). The heat quantity needed also varies from species to species. Once this requirement has been met, pollen release can occur on warm, dry days. Clearly further study is needed to identify the precise meteorological and physiological factors involved in this process.

Variations in the start date may have an impact on the length of the pollen season as well as the date of the peak concentration and end date. The total seasonal pollen yield for a given taxon also depends on weather the previous summer when flower buds were initiated as well as on the daily weather during the flowering season (Solomon, 1979).

The pollen taxa recorded in this study reflect the local vegetation in the Tulsa, Oklahoma area. Much of the natural landscape around Tulsa, is a contact zone between the eastern deciduous forest and the tallgrass prairie (Levetin and Buck, 1980). The dominant vegetation is woody and includes *Quercus stellata* (post oak), *Q. marilandica* (blackjack oak), and *Juniperus virginiana* (eastern redcedar).

There are 26 species of *Quercus* in Oklahoma with ten species occurring in the Tulsa area (Buck, 1983). Although *Q. stellata* and *Q. marilandica* are clearly the dominant oaks, *Q. rubra*, *Q. muehlenbergii*, *Q. pallustris*, *Q. nigra*, and *Q. shumardii* are also important sources of oak pollen in the region. During 6 years of the current study, the seasonal totals for *Quercus* pollen were greater than other taxa investigated.

Juniperus virginiana is the dominant species of *Juniperus* in Oklahoma and populations within the state have been increasing (Snook, 1985). An Oklahoma Soil Conservation Service survey in 1985 estimated that the distribution within the state has increased by 141% since 1950. Of the 77 counties in Oklahoma, 33 indicate problems with the increased distribution of eastern redcedar. The increasing pollen concentrations recorded in this study may reflect the increase in population. Although *J. virginiana* is the dominant member of the Cupressaceae in the Tulsa area, other *Juniperus* species as well as other members of the Cupressaceae are widely used in landscaping, and undoubtedly contribute to the airborne pollen load. As a result it is likely that some of the pollen identified in the spring may belong to these other members of the Cupressaceae. The seasonal totals for these pollen were the most abundant during two years of the present study.

Four native species of *Ulmus* are found within the state with two of these, *U. americana* and *U. rubra*, widely distributed in the eastern half of the state. In addition *U. pumila* and *U. parvifolia* are used as ornamentals and are spreading without cultivation (Buck, 1983). *Ulmus parvifolia*, however, pollinates in late summer, and the data were not included in the present study. Although Dutch elm disease continues to decimate elm populations in Oklahoma, the airborne concentrations of elm pollen are still at significant levels and represent one of the most abundant atmospheric pollen types. In fact, during two years of the present investigation, 1987 and 1990, the seasonal totals for *Ulmus* pollen were larger than other taxa.

The only native birch in Oklahoma is river birch, *Betula nigra* (Levetin and Buck, 1980). This species typically occurs in stream banks, swamps, and flood plain forests in the eastern part of the state (Buck, 1983). It is also used as an ornamental throughout the area. Pollen concentrations were the lowest of the four pollen types studied, and this may reflect the smaller distribution of the taxon.

The occurrence of *Juniperus* pollen in the Tulsa atmosphere in December and January has continued to provide evidence of LDT. During this time, *Juniperus* pollen typically occurs in the Tulsa atmosphere on 40% of the days with concentrations as high as 2400 pollen grains/m^3 of air. Although no local populations of *Juniperus* pollinate at this time of the year, *Juniperus ashei* does pollinate during these months, and large populations of this species occur in southern Oklahoma and Texas. The high concentrations of *Juniperus* pollen in Tulsa occur on days with southerly winds suggesting that *Juniperus ashei* populations are the pollen source.

At the present time, we are involved in a multi-year project to determine the overall importance of LDT to the Tulsa air spora. Oklahoma may be an ideal location for studying LDT of allergenic pollen because of the presence of the Oklahoma Mesonet. The Mesonet is a system of 114 automated environmental monitoring stations spaced an average of 32 km apart across Oklahoma. Multiple sensors at each Mesonet site provide observations at either 5 min or 15 min intervals. The observations are transmitted to a central site every 15 min, archived, and then made available on-line. Meteorological parameters measured include solar radiation, temperature, rainfall, barometric pressure, and wind speed and direction at two levels on a 10 meter tower (Crawford, 1993). The availability of Mesonet data will facilitate tracking the movement of pollen and spore-laden parcels of air in future studies.

Four additional Burkard spore traps are now in operation in Oklahoma at Mesonet sites. One is located approximately 32 km southeast of the Tulsa sampling site, a second is located approximately 48 km southwest of the Tulsa site. A third sampler is 240 km south of Tulsa, and the fourth is approximately 400 km southwest of Tulsa. It is anticipated that data supplied from the southern Oklahoma Burkard Spore Traps along with the wind profiles supplied by the Mesonet data will be used to generate models of long distance transport.

5. Conclusion

The study demonstrated the continued LDT of *Juniperus ashei* pollen into the Tulsa atmospheric each winter. This investigation also found that the early spring pollination periods for allergenic tree species are highly variable and that more research is needed to understand the intrinsic and environmental mechanisms which govern the onset and magnitude of the pollen season. Meteorological data will be analyzed to determine a more objective criterion to signify the start date and identify pre-season pollen.

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