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Contribution of upwind pollen sources to the characterization of *Juniperus ashei* phenology

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Local and long-range components of *Juniperus ashei* pollen deposition were isolated to provide a more accurate record of local pollination activity in the Arbuckle Mountains of south central Oklahoma. An aerobiological sampler recorded airborne pollen concentrations and deposition at the sample site from mid-December 1998 to the end of January 1999. Grid-based weather data was used to model the movement, position, and elevation (air mass trajectories) across the region. While a normal concentration distribution is expected for a pollination event at a single site, "very high" concentrations (>1500 pollen grains per cubic meter) creating "peaks" in the deposition record were identified using bi-hourly sample analysis of the pollen registrations in the sampler. These occurrences happened over a 2½ week period beginning January 11 and are coincident with the occurrence of southerly winds throughout the region. Modeled trajectories indicate that the air masses associated with those occurrences traveled at ground level through the *J. ashei* population on the Edwards Plateau, some 200 kilometers to the south in Texas, then gained altitude prior to crossing the sample site, thus introducing a long-range pollen component at the sample site. Peaks with "high" concentrations (90 to 1500 pollen grains per cubic meter) were evaluated using the same methodology. Those peaks associated with trajectories having the potential of introducing a long-range component to the pollen deposition record were removed from the aerobiological record. The resulting adjusted aerobiological record shows a more normal pollen concentration distribution, reduced hourly variability, and a marked shift in the pollination initiation date. Based on the comparison of non-adjusted and adjusted aerobiological records, contributions from upwind pollen sources account for 55% of the total pollen record.

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The initial presentation of palynology to the scientific community in the early 1900's discussed long-distance transport and deposition of pollen and spores as contributing to the air spora at a given site (von Post 1967). Early studies found clear examples of downwind pollen and mold spore migration distant from their source (Hesselman 1919, Erdtman 1937). This demonstrated the ability of micron-sized particles to become entrained into an air-stream and carried great distances. More recent reporting of long-distance pollen transport from snow and ice deposits at high latitudes and above tree line in the Arctic (Bourgeois 1986, 1990, 2000, Fredskild & Wagner 1974, Mc Andrews 1984) and Antarctic (Smith & Lewis 1991, Wynn-Williams 1991) to exotic pollen in sedimentary profiles. An example of the later is the occurrence of *Ephedra* spp. and *Nothofagus* spp. pollen in peat deposits on Tristan da Cunha. The nearest source is tracked to South America, 4500 km away (Hafsten 1960). A common element of these studies is the ability to identify the influx of exotic pollen from local taxa. However, identification of local and long-distance components of shared common taxa is less clear.

Identification of the path traveled by the air masses from which pollen is deposited can be crucial for the identification of a long-distance component. Atmospheric modeling now allows air-mass trajectories to be estimated through space and time (Draxler & Hess 1998). However, their use has been limited, focusing on the identification of non-local taxa (Cabezudo et al. 1997) and non-seasonal influx of common taxa (Wallin et al. 1991, Hjelmroos, 1991). The preceding examples show the power of identifying air mass trajectories carrying aerobiological particles. It also is a reminder that pollen deposited at any time can originate from a variety of sources such as nearby pollinating plants, pollen entrained into the local atmosphere, re-entrained pollen previously deposited and/or pollen transported from distant sources. Empirical studies show pollen dispersal in most plants including Cupressaceae occurs in the mid-afternoon on clear warm days with low relative humidity (see Jackson & Lyford 1999, Gregory 1973, Galán et al. 1998). If this premise is accepted, it follows that pollen deposited at other times represents sources other than directly from the local population. For example, nighttime pollen peaks have been investigated in relation to changing atmospheric conditions resulting in particle deposition (Galán et al. 1989, Mullins et al. 1977, Norris-Hill & Emberlin 1991, Spieksma 1983, Spieksma & Tonkelaar 1986, Steel 1983). The particles include locally produced and re-entrained pollen as well as material transported over longer distances.

Once pollen is entrained into the atmosphere deposition is dependent upon changing atmospheric conditions (Jackson

& Lyford 1999). If the location of the upwind source area is known, then air masses that move over the population during pollen release are identifiable as potential pollen sources. By eliminating the pollen carried to the sampler by these winds, the local pollination phenology should become clearer. However, the resulting record provides only descriptive measures of the local phenology and not an estimate of the total pollen released. The exact air-mass characteristics that correlate with the downwind movement of "very high" pollen concentrations are currently unknown. However, it appears that the interplay of meso-scale weather systems in the southern Great Plains is particularly suited for long-distance dispersal. During the winter, dry cold air moves east out of the Rocky Mountains and south from the Canadian Arctic and collides with warmer, more humid air of the tropical Atlantic region to the southeast, resulting in region-wide atmospheric instability (Borchert 1950). As these weather fronts pass regional winds often blow strongly and change direction abruptly. To illustrate, an extreme case occurred on November 10, 1995 when a cold front pushed across the state of Oklahoma. Noontime temperatures in Tulsa dropped from 28.3 °C to 0.6 °C, the dew point temperature dropped from 9.4 °C to − 1.7 °C and winds shifted from the southwest (230°) to the north (350°) all within a 6 hour period (Oklahoma Mesonet; US Weather Service). This type of weather variability plays an important role in controlling particle dispersal within the *J. ashei* system.

To determine the contribution of long-distance pollen transport, aerobiological samplers monitored pollen deposition in southern Oklahoma from December 1998 to January 1999. This small isolated community presented a unique area to characterize pollination phenology because of reduced pollen influx from non-local sources. However, the potential of short-term major influx events, from the larger upwind population remained. Atmospheric modeling of air mass trajectories prior to arriving over the sampling site was used to characterize the periods of "very high" pollen registration. The same characteristics were applied to "high" registrations as a means to identify pollen concentrations that may contain a significant portion of long-distance transported pollen. The identified periods containing non-local pollen were removed from the Arbuckle Mountain aerobiological record to redefine the local phenological characteristics.

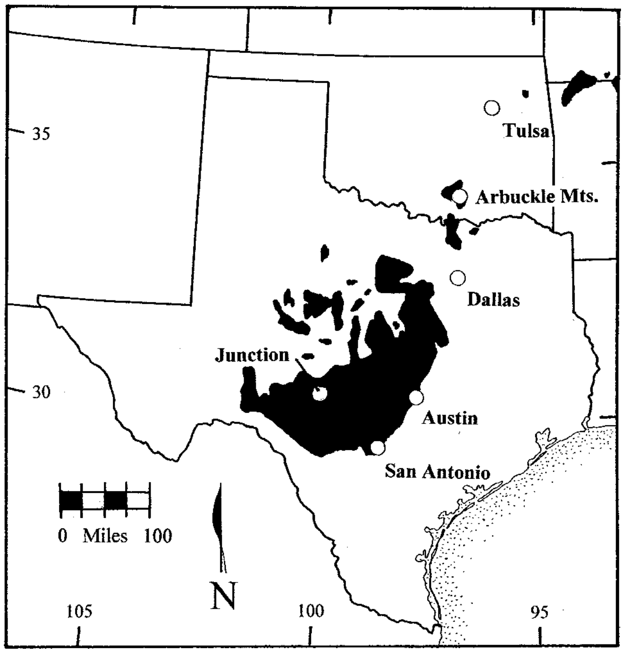

Fig. 1. The distribution of *Juniperus ashei* in the southern Great Plains of central North America. The Texas population, taken from Smeins et al. (1997) and Hatch et al. (1990), grows primarily along the southern and eastern edge of the Edwards Plateau. The populations growing in Oklahoma and the Ozark Mountains (Missouri and Arkansas) were taken from Little (1971). The current distribution of the smaller isolated communities is unknown. Data is reported from the Arbuckle Mountains of south-central Oklahoma, however sampling sites at Tulsa, OK and Junction, TX are also discussed.

METHODS

In 1998, an aerobiological sampling site was established in the Arbuckle Mountains of southern Oklahoma (Fig. 1) to determine the pollination period of the local *J. ashei* population. The site lies approximately halfway between the larger *J. ashei* population growing on the Edwards Plateau, Texas and Tulsa, OK, a site devoid of *J. ashei*, but where significant concentrations of juniper pollen have been recorded during December and January since 1980 (Levetin 1998, Levetin & Buck 1986, Rogers & Levetin 1998). The *J. ashei* population in the Arbuckle Mountains covers approximately 130 km^2 and is confined to areas with rocky exposed limestone and shallow carbonate-rich soils. Sampling occurred in the southeastern quadrant of the *J. ashei* population. The station was initially located near the Ardmore Municipal Airport (Lat. 34°18′35″N, Long. 96°59′21″W, Elev. 210 m) but was moved on January 11 approximately 2.4 km to the southeast (Lat. 34°17′15″N, Long. 96°58′59″W, Elev. 220 m). At both locations, a Burkard sampler was positioned at ground level in large clearings to prevent over-representation by nearby trees. The sampler consists of a chamber that contains a removable rotating drum with sticky tape along the outside edge. Access to the atmosphere is gained through an orifice that is positioned in front of the rotating drum. The chamber was evacuated at a constant rate of air volume (10 l/m^3) drawing particles from the atmosphere onto the sticky tape. The chamber rotates using an attached vane to ensure that the orifice faces the prevailing winds. The sampler was changed weekly and the sampling drum sent to the Aerobiology Laboratory at The University of Tulsa for processing.

In the laboratory, the sticky tape was removed and divided into 24-hour periods, mounted onto glass slides and the number of *Cupressaceae* pollen grains microscopically determined at 400×. Each slide represents a single day and was counted along 12 traverses that correspond to each even hour at 2-hour intervals. The raw counts were converted to concentrations using a standard equation that assumes a constant pumping rate. The trap malfunctioned during the study between the hours of 18:00 on December 21 and 8:00 December 22. Fortunately the period was not characterized by high pollen concentrations. Each hourly concentration value was further categorized for comparison purposes (Table I) using divisions suggested by the American Academy of Allergy, Asthma and Immunology (http://www.AAAI.org).

Air-mass trajectories were calculated using the HYSPLIT_4 particle dispersion model provided by the Air Resources Laboratory of the National Oceanic and Atmospheric Administration (http://www.arl.noaa.gov). The HYSPLIT_4 model uses the geographical position (latitude and longitude) and specified height of an air parcel to calculate the air-mass position forward and backward in time. Calculations used grid-based meteorological data from analysis or short-term forecasts using numerical weather prediction

Table I. *Pollen concentration categories.*

Used to classify each hourly pollen concentration. Categories follow the system used by the AAAAI.

Category	Pollen concentration (grains/m^3)	Pollen grains per hourly transect
Low	1–15	1–2
Moderate	16–90	3–12
High	91–1500	13–207
Very High	>1500	>207

models (Draxler 1991, Draxler & Hess1998). The backward projections used in this study were calculated using archived model results from the EDAS and EVAN databases for 73% and 23% of the cases, respectively. Trajectory data was missing in 5 (2%) of the cases. The location of the sampler provided the geographical position, and elevations used for the calculation ended at 10 m, 200 m, and 500 m above the sampler. The 10 m height represents surface winds, the 200 m height is intermediate and at 500 m the winds become increasingly influenced by upper-level weather patterns. Throughout, modeled trajectories are assumed to represent accurate estimates of past air-mass positions. The accuracy of each trajectory calculation has an associated error of 10% to 20% of the distance traveled (Draxler 1996, 1991, Stohl 1998). For example, the center of the southern *Juniperus ashei* population is approximately 400 km from the Arbuckle sampler (Fig. 1) therefore the air-mass position could vary by 40 to 80 km from the calculated location.

The *J. ashei* pollination season spans the winter months of December and January when daylight is shortened. Pollen dissemination is assumed to occur during the warmer, dryer daylight hours (Jackson & Lyford 1999, Gregory 1973, Galán et al. 1998). During this 2-month period sunrise and sunset in southern Oklahoma occurred between 07:27 and 17:58, respectively, with the winter solstice on December 22. Each model run returned the latitude, longitude and elevation of each air mass at 1-hour increments. However, only the even hours were used to match the pollen concentration data. Air-mass trajectories were calculated for each two-hour interval occurring between December 15 and January 31. This study focused on the location of each air parcel traveling during the previous day's period of pollination to determine if they were positioned over the larger pollinating populations to the south. For example, the trajectories calculated for a 12:00 sample includes the position and elevation of the air mass during the previous daylight hours at 8:00, 10:00, 12:00, 14:00 and 16:00. It is recognized that additional pollen, released locally or regionally, may be incorporated into an air mass at any time during its travel. The different source components are hard to delineate, but could contribute an unknown portion of the pollen to the sampler.

Air trajectories identified as potentially containing extra-local pollen were matched to the corresponding pollen concentrations and removed from the Arbuckle Mountain pollen record. The initial criteria applied to identify trajectory positions consist of movement over the large upwind source area on the Edwards Plateau, defined at latitudes less than 34.17° N (34° 10′00″) and longitude greater than 97.00° W (97° 00′00″). This zone encompasses an area south and west of the northwestern most *J. ashei* distribution of the Edwards Plateau population (Smeins et al. 1997, Hatch et al. 1990) (Fig. 1). Air-mass trajectories ending at 200 and 500 m above the sampling site were further analyzed to determine changes in elevation prior to arriving over the Arbuckle Mountains. Trajectories that rise over time indicate increased buoyancy resulting in the retention of entrained particles, whereas stable atmospheric conditions or sinking air is less buoyant leading to particle deposition. The elevation of each air-mass trajectory was compared at 1-hour intervals from 8:00 the previous day. Trajectories were categorized as stable if the mean trajectory elevation was $\pm 10\%$ of its height over the Arbuckle Mountains. Trajectories that rise or sink during travel were defined by their mean elevation being above or below the stable air criteria. Calculation of the vertical component assumes the same error as the trajectory pathways. However, trajectories are terminated if they exit the top of the model but if the calculated elevation intersects the ground, advection continues along the surface (Draxler & Hess 1998). The travel characteristic of each air trajectory was compared to the corresponding pollen concentration at the Arbuckle site to determine atmospheric conditions correlating to "very high" pollen influx conditions. Similar characteristics were checked against the deposition of "high" concentrations.

RESULTS AND DISCUSSION

Juniperus spp. pollen is generally considered unidentifiable at the species level. However, *J. ashei* releases pollen during a period in the winter that is distinct from other local juniper species. *Juniperus ashei* pollen was registered in the Arbuckle Mountain sampler over 46 days between December 15, 1998 and January 31, 1999 (Fig. 2). During this period, analysis of the even hour transects shows *J. ashei* pollen in 350 of the 568 analyzed, with a total of 13017 pollen grains identified. The 5th and 95th percentiles of the pollen registration

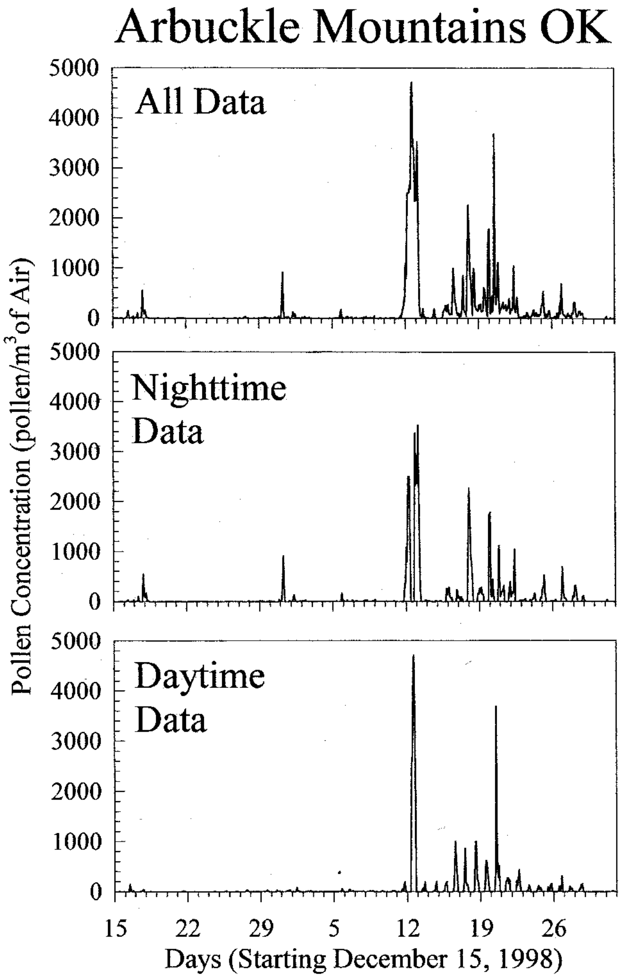

Fig. 2. Pollen concentrations recorded at the Arbuckle Mountains aerobiological sampler during the 1998/1999 pollination season. Nighttime is defined as the period between 18:00 and 6:00 whereas daytime is between 8:00 and 16:00.

distribution fell between January 7 and January 25 (Fig. 2). Peak concentrations occurred at 14:00 on January 12 (4717 pollen grains/m^3) and at 10:00 on January 20 (3688 grains/m^3), respectively. The greatest pollen concentrations, "high" and "very high" levels, occur for an extended period between January 11 and 13, whereas a secondary "very high" influx event occurs on January 20 as a single isolated reading preceded and followed by significantly lower levels.

Division of the daily pollen concentrations into daytime and nighttime registrations shows 42% (5425 pollen grains) of the pollen grains were deposited during daylight hours (8:00 to 16:00) and 58% (7592 pollen grains) were registered at night (18:00 to 6:00). The nighttime registrations occurred throughout the pollination season, with peak values recorded on January 13 (4:00; 3536 grains/m^3) and 17 (24:00; 2268 grains/m^3) (Fig. 2). In addition to peak concentrations, the influx event of January 11 to the 13 accounted for 48% of the total nighttime recordings. Additional peaks, later in the season, occur with declining intensity thought to be indicative of reduced pollen availability as the season wanes (Fig. 2). It is recognized that pollen entrained in the atmosphere at any time can represent multiple source area components. Because of this, the absolute pollen production of a population is not resolvable. To better delineate the pollination phenology of the Arbuckle Mountain trees the nighttime pollen registrations were eliminated on the assumption that local pollen production ceases after sunset (discussed later). If true, the remaining daytime registrations represent deposition from the local population in addition to a long-distance dispersal component (Fig. 2).

To determine the source of daytime pollen, each bi-hourly air mass was tracked back in time to determine the flight path position during the previous day's pollination (Figs 2, 3). Trajectories were calculated for each air mass positioned over the Arbuckle Mountains at 10 m, 200 m, and 500 m. Over 56% of the trajectories met the single criteria of crossing the southern exclusion zone. To refine the identification of those air masses transporting pollen, an additional characteristic of elevation change during transport was evaluated. During this analysis trajectories ending at 10 m were excluded because their movement was constrained by the ground surface. However, the elevation track of individual trajectories was used when associated with long-distance influx conditions. Trajectories ending at 200 m show 16 (7%) cases of "stable" conditions with "sinking" and "rising" air occurring 96 (40%) and 125 (53%) times, respectively. The 500 m trend was similar with 13 (5%) "Stable", 124 (53%) "Sinking" and 100 (42%) "Rising" cases. Combining the past position of the air masses with the change in elevation resulted in the identification of characteristics leading to "very high" concentrations at the Arbuckle Mountain sampler.

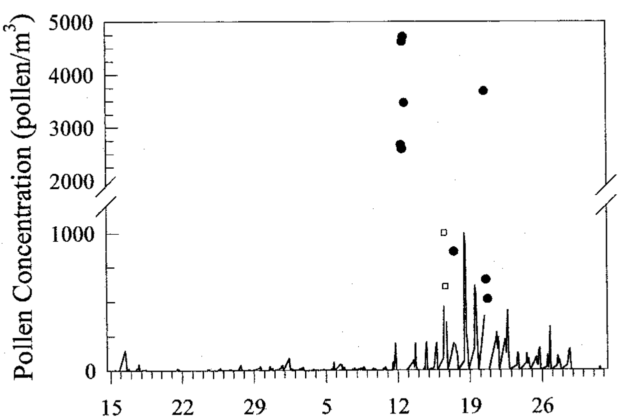

Fig. 3. The Arbuckle Mountains daytime pollen record. The resulting curve (black line) represents the phenology of the *J. ashei* trees growing at the Arbuckle Mountains. The "very high" and "high" concentrations (black circles) fitting the criteria for long-distance transport of pollen are plotted separately. In two cases (squares), "high" concentration trajectory models were not available to determine past air mass positions. However, their value in relation to the underlying distribution suggests that they fit the long-distance criteria.

Trajectories for five of the six "very high" events, occurring on January 12, track over the southern source area and are associated with a strong cold front moving south across Oklahoma. Strong southerly winds preceded the passing cold front and correlate with "very high" and "high" registrations suggesting long-distance transport from southern source region. This period is also consistent with the influx of *Juniperus* spp. pollen into the Tulsa region, 200 km further north (data not shown). Further analysis of the "very high" events show that all air masses ending at 200 m were characterized as "rising" whereas only half of the trajectories ending at 500 m share similar characteristics. The remaining trajectories show each air mass "sinking" from upper elevations. These results suggest that pollen becomes entrained and transported as each air mass moves through the southern source area near the ground, the pollen clouds then rise in elevation 6 to 12 hours prior to crossing the Arbuckle Mountains (Fig. 4, Table II). In addition, characteristics of the 500 m trajectories suggest that upper elevation air masses are more variable and because over half descended from elevations greater than 1000 m (Table II), "sinking" air probably contributes less to "very high" pollen registrations.

The January 20 "very high" event differs dramatically from the other influx periods. "Very high" concentrations occur for a single hourly count but are preceded and followed by substantially lower values. In addition, lower elevation wind trajectories associated with this event prevailed from the north and east (Fig. 5). Calculation of the 10 and 200 m air-mass positions show trajectories that begin to the west of the Arbuckle Mountains, move north along the 98th meridian then trace a clockwise spiral over Oklahoma City and into the sampler (Fig. 5). The 500 m trajectory begins in north-central Texas moves northeast then loops over itself south of the sampling site. All three trajectories were at or near ground level for an extended period of time prior to their arrival over the sampler (Table II, Fig. 5). The ultimate source of the pollen deposited at the sampling site remains unclear. Two of the three trajectories (10 and 200 m) were positioned away from *J. ashei* communities during the 32 hours proceeding deposition, whereas the 500 m trajectory was positioned close to the northern distribution of *J. ashei* (Smeins et al. 1997) (Figs 1, 5). The short duration and

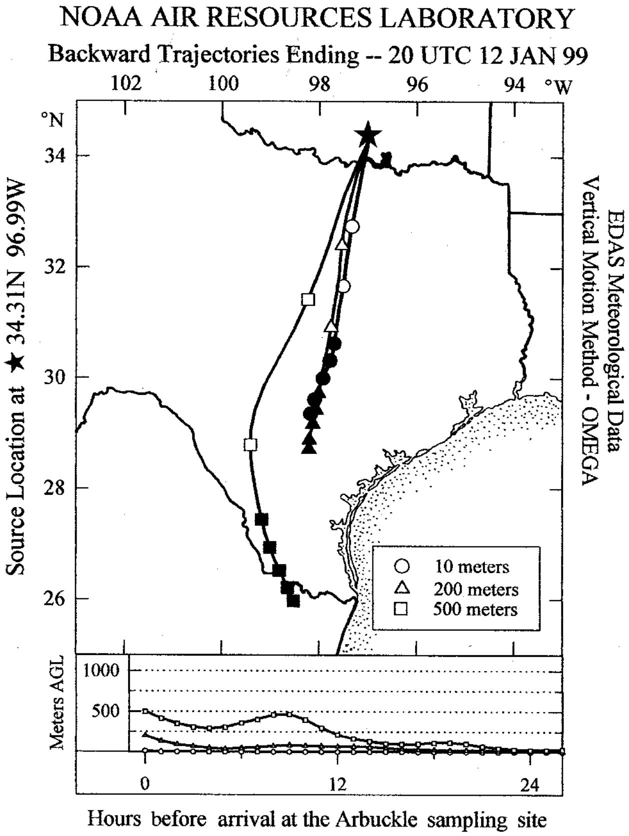

Fig. 4. Air-mass trajectories ending at 10 m, 200 m and 500 m above the Arbuckle Mountain aerobiological sampler on January 12 at 12:00. The clear symbols mark each 6-hour interval. Darkened symbols represent each of the 2-hour time periods during the previous day's period of pollination. The large influx event that occurred between the evening of January 11 and 13 shows trajectories following essentially the same pathway. The five daylight hours of January 12 are all listed as "very high" pollen concentrations. Comparison with Fig. 1 shows the trajectory pathways passing over the *J. ashei* population growing on the Edwards Plateau.

increase by an order of magnitude between 8:00 and 10:00 (Table II) suggests that the "very high" concentrations does not represent local pollen production. If so, then the influx event resulted from; 1) pollen entrained in northern Texas by the air mass trajectory tracked at 500 m, 2) pollen sustained below 500 m in air-masses that traveled through west central Oklahoma for a period greater than 24 hours, or 3) "high" concentrations incorporated from areas not directly over *J. ashei* populations.

The contribution of pollen from the 500 m trajectory appears to be the likeliest source for the January 20 event. Past studies record significant pollen concentrations well above 500 m (Hirst et al. 1967, Mandrioli et al. 1984). However in this case, the elevation characteristics are similar to the five "very high" influx events previously described. The 500 m air mass was near ground level, rising approximately 6 hours before crossing the sampler locality. The confounding factor with this source identification is that pollen transported at high elevations must fall through the 10 m and 200 m air masses that are converging from the east and southeast (Fig. 5). As these air masses cross the sampler the interactions of different wind directions with elevation should increase turbulence and lift the carrying capacity of the atmosphere (Jackson & Lyford 1999, Di-Giovanni & Kevan 1991) making settling more difficult. It is possible that the 10 m and 200 m air masses also contained significant pollen concentrations. However, to load each air mass with particles from the southern source area requires travel times greater than the previous day's pollination period. Entrained pollen can stay buoyant for an indefinite period. However, like the 500 m air mass, the 10 m and 200 m trajectories traveled at ground level for a significant period of time prior to deposition (Fig. 5). Low-level travel increases the likelihood of filtration and impaction from ground surface interactions and sedimentation as wind velocities are reduced (Di-Giovanni & Kevan 1991). The transfer of pollen from one air mass to another is an additional complicating factor. Air masses that originate over the source area may move downwind as coherent packages. If air masses join, their air mass trajectories may shift showing a pathway over seemingly sterile source locations then even though they carry pollen. However, It is envisioned that this mechanism occurs at large spatial scales where high concentrations are being exported from the large pollinating populations to the south. The characteristics of the January 20 event, a single hourly reading of "very high" levels, argues against the incorporation of pollen moving from the southern source area to the position of the previous days' trajectories. However, the five "very high" concentrations during early January probably share a component of this type of dispersal.

Characteristics associated with the deposition of "very high" pollen concentrations were used to identify similar conditions during periods of "high" registrations. The "high" concentrations were divided into two groups, those with registrations from 1500 to 500 pollen grains/m^3 (n = 9) and concentration from 500 to 90 pollen grains/m^3 (n = 5). Elevation data was unavailable for January 16th resulting in incomplete analysis of two of the nine cases in the upper division. Of the seven remaining "high" pollen events, air masses were near equally divided between "rising" and "sinking" air at 200 m (4 versus 3 cases) but shift towards sinking characteristics at 500 m (5 out of 7 cases). Mean elevation estimates of all three trajectories shows three cases for the 10 m, two for the 200 m and a single 500 m where the trajectory rises from near ground level during pollen release on the previous day (Table II). These conditions occur in association with the influx event of January 17 and 20. On January 17 only the 10 m trajectory is near ground level but is positioned over the Edwards Plateau area. On January 20, the 12:00 trajectories shows the 10 m and 200 m positioned at low elevation in the southern source area whereas only the 10 m trajectory has similar characteristics at 16:00 (Table II). The two cases where data was unavailable show similar characteristics and are thought to also represent long-distance dispersal (Fig. 3).

Analysis of the second group of "high" pollen concentrations has even fewer cases where characteristics suggest contributions made by long-distance transport. Of the remaining "high" pollen concentration trajectories, only 15 of 41 are characterized by "rising" air at both 200 m and

Table II. *Trajectory characteristics associated with the "very high" (>1500 pollen grains/m^3) and the upper two-thirds (500–1500 pollen grains/m^3) of the "high" (90–1500 pollen grains/m^3) pollen concentrations.*

The trajectory associated with each concentration was modeled using air masses at 10 m, 200 m, and 500 m trajectories. Any trajectory position within the exclusion zone (marked Y) indicates that the potential exists for long-distance transport. Air-mass characteristics were further analyzed for changes in elevation using trajectories from 200 m and 500 m. The mean elevation of each air mass during the previous days period of pollination (8:00 to 16:00) is also listed. Criteria identifying long-distance transport were established for the "very high" concentrations and then applied to the "high" concentrations. All of the top (1500–500 grains/m^3) "high" concentrations are listed whereas only those that met criteria making them potential long-distance contributors (15of 41 trajectories) are listed for the remaining "high" concentrations.
*R = rising air, S = sinking.
Mean elevation of the air mass during the previous day's period of pollination (8:00 to 16:00).

			Southwestern Trajectory			Air-Mass Characteristic*		Mean Elevation of the Previous Day's Pollination#		
Date	Hour	Pollen Conc. (pollen/m^3)	10	200 (meters)	500	200 (meters)	500	10	200 (meters)	500
Very High Concentrations										
01-12	14:00	4720	Y	Y	Y	R	R	0	2	44
01-12	12:00	4620	Y	Y	Y	R	S	1	19	1138
01-20	10:00	3690	N	N	Y	R	R	0	1	39
01-12	16:00	3460	Y	Y	Y	R	R	0	0	22
01-12	8:00	2670	Y	Y	Y	R	S	1	3	1445
01-12	10:00	2590	Y	Y	Y	R	S	0	5	1188
High Concentrations (500–1500 grains)										
01-16	12:00	1000	N	Y	Y	–	–		Unavailable	
01-18	10:00	1000	N	N	N	S	S	904	1854	2147
01-18	12:00	910	N	N	N	S	S	738	1805	2107
01-17	10:00	860	Y	Y	N	R	S	3	110	1662
01-20	12:00	660	Y	Y	N	R	R	1	3	15
01-19	10:00	620	Y	N	N	S	S	261	387	2620
01-16	14:00	610	Y	Y	Y	–	–		Unavailable	
01-19	12:00	550	N	Y	N	R	S	259	59	2269
01-20	16:00	510	Y	N	N	R	R	10	7	434
Potential Long-Distance, High Concentrations (90–500 grains)										
01-20	8:00	391	N	N	N	R	R	0	1	225
01-16	16:00	348	N	Y	Y	R	R	0	12	0
01-20	14:00	283	N	N	Y	R	R	4	19	415
01-28	14:00	152	N	N	N	R	R	0	20	74
01-27	10:00	101	N	N	N	R	R	1	5	14

500 m. One third of those trajectories, five, are characterized by mean elevation during the previous day's pollination for the 10 m and 200 m trajectories near ground level. Yet, only one of these trajectory pathways crosses the southern source zone. The trajectory occurs at 16:00 on January 16 and shows both the 200 m and the 500 m trajectory at low mean elevations over the source area during the previous day's period of pollination. The lack of characteristics in the remaining trajectories suggests that they reflect local and regional but not long-distance pollen sources.

Concentrations associated with trajectories that met the criteria for long-distance pollen influx along with all nighttime pollen depositions were eliminated from the Arbuckle Mountains record. Removal of the nighttime pollen values assumes that pollen is released during daylight hours. Warm temperatures and dry conditions are reported to influence pollination in the Cupressaceae family (Gregory 1973, Galán et al. 1998). At the Sulphur OK meteorological station mean daytime and nighttime temperatures between December 1 and January 6, the beginning of the local pollination season (5% of total pollen) in the nearby Arbuckle Mountains averaged 3.4±6.3 °C and – 1.3±5.7 °C respectively. With such low temperatures, it is reasonable to assume that warm, dry conditions exist primarily during daylight hours. However, exact climatic signals for pollen release are unknown and warrant further study. Concentrations associated with long distance dispersal characteristics were removed leaving a curve that better reflects pollination phenology within the Arbuckle Mountain population. "Low" to "moderate" pollen levels characterize the pollen record until approximately January 11. Over the next 16 days concentrations rise and fall approximating a normal curve, with peak concentrations of 1000 pollen grains/m^3 reached on January 18. The pollination season start date (5% of total) shifts to January 6, 1999, five days earlier than the date recorded (16:00 01-11-99) with daytime values including the long-distance concentrations. The season extends an additional three days (10:00 01-28-99) compared to calculations using all of the data. The resultant distribution curve appears slightly skewed toward the later portion of the month (Fig. 3). The skewed distribution is consistent with previous reports and may result from the re-entrainment of previously released pollen (Rogers 1993) or release of residual pollen grains from open cones.

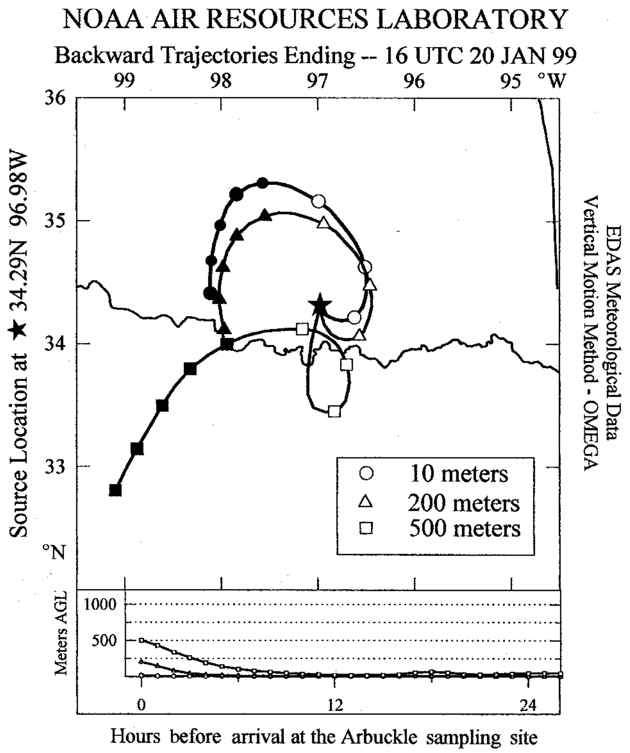

Fig. 5. The diagram shows the air-mass trajectories from the single hourly event associated with "very high" pollen concentrations on January 20 at 10:00. The symbols are the same as in Fig. 4. Unlike the other "very high" trajectories, winds associated with the January 20th event swept over areas that do not support *J. ashei* communities as can be seen by comparison with Fig. 1.

Recent studies involving genetically modified crops suggest that long-distance transport and deposition of pollen is a relatively rare occurrence (Conner & Dale 1996, Lavigne et al. 1996, 1998), a view also established in the palynology literature (Faegri & Iversen 1989:143). Yet, long-distance dispersal in the *J. ashei* system is remarkably common. This study shows more than 55% of the pollen registered at the Arbuckle Mountains can be tracked to distant, up-wind sources. During the same period more than 3500 pollen grains were recorded in Tulsa (600 km distant) (data not shown). In addition, influx events in Tulsa over the past 19 years have recorded *J. ashei* pollen on 40% of the days during December and January (Levetin 1998). The large number of pollen grains produced by J. ashei trees aids the ease of dispersal. Recent work with related species report pollen production values reaching 6.4×10^9 to 1.1×10^{12} pollen grains per individual tree (Hidalgo et al. 1999), a value that breaks down to approximately 400,000 pollen grains per male cone (Nilsson & Praglowski 1992, Hidalgo et al. 1999). The large distribution of *J. ashei* on the Edwards Plateau provides an ample airborne pollen source. However, the strength of the potential source ultimately lies with the distribution and density of male trees within the population (Hidalgo et al. 1999). Van Auken (1988) found mean vegetation densities on the Edwards Plateau in evergreen woodlands of 2568 ± 973 plants/ha of which 40% to 70% were *J. ashei.* Yet, the distribution of males to females remains unknown.

This study shows that pollen influx from extra-local sources can contribute a significant percentage of the registrations at a sampling station. This is problematic where the pollination phenology of the local population is being studied. Climatic factors leading to the initiation of pollen release have been modeled in *Alnus* and *Populus* (Andersen 1991, Frenguelli et al. 1991), *Betula* (Dahl and Strandehede 1996), *Corylus* (Frenguelli et al. 1992), *Fraxinus* (Candau et al. 1994), *Olea Europaea* (Frenguelli et al. 1989, Gonzalez Minero & Candau Fernández-Mensaque 1996), Poaceae (Frenguelli et al. 1989, Emberlin et al. 1994) and Cupressaceae (Galán et al. 1998). Studies employ aerobiological samplers to register pollen concentrations that are then compared to climatic records. Parameters that drive pollen release are calculated using multiple years of aerobiological data. However, without considering the source of the pollen that is trapped, long-distance transport may unrealistically influence these results. For example, using the Arbuckle Mountain record without considering the pollen source would conclude that heavy pollination began earlier, peak concentrations lasted longer, and concentration values were four to five times greater. This study indicates that long-distance transport of pollen must be considered as a significant component when analyzing aerobiological records.

CONCLUSIONS

The long-distance transport of significant pollen concentrations from upwind sources can significantly alter registrations in aerobiological samples, affecting the interpretation of the resulting records. Nighttime pollen deposition was the most significant pollen contributor to the Arbuckle Mountain sampler. Once removed, air mass trajectories were reconstructed for each of the bi-hourly pollen registrations. Air masses crossing the southern source area on the Edwards Plateau were identified as potential contributes to long-distance pollen concentrations. Additional analysis shows "very high" concentrations traveling at or near ground level through the source area that then climb in elevation before arrival at the aerobiological sampler. These characteristics were used to identify trajectories contributing pollen from outside sources during "high" pollen concentrations. The removal of those pollen concentrations associated with the suspect trajectories resulted in a more normal pollen distribution thought to better reflect the local pollination phenology.

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