
Hourly variation of airborne ragweed pollen in Kansas City

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Introduction: Ragweed pollen is one of the major causes of allergic rhinitis in the midwest United States. Previous studies have demonstrated that ragweed pollen production begins after sunrise and airborne pollen levels peak several hours later. Variations in this pattern that may be of clinical importance within a small region and the effect of weather on these variations have not been investigated.

Methods: Volumetric pollen collectors were stationed at four sites around the metropolitan area. Ten-minute grab samples were taken at each location every 2 hours for continuous 24-hour periods during the 1997 ragweed season. The downtown location had a weather station that logged meteorological conditions at hourly intervals during this time. Ragweed pollen grains were counted microscopically at 400 $\times$. Uninterrupted data covering at least 20 days during the season were evaluated for each collection site.

Results: The lowest ragweed pollen counts occur at 6:00 AM and the highest occur at noon for both suburban and urban sites. Rainfall was seen to be the most influential weather-related factor. Significant rainfall events effectively removed pollen grains from the air.

Conclusions: Though ragweed pollen emission begins at 6:00 AM, peak pollen exposure occurs at midday. This observation is in agreement with many other studies. The myth that highest ragweed exposure occurs in the early morning hours is not supported by this or previous studies.

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INTRODUCTION

Since early Durham sampler measurements in 1944, the determination of airborne concentrations of ragweed pollen has been of interest to the community of allergists.¹ Several studies conducted from 1954 to 1970 evaluated the diurnal pattern of ragweed pollen emission using several different collection devices and proximity to the source of pollen.^{2–6} These studies, along with extensive and elegant work by Dingle et al,⁷ concluded that plants tend to release their pollen 1 to 3 hours after sunrise with the largest number of grains reaching downtown metropolitan areas 2 to 4 hours later, depending

on meteorological conditions for transport. Despite this information, an informal poll of practicing allergists revealed a common belief that peak ragweed pollen exposure occurs early in the morning, leading them to give advice that ragweed-allergic patients should avoid outdoor exposure during the early morning hours.

The purpose of this study was to determine the timing of the distribution of airborne ragweed pollen throughout a metropolitan area. In addition, we wanted to determine how weather affects pollen transport. Our hypotheses were that pollen levels would be higher in the suburbs than in the center of the city, and that center-city peaks would occur later in the day. We also hypothesized that warm, dry, mildly windy weather would be conducive to pollen transport. To test these hypotheses, we measured pollen concentrations at every 2-hour interval at four locations scattered over an area of approximately 1,600

square miles while simultaneously measuring relevant weather conditions.

MATERIALS AND METHODS

Bioaerosol Samplers

Air for visual identification of pollen grains and fungal spores was collected at four sites throughout the Kansas City metropolitan area using a volumetric suction collector (Sampler MK-3; Allergenco/Blewstone Press, San Antonio TX). The Allergenco collector was calibrated to sample 15 L of air per minute using a Vitalograph spirometer (Vitalograph Inc, Lenexa, KS) that had itself been calibrated with a 3-liter syringe. Materials for collection including microscope slides, cover slips, and storage boxes were obtained from Curtin Matheson Scientific (Houston, TX). Chemicals and ingredients for mounting media and stains were obtained from Sigma Chemical Company (St. Louis, MO).

The MK-3 Sampler collects air through a vertical slit on its top, so we protected it from direct rainfall with a 1-meter square roof suspended 2 feet over the collector. This device draws air into the unit through the 1.117 $\times$ 14.5 mm slit at a rate of 15 L per minute. Particles in the air, including spores and pollen grains, impact onto a microscope slide that we coated by dipping into a suspension of silicone grease in hexane. The slide is mounted on a tray located inside the unit. The slide moves in discrete intervals of 1 mm at the beginning of each programmed collection interval. For this study the collectors were programmed to collect for 10 minutes at the beginning of each 2-hour period. The unit therefore produced 12 individual discrete collections during every 24-hour period that was sampled.

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Sampling Protocol

The air samplers were installed in four locations throughout the Kansas City metropolitan area (Fig 1). The central location was on the roof of a hospital building in the center of the city (designated A). It is in the vicinity of other tall buildings, but it is one of the highest points in the area and the highest point for at least a 1-kilometer radius. The other three samplers were placed approximately 20 miles away from the central unit to the East (B), Northwest (C), and Southwest (D). All the peripheral samplers were located in suburban residential areas at least 10 m away from any structure. The residential areas were all well-foliated with many mature trees and lawns in the immediate vicinity. Two of the residential locations (East and Northwest) were in proximity to large lakes, and all suburban locations were within 1 kilometer of parkland or other unmanaged areas of vegetation. The central sampler was located five stories above ground level whereas the other samplers were placed in their individual covers approximately 3 feet above the ground. Air for this study was collected between August 15 and October 1, 1997, a time period that included the ragweed pollen season for the region. Samplers were operated in accordance with specifications for optimum performance given by the manufacturer.

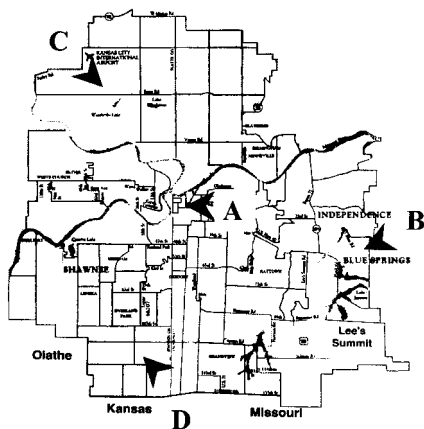


Figure 1. Picture of Kansas City metropolitan area indicating the collection sites for the study. The sites are located in the Center of the city (A), East (B), Northwest (C) and Southwest (D).

Weather Data

Meteorological information was monitored at the central collection site using an Automated Weather Source weather station (Gaithersburg, MD). The station recorded temperature, humidity, rainfall, wind velocity, and wind direction at 2-hour intervals throughout the duration of this study. Calibration of the weather station was done remotely by the manufacturer over the Internet using averaged data from similar stations scattered over the local area.

Quality Assurance

To measure variation in pollen counts introduced by different persons counting slides, a subset of the slides that contained different total pollen counts was enumerated by each of the three people who did the counting. A coefficient of variation was therefore determined for values obtained within and among counters.⁵ The Pollen and Mold Network of the American Academy of Allergy, Asthma, and Immunology has certified the individuals who did the counting for this study. To determine the effect of wind velocity on pollen collection efficiency, approximately 100 2-hour counts generated by both a nearby Burkard (Burkard Manufacturing, Ltd) collector (which is wind-oriented) and the central Sampler MK-3 (which is not wind-oriented) were compared. These results have been reported previously.⁵

Pollen Counts

All slides were examined using methods described previously.⁸ Briefly, slides were stained with glycerin jelly containing 1.0% Calberla's solution (MultiData LLC, St. Louis Park, MN), fitted with a coverslip, and examined at 400 $\times$ for pollen using a Zeiss Axioscope (Carl Zeiss, Inc., Thornwood, NY) microscope. No factors reflecting a presumed collection efficiency of the sampler units were applied. Pollen counts are all expressed as particles per cubic meter of air.

Handling and Storage of Slides

Slides were changed daily between 6:00 and 8:00 AM. Weekday slides

were transported to the central station for staining, mounting, and counting. Weekend slides were also transported to the central station to be stained and mounted once a week and saved for counting at a later date. All slides were archived for reference. This report conveys only the result of daily counts for which every 2-hour interval was available. So that numbers from the 2-hour intervals could be averaged, no incomplete or partial day counts were included in the data set.

Calculations and Statistical Methods

For determination of average hourly ragweed counts, only days with full data for all periods were included. The percentage of daily ragweed was calculated by summing counts for all periods in 1 day (0:00 to 22:00), and dividing each 2-hour ragweed count by that sum to give hourly percentages for each day. The time points for all days were averaged and the average of the daily percentages for each of the collection sites is reported in Table 1.

RESULTS

Quality Assurance

The purpose of this study is to compare the ragweed pollen counts in the Kansas City metropolitan area as they vary from hour to hour during the 1997 pollen season. We initially looked for factors that might introduce variations in the counts because of individual differences in counting. Those differences that occurred between and within individuals who produced the counts showed very little deviation. For particle densities up to 400 per cubic meter of air, no person produced counts that deviated more than 20% from the mean generated by all three counters.

Ragweed Pollen Counts

Daily ragweed counts for the four collecting sites throughout the entire season are shown in Figure 2. Ragweed pollen was present for 11 weeks with the highest counts occurring during the first and second weeks in September. Two of the suburban sites, B and C, had the highest daily pollen counts with counts at B exceeding 500 parti-

Table 1. The data represent the average percent of the total daily ragweed collection that is collected at each time point. The sites are located in the Center of the city (A), East (B), Northwest (C) and Southwest (D). The sites are described in Figure 1.

Time	Percentage of Daily Total Ragweed			
	Center City A	East B	Northwest C	Southwest D
0:00	7.8 ± 7.1	5.2 ± 2.3	5.6 ± 5.1	7.5 ± 4.5
2:00	6.1 ± 6.5	4.4 ± 2.1	12.6 ± 22.9	4.6 ± 2.5
4:00	7.8 ± 9.0	3.5 ± 2.1	7.4 ± 8.0	3.3 ± 2.4
6:00	4.6 ± 3.3	6.6 ± 3.2	8.1 ± 9.2	3.1 ± 3.7
8:00	8.2 ± 5.0	9.1 ± 9.3	4.7 ± 5.4	3.7 ± 3.0
10:00	10.1 ± 5.5	10.4 ± 7.3	10.2 ± 7.9	10.8 ± 8.8
12:00	13.6 ± 7.9	15.2 ± 4.2	10.1 ± 8.1	18.4 ± 17.1
14:00	10.1 ± 4.0	10.8 ± 4.1	11.2 ± 9.4	16.8 ± 8.5
16:00	9.3 ± 4.5	9.3 ± 2.1	10.3 ± 8.1	14.1 ± 4.4
18:00	8.5 ± 4.3	8.8 ± 6.2	7.6 ± 5.0	14.5 ± 6.7
20:00	9.4 ± 6.1	9.3 ± 11.3	6.7 ± 5.3	8.9 ± 5.3
22:00	7.2 ± 4.2	7.3 ± 3.6	5.4 ± 5.6	6.2 ± 3.9

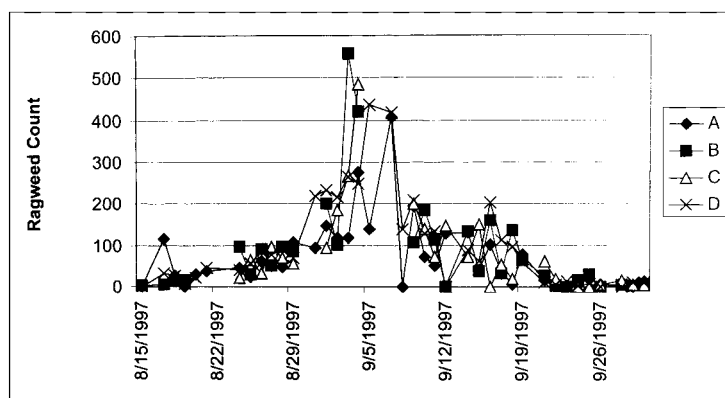


Figure 2. A graphical representation of the daily ragweed counts for the four collection sites. Daily counts are determined by averaging the 2-hourly counts for all time periods over a 24-hour period. The sites are located in the Center of the city (A), East (B), Northwest (C), and Southwest (D).

cles per cubic meter during one period (Fig 2). The highest daily counts generated at the center city site (A) were just more than 400 particles per cubic meter. At the height of the season, daily counts in the suburbs were often double the counts at A. All the sites generated daily counts more than 400 particles per cubic meter at least once during the season. The counts at the center city location were higher at times both early in the season (third week in August) and later in the season (first week in October), but the suburban sites produced higher counts on most days.

The routine daily cycle of humidity had little relation to the overall pattern

of ragweed pollen (data not shown). On a few occasions when relative humidity (RH) was 100% and a rainfall event occurred, pollen was washed from the air. Likewise, the relation of temperature and airborne ragweed pollen showed no discernible interdependency (data not shown). There is a clear pattern of dependency when ragweed pollen counts are displayed in conjunction with rainfall events (Fig 3). The occurrence of 100% RH and a rainfall event effectively washed the pollen from the air. There were two clear occurrences: one on August 18th and another on September 22nd (Fig 3).

The average 2-hourly counts from suburban and urban sites are seen on

Table 1. All indicate that ragweed counts are lowest just before sunrise between 4 and 6 AM. Counts rise after 6 AM and reach peak concentrations around noon. When individual daily counting data are examined (data not shown), no day had the highest counts at 6 AM and 70% of the days had the highest counts at noon. For the four sites examined, there was a significant difference between the average count at noon and the average count at 6 AM, but counts at other hours did not have any significant differences.

DISCUSSION

Overall, these data relate specific airborne ragweed pollen particulate counts at four different sites around the Kansas City metropolitan area for the 1997 ragweed pollen season. The pollen levels generally agree from site to site, but there is a distinct disparity in the magnitude of the counts between the suburban sites and the urban site. As would be predicted, the pollen levels are generally higher at the suburban sites. Weather conditions produced an effect on ragweed pollen levels mostly in the ability of precipitation to wash pollen grains from the air. Pollen levels were mostly unperturbed by temperature in this study. The daily collection results agree with numerous other investigators who observe that ragweed pollen production begins at sunrise (around 6:00 AM) and continues throughout the morning with highest counts around midday.

The results of our quality control efforts are mostly as anticipated. Variations in the counts that could have been introduced by different individuals who produced the counts were not observed. The three individuals who produced the 2-hourly counts offered quite similar results. Also, ragweed pollen grains are of a very characteristic appearance and quite easily distinguished from other airborne pollens found in this area at this time of year. The collections for the MK-3 device were obtained in precise 10-minute periods spaced by 110-minute intervals. The lack of wind orientation of the

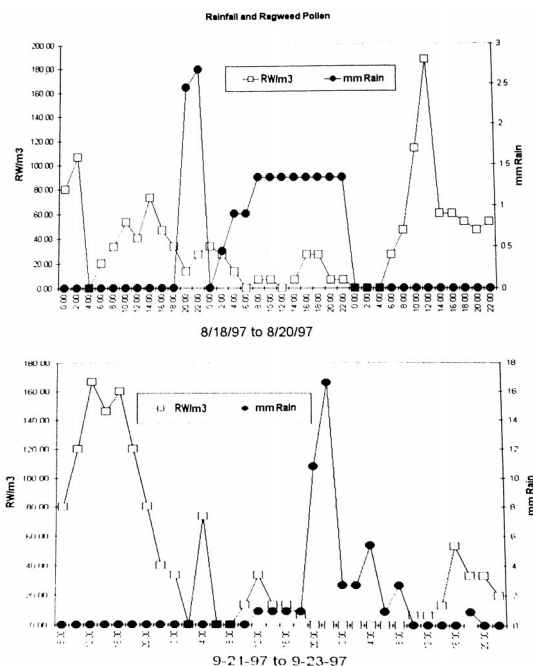


Figure 3. Chart of 2-hourly ragweed particle counts at location A in particles per cubic meter of air and rainfall rates in mm per hour at the same location for the rainfall periods August 18th, 1997 to August 20th, 1997 and September 21st, 1997 to September 23rd, 1997. This chart demonstrates pollen grain removal from the air in the wake of rainfall events

collecting device did not have a significant impact on the pollen collections. The absence of a bias in favor of the wind-oriented collector was not unexpected and has been addressed in a separate publication.⁵ Also, Ogden and Raynor⁹ evaluated this topic in 1960. They indicated that variations in collection efficiency are not expected at wind speeds near the intake velocity of the collector. We do understand that special circumstances producing sustained wind speeds more than 15 mph may result in low collection efficiency in nonwind-oriented devices.¹⁰ However, this was not a practical problem in our circumstances, which may have been impacted by a wind baffle effect,¹¹ caused by the proximity of adjacent buildings.

This represents a fairly typical ragweed season for this part of the country, and the weather conditions are not out of the ordinary. The ragweed season this year began on August 6th, 1997, but the first significant counts

were not seen until August 24th. High temperatures were in the 90s and low temperatures were in the 70s for most of the period. The temperature did not exceed 100° F at any point during the season.

The influences of weather on the ragweed pollen counts were variable. Because we had very few extremes in temperature, we saw no significant trends relating pollen production and ambient temperature. Our findings agree with those of Ogden et al⁴ in that temperature did not seem to affect pollen levels except as temperature impacts RH and precipitation events. Perhaps, if there had been a period of very hot, dry weather (temperatures > 100° F.), we would have seen an effect; but, this year, temperatures were quite moderate. RH affected pollen levels because of its correlation with rainfall. A rainfall event as seen on August 18th and September 22nd (Fig 3) can wash virtually all the pollen from the air. We did not see any nighttime release events as described by Ogden et al.⁴ However, the average pol-

len levels seen at midnight throughout the study (Table 1) were 5% to 8% of daily totals, which does not preclude such events. These data are not sufficient to test the previous observation^{3,4} that ragweed release occurs when RH and temperature invert. Those authors monitored pollen within a few meters of the plants whereas our collections were at least 100 meters from the nearest pollinating plant.

There were some differences between the collecting sites, but these were mostly as anticipated. The first ragweed pollen of the season was seen in our suburban sites. These were only 1 or 2 isolated grains. The first significant numbers of pollen grains were counted at the central location beginning August 19th (Fig 2). Likewise the central collecting site collected the last significant numbers of pollen grains on October 14th. On both occasions, the pollen grains were probably a result of transport from distant locations. The collector at the central location is on the top of a five-story building and is expected to be much more sensitive to long-range transport than the collectors located only 3 feet above ground level. The highest counts were recorded during the first and second weeks in September, which is very much expected for a site at this latitude^{12,13}. The highest counts for the year were seen at the suburban sites (Fig 2). When specific time periods were examined, the East site recorded over 1,200 grains per cubic meter of air on September 3rd at 4:00 PM, but the calculated daily ragweed counts did not reach this level. This site is located adjacent to a lake in an area heavily foliated with *Ambrosia*. The Northwest suburban site recorded counts of 1,086 grains per cubic meter of air on September 3rd at noon. The increased magnitude of the counts may have been caused by the difference in the aboveground height of the collectors. However, there may also have been reduced airflow around the ground level collectors. The greatest variation in counts for any 24-hour period was at the East site on September 9th, when counts dropped from 1,066 at noon to 93 at 10:00 PM. This

fluctuation did not occur in conjunction with a rainfall event or with a rapid change in temperature or humidity. However, there was an unusual fluctuation in barometric pressure with some accompanying wind gusts more than 20 mph around the time that counts were highest. This is in good agreement with the observations of Ogden et al.⁴ who recorded peak pollen emissions associated with the establishment of unstable weather conditions, including increasing winds.

The finding that 2-hourly counts from all sites (Table 1) indicate ragweed counts are lowest just before sunrise between 4 and 6 AM and rise after 6 AM reaching peak concentrations at noon is not surprising. Numerous other authors have documented this phenomenon^{1-3,14,15}. An observation of the plants reveals phenomena as described by Bianchi et al.³ Specifically, the anther sacks extend in the early hours after sunrise and pollen grains are ejected and deposited on proximal vegetation at that time. At a later time, after sufficient drying occurs, the pollen grains become airborne in response to wind speed and turbulence. Studies of planted ragweed fields where plants were induced to pollinate early by manipulating the photoperiod indicated pollen deposited on gravity slides 2 feet aboveground level was maximum at 8:00 AM and 90% of pollen was deposited before noon.⁷ Because we would expect there to be little or no ragweed adjacent to the central location, it is reasonable to assume that peak levels might occur earlier in the day at the suburban sites and later in the day at the urban site. This presumes all the pollen counted at the urban site originates in rural areas. As seen in Table 1, this was not the case. A subsequent examination of ragweed sources revealed good stands of *Ambrosia* along the sides of a railroad track, which was within 1 kilometer of the urban site. Our results are consistent with a similar study in Iowa City in 1953.¹⁶ The observation of highest counts at noon and lowest counts at 6:00 AM is consistent with both ex-

pected results and previous observations. There has, however, been a perpetual and persistent myth associated with daily ragweed levels. This myth relates that highest counts occur at 6:00 AM. This misinterpretation was probably a result of reports that pollination starts at sunrise which is around 6:00 AM at that time of year. This myth has been carried to the extent that some physicians advise their ragweed-sensitive patients to avoid early morning activities, such as jogging. This advice seems to be nonproductive because the lowest ragweed counts of the day are generally found at this time.

CONCLUSIONS

The conclusions we draw from this study are not unexpected, but they have not been restated for some time. Primarily, we conclude that airborne ragweed pollen counts are generally lowest at 6:00 AM, around sunrise, and highest around noon after pollen grains have had the opportunity to dry and become airborne. This is consistent not only with previous measurements, but also with observations of the pollination process itself. The hypotheses that pollen levels would be higher in the suburbs than in the center of the city, and that center-city peaks would occur later in the day were not strongly supported. The peak and nadir pollen concentration at all sites occurred at approximately the same time. Our hypothesis that warm, dry, mildly windy weather would aid pollen transport was partially supported in that rainfall reduced airborne pollen. We conclude that under normal weather conditions, temperature and relative humidity have minimal effects on the day-to-day ragweed pollen counts. In contrast, rainfall events and unstable atmospheric conditions have the greatest impact on airborne ragweed pollen counts of all the weather-related events.

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