

Interannual variability of pollen productivity and transport in mid-North America from 1997 to 2009

Kendra K. McLauchlan · Charles S. Barnes ·
Joseph M. Craine

Received: 23 March 2010 / Accepted: 26 October 2010
© Springer Science+Business Media B.V. 2010

Abstract Understanding the causes of interannual variability in atmospheric pollen concentration is an important but elusive goal for public health and environmental change. We analyzed long-term daily records of pollen counts from urban Kansas City, Missouri, USA collected from 1997 to 2009 for three pollen groups: *Ambrosia*, Poaceae, and a third group which is mostly composed of arboreal pollen types. The annual pollen index varied from 8,368 to 80,822 over the thirteen-year period. Although *Ambrosia* pollen is often thought to be associated with droughts and disturbance, years with high *Ambrosia* pollen were associated with high summer precipitation to the south of Kansas City. Years with high Poaceae pollen were associated with high spring precipitation to the south of the city. In support of the southern influence to Kansas City pollen, *Ambrosia* and Poaceae pollen mostly arrived on southern winds. In contrast to the other two pollen groups, the arboreal pollen was most associated with growing

season precipitation to the east of Kansas City, although it was still highest on days with southern winds. Based on the correlations with climate, the severity of an upcoming allergy season may be predicted with early-season precipitation data, while short-term severity can be forecast from local weather patterns.

Keywords Climate · Grass · Great plains · Pollen · Ragweed

1 Introduction

Pollen is a potent allergen, and it is ubiquitous in the Earth's lower atmosphere. Yet, it has been surprisingly difficult to predict pollen abundance at a given time and place. Pollen abundance from atmospheric samples is frequently quantified, particularly in urban areas, as part of public health programs (Ziska et al. 2009; Kinney 2008). Over time, records of these pollen counts can be queried with respect to environmental variables to determine drivers of pollen productivity. One striking pattern that emerges from these records is the degree of variability in pollen concentrations from year to year (Garcia-Mozo et al. 2006; Reese and Liu 2005; Peternel et al. 2006). We know little about the causes of this interannual variability and what factors, physical or biological, influence pollen production.

K. K. McLauchlan (✉)
Department of Geography, Kansas State University,
Manhattan, KS 66506, USA
e-mail: mclauch@ksu.edu

C. S. Barnes
Children's Mercy Hospital, Section of Allergy
and Immunology, Kansas City, MO 64108, USA

J. M. Craine
Division of Biology, Kansas State University,
Manhattan, KS 66506, USA

Climate is likely one of these factors because it influences both plant biology (growth, flowering, phenology) and pollen transport. Precipitation has been identified as a meteorological variable correlated with pollen counts, but its mechanism is often unclear. For example, rainy days have been observed to lower pollen counts (Perez et al. 2009; Peternel et al. 2006), but low precipitation was correlated with high amounts of *Ambrosia* pollen in Poland over a 15-year period (Stepalska et al. 2002; 2008). Similar correlations occurred in both rural and urban areas in Europe, leading to the possibility of constructing regional models that could predict pollen counts (Sikoparija et al. 2006; Pashley et al. 2009). However, the identity of the most important climate parameters for pollen counts, especially in North America, is still unknown.

Another factor to consider is the spatial area contributing to the pollen loading of a particular location. In aerobiology, most researchers consider local conditions, within a few hundred metres of a pollen sampling station, to be most relevant. Theoretical work on the spatial details of pollen production and transport confirms that any specified point receives most of its pollen from a local (within 2 km) source area (Sugita 2007; 1994). However, regional and large-scale patterns certainly play a role in local pollen loading. There are spatial connections among the amounts of grass pollen received by 13 sites in Europe (Smith et al. 2009). Episodes of long-distance transport between 100 and 1,000 km have been demonstrated for birch (*Betula*) pollen (Mahura et al. 2007) and ragweed (*Ambrosia*) pollen (Smith et al. 2008; Cecchi et al. 2007).

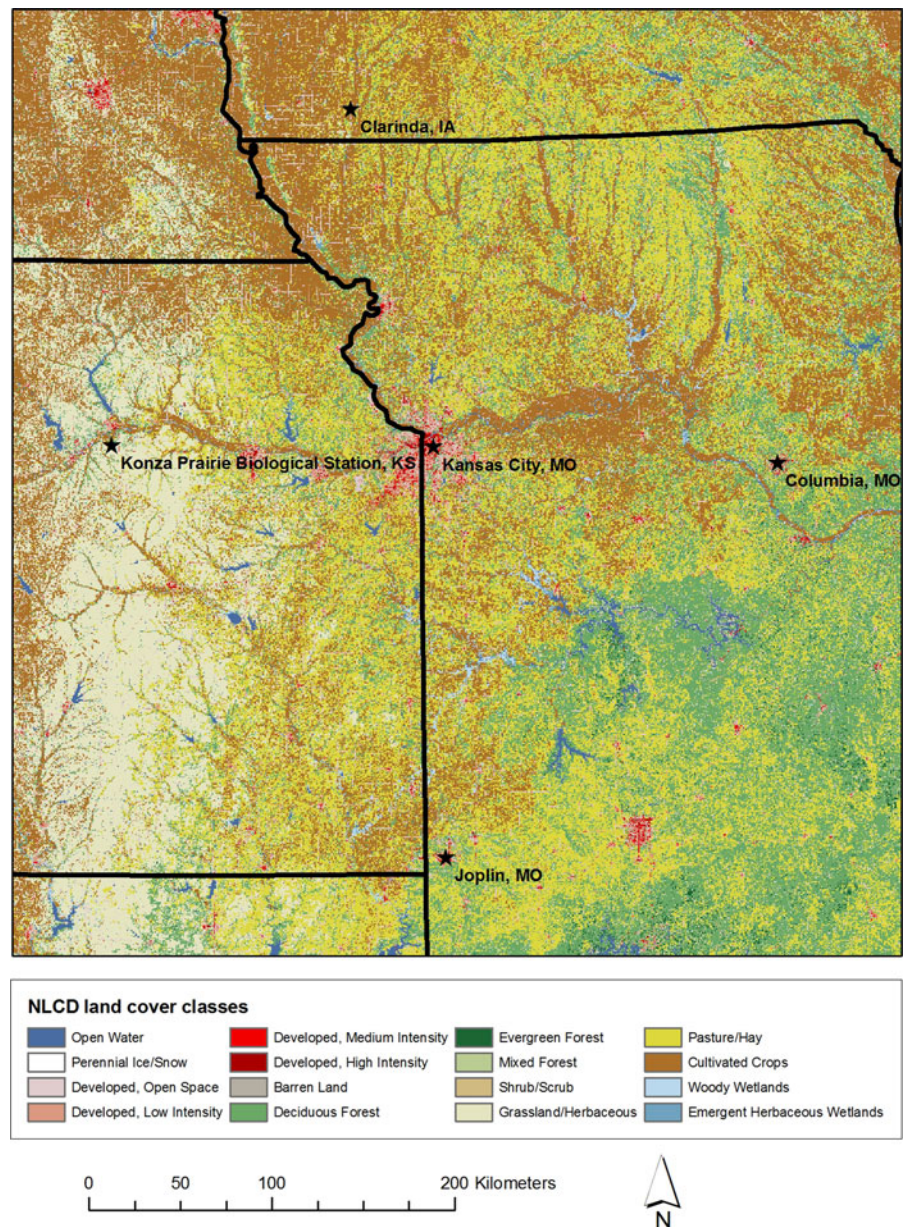
To further investigate spatial relationships between climate and pollen loading, we focused on the Great Plains of North America, a region dominated by grassland vegetation but bordered by forest (Fig. 1). As a result of its proximity to grassland, the Kansas City, Missouri metropolitan area receives some of the highest *Ambrosia* and Poaceae pollen counts in the U.S.A. These two pollen types are both highly allergenic and highly abundant. There are several species of ragweed (genus *Ambrosia*) native to North America, and three species in particular are abundant on the grasslands of the Great Plains: *Ambrosia artemisiifolia*, *Ambrosia psilostachya*, and *Ambrosia trifida* (Weaver 1968). *A. artemisiifolia* and *A. trifida* have annual life cycles; *A. psilostachya* is a perennial.

The pollen of these three species is morphologically identical in a light microscope, and thus they comprise an *Ambrosia* pollen type in most palynological studies. Poaceae cannot reliably be resolved to further taxonomic levels except for cultivated crops. Poaceae is therefore a single pollen type in grasslands, despite clear ecological differences among species, especially cool-season and warm-season grasses (Towne 2002). Our goals in this study were (1) to quantify the degree of interannual variability in pollen counts for *Ambrosia* and two other pollen groups, (2) to identify the climate variables correlated with variation in pollen counts, and (3) to determine the spatial locations correlated with pollen counts in the Kansas City metropolitan area.

2 Methods

The average climate of Kansas City, Missouri, is midcontinental, with most of the precipitation received during the growing season in northern hemisphere summer. Average annual precipitation is 95.5 cm. Temperatures average 12°C annually and monthly averages range from 6.5 to 17.6°C throughout the year. The atmosphere at a single location in Kansas City, Missouri, USA was sampled with a Hirst type spore and pollen trap (Burkard Manufacturing Company Ltd., Rickmansworth, Hertfordshire, UK). The collection unit is located on top of a 5-story building, Children's Mercy Hospital, near the middle of the Kansas City Metropolitan Area (Fig. 1). Material from the atmosphere is collected onto grease-coated slides or Melinex tape and stained with Calberlas stain in glycerin jelly (Barnes et al. 2001). Pollen and spores are visually identified at 400X using a Zeiss Axioscope light microscope. An air volume of approximately 14.4 m³ is sampled each day. For this study, we analyzed records of certain pollen types in these samples from 29 March 1997 to 26 November 2009 by adding the number of pollen grains collected during a 24-hour period and expressing them as an average of daily pollen grains m⁻³ of air. For some analyses, we added the daily pollen counts for each individual year to calculate an annual pollen index. In this study, we focused on three pollen categories: (1) *Ambrosia* pollen type, (2) Poaceae pollen type, and (3) all other taxa. This third group can be justified by its unique pollen

Fig. 1 Map of study region with five weather station locations and National Land Cover Database cover classes



season and large proportion of arboreal pollen. The “other taxa” category includes all arboreal pollen types (*Quercus*, *Juniperus*, *Pinus*, etc.) and miscellaneous herbaceous taxa such as *Artemisia*, Asteraceae, and Chenopodiaceae.

Meteorological data were monitored within 20 m of the pollen sampling location using a station from Automated Weather Source (Gaithersburg, MD, USA). Data for five weather variables were collected and recorded: temperature, humidity, rainfall,

wind velocity, and wind direction. Because weather conditions distal to the pollen collection station may also influence pollen amounts and types, we obtained data for four weather stations surrounding the Kansas City metropolitan area. These four weather stations are located approximately 200 to 250 km from the pollen sampling station in each of the four cardinal directions. The station to the north is located in Clarinda Iowa, to the east in Columbia, Missouri, to the south in Joplin, Missouri, and to the

west at Konza Prairie Biological Station in Manhattan, Kansas (Fig. 1).

To determine the relationships between weather conditions and annual pollen index over the 13-year period, we determined the critical climate periods among the five stations for each pollen type. An analysis of critical climate period identifies the most influential period of time for a biological response variable using statistical tests as described below (Craine et al. 2009). From the daily data of the five weather stations, we calculated total precipitation for 861 periods between 1 March (Day of Year 60) and 3 October (Day of Year 276). This period of time is the growing season for this region. The minimum length of a period was 15 days and the maximum length was 215 days. Essentially, this produces all the possible climate periods that could be influencing plant growth and flowering. To determine when precipitation at a given time of year most affects the Kansas City pollen flux, we performed three forward step-wise regressions with summed precipitation during all 861 climate periods at the five weather stations. The climate period with the highest sums of squares value was selected as the critical climate period for the 13-year record. The climate period with the next highest sums of squares was added to the model if it did not temporally overlap with the first one and was from the same location, or if it was at a different location. Secondary critical climate periods were required to increase the coefficient of determination by 0.10. In general, a parallel process with temperature found that there was no direct effect of temperature at any time on pollen production beyond what could be explained by precipitation. All statistics were analyzed in JMP 8.0.2 (SAS Institute, Cary, NC).

3 Results

3.1 Daily patterns

The basic phenology of the pollen season varies among the three pollen types (Fig. 2). The *Ambrosia* season is relatively short and late in the year, with 95% of the grains being received from 17 August to 1 October over all 13 years. The grass season is more prolonged, with 95% of the pollen falling between 21 April and 9 September. There is a peak in grass

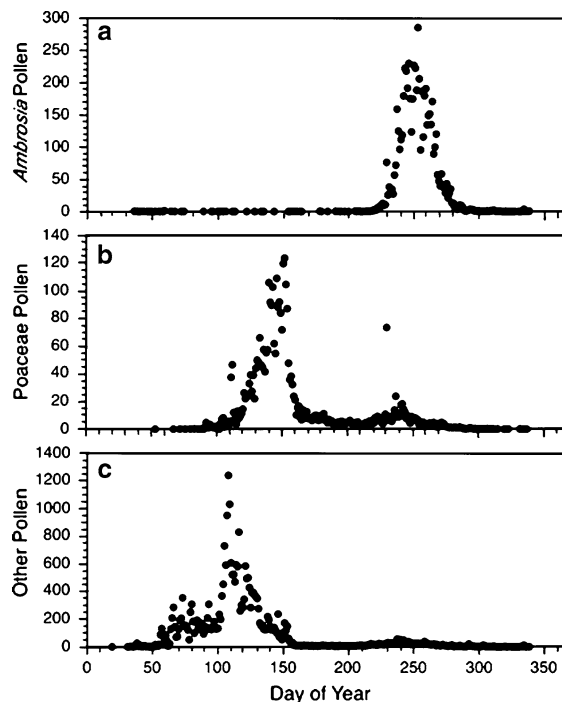


Fig. 2 The basic annual pattern of pollen seasons in the Kansas City metropolitan area. The total annual pollen sum for a single Day of Year was averaged for a 13-year period 1997 to 2009 for **a** *Ambrosia*, **b** *Poaceae*, and **c** other pollen types

pollen at 23 May reflecting the flowering of cool-season (C_3) grasses and a smaller second peak at 18 August reflecting the flowering of warm-season (C_4) grasses. All other pollen types have a relatively early peak in early April, as this category reflects a variety of different arboreal pollen types.

Daily pollen counts at Kansas City are most closely associated with wind direction and not with other weather variables such as wind velocity, precipitation, air pressure, and humidity (Fig. 3). The wind direction is usually from the south, which creates high pollen fluxes from the south. In fact, 41% of all pollen grains are received when wind direction is from the south (135° – 225°) (Fig. 3a). Concentration of pollen is relatively evenly distributed among wind directions. Winds from the south do not carry more pollen than winds from other directions (Fig. 3b). Within the *Ambrosia* pollen season (8 August through 7 September), there was no relationship between daily precipitation and daily *Ambrosia* pollen flux ($P = 0.44$). Similarly, pollen fluxes were not related to daily precipitation for *Poaceae* ($P = 0.84$) or other pollen types ($P = 0.91$).

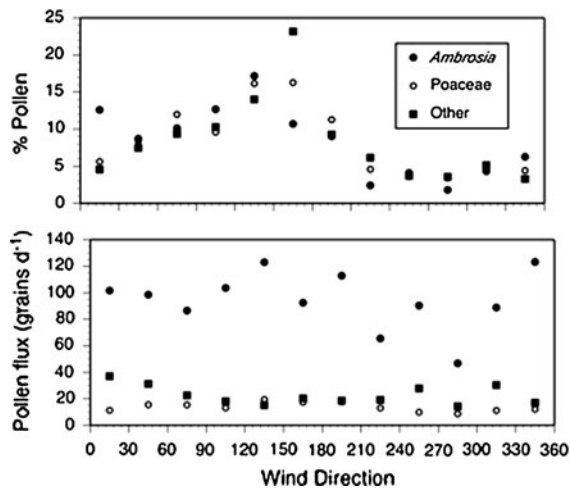


Fig. 3 Average wind direction and quantity of three pollen groups at the Kansas City, Missouri, sampling station for the period 1997 to 2009. Wind direction is binned in 30-degree increments with the midpoint shown such that North is 0°, East is 90°, South is 180°, and West is 270°. The y-axis of the top panel is calculated as the percentage of a single pollen type arriving with that wind direction averaged over all 13 years

during their respective seasons (21 March through 16 November; 1 February through 26 November, respectively). Daily average air pressure and humidity explained no more than 2% of the daily variation in pollen counts for any group in their respective season.

3.2 Interannual patterns

Over 13 years, there was over an order of magnitude variation among years in the quantity of pollen grains reaching the Kansas City sampling station. The total number of grains reaching the station in a year ranged from 2,856 to 11,963 grains of *Ambrosia*, 1,205–11,237 of Poaceae, and 3,903–58,274 of all other types (Table 1). *Ambrosia* makes up on average 17% of the pollen reaching the Kansas City sampling station in a year, while Poaceae comprises 10% on average. Overall, 2007 and 2008 were high pollen years for *Ambrosia* (>11,000 grains). For Poaceae, 2008 was also an exceptionally high pollen year (>11,000 grains), while 2008 and 2009 were high years for the other pollen types (>50,000 grains).

There is a strong regional climatic influence on the amount of pollen received in Kansas City. Among the five weather stations, the best overall predictor of pollen sums in Kansas City is the weather station in Joplin, MO (Table 2). Years with high precipitation between 5 May through 13 September in Joplin, MO, was associated with high annual flux of *Ambrosia* pollen (Fig. 4; $r^2 = 0.74$, $P < 0.001$). The general relationship was consistent even if the two very high pollen years of 2007 and 2008 were excluded from the analysis (data not shown). Like *Ambrosia*, Poaceae pollen was most influenced by precipitation

Table 1 Annual pollen influx and percentage of annual influx summarized for each year of the monitoring record for Kansas City, Missouri, USA

Year	<i>Ambrosia</i>		Poaceae		Other	
	Annual sum	Percent of total pollen	Annual sum	Percent of total pollen	Annual sum	Percent of total pollen
1997	4,926	29.7	2,001	12.1	9,648	58.2
1998	2,856	16.3	2,172	12.4	12,541	71.4
1999	3,191	16.7	1,329	7	14,584	76.3
2000	5,462	21	1,916	7.4	18,686	71.7
2001	2,979	16.6	1,857	10.3	13,121	73.1
2002	6,712	15.5	4,989	11.5	31,580	73
2003	6,880	16.5	4,322	10.4	30,468	73.1
2004	4,667	11.2	3,587	8.6	33,599	80.3
2005	6,326	18.8	3,020	9	24,301	72.2
2006	4,304	15.1	2,722	9.5	21,544	75.4
2007	12,052	35.2	2,747	8	19,447	56.8
2008	11,311	14	11,237	13.9	58,274	72.1
2009	7,213	11.6	4,181	6.7	50,999	81.7

Table 2 Results of regressions for the annual sum for each of three pollen types in Kansas City, Missouri, from 1997 to 2009

	Date range	Location	r^2	Intercept	Estimate	P
<i>Ambrosia</i>	5 May to 13 September	Joplin, MO	0.74	−2,232	16.0	<0.001
Poaceae	16 March to 11 April	Joplin, MO	0.72	−507	38.1	<0.001
	5 May to 21 May	Joplin, MO	0.16		16.0	0.004
Other	1 March to 3 October	Columbia, MO	0.75	−23,938	69.1	<0.001

to the south, but was driven by precipitation earlier in the season. Poaceae pollen increased with precipitation during the critical climate period of 16 March through 11 April (partial $r^2 = 0.68$, $P < 0.001$) as well as 5 May through 21 May (partial $r^2 = 0.16$, $P < 0.004$). These results are broadly consistent even if the extremely high pollen counts from 2008 are excluded. In contrast to *Ambrosia* and Poaceae pollen, pollen from all other types was most associated with precipitation to the east of Kansas City, increasing with increasing precipitation over the entire growing season. Precipitation from 1 March through 3 October in Columbia, MO, is the critical climate period for pollen types that are not *Ambrosia* or Poaceae ($r^2 = 0.75$, $P < 0.001$).

4 Discussion

We observed a large amount of interannual variability, up to an order of magnitude, in quantities of pollen received in Kansas City among years. These differences likely have clinical implications for allergy symptoms in this urban area (Portnoy and Barnes 2003). Variation in precipitation is driving most of this variability, with number of grains of all three pollen groups increasing with increasing precipitation. There are a few years with anomalously high pollen counts, and these causes remain unknown. Sometimes, a given pollen year is high for all three allergenic pollen types (i.e. 2008), and sometimes only one type increases (i.e. *Ambrosia* in 2007). Long-distance transport has been implicated in particularly high *Ambrosia* counts in Italy (Cecchi et al. 2007). Our current analysis did not distinguish between differences in pollen productivity or pollen transport, both of which may be influenced by climate (Edmonds 1979).

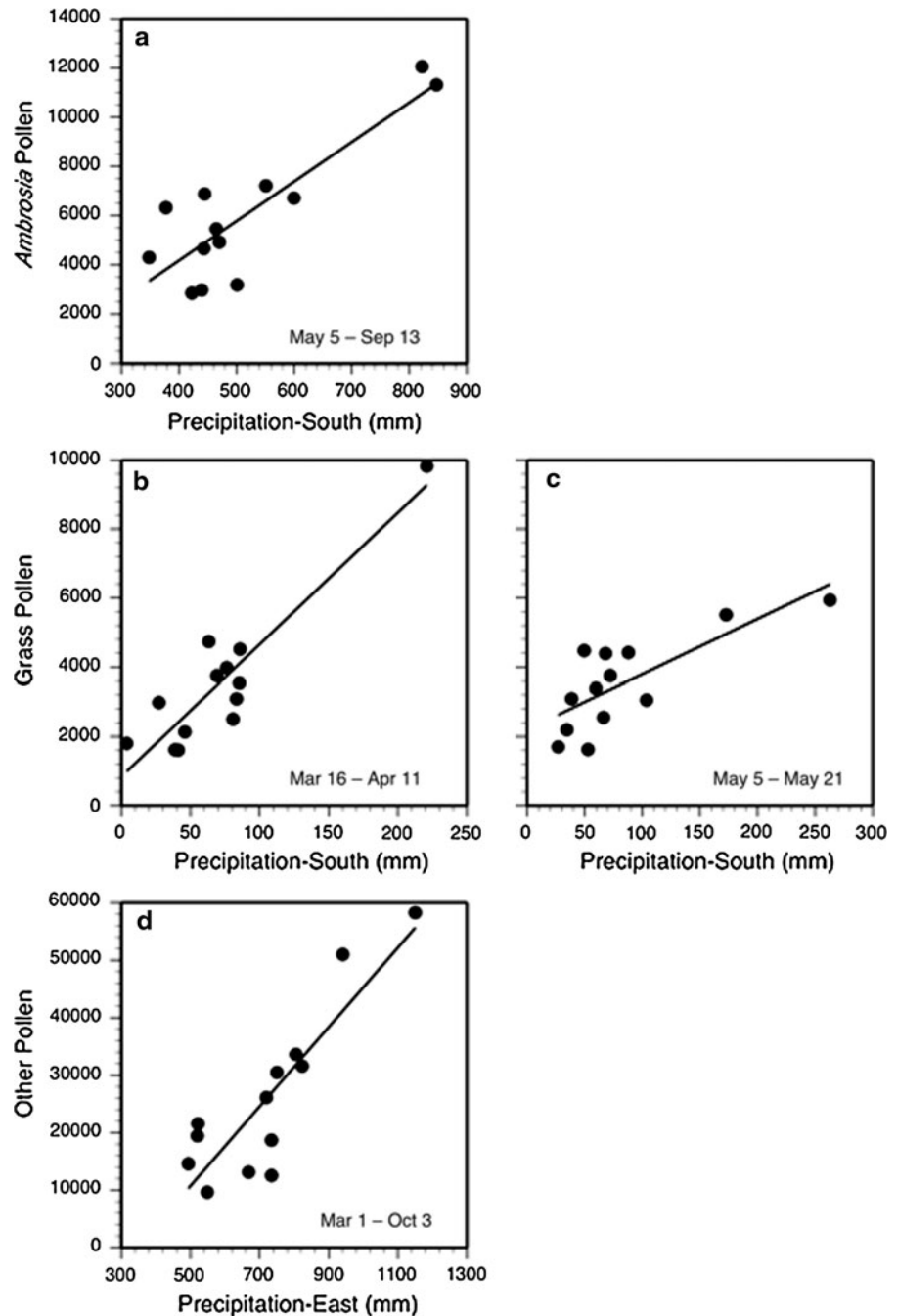
The lack of an effect of rainfall on daily pollen counts, especially *Ambrosia*, was unexpected. Other

researchers in a variety of regions have found that heavy rainfall during the season can lower pollen counts either through damage to flowers or decreasing atmospheric transport (Barnes et al. 2001; Perez et al. 2009). Theoretically, there should be an upper limit to amount of rainfall that plants can tolerate during certain times of their life-cycle (Mao and Huang 2009). However, we did not observe these relationships in this study. In this region, plant growth appears to be limited by moisture availability (Knapp et al. 2001); similarly, pollen production likely increases when more water is available to plants through precipitation. This water limitation of plant growth may override any negative effect of rain events on pollen transport.

The timing of the pollen seasons for each taxon correlates with the timing of regional flowering. *Ambrosia* species begin flowering in eastern Kansas in late July (Towne 2002). Poaceae pollen exhibits two flowering peaks associated with C₃ and C₄ grasses. C₃, or cool-season, grasses contribute most of the Poaceae pollen to the Kansas City area but seem to be influenced by the same climatic variables as the C₄, or warm-season, grasses. The other pollen types, which are mostly arboreal pollen, are associated with the early spring flowering of trees (Pendell et al. 2007; Pendell et al. 2008).

Two lines of evidence indicate that a region to the south of Kansas City influences pollen counts. Both the wind direction analysis and the critical climate period analysis show the importance of forested areas to the south of the city for pollen counts. This is unexpected in light of Environmental Protection Agency regulations on air quality in Kansas City implicating rural areas to the west of the metropolitan area. In particular, agricultural burning of rangeland in the Flint Hills of Kansas contributes source pollutants for the Kansas City area. We did not see a similar source area for pollen grains, possibly due to differences between smoke and pollen transport

Fig. 4 Linear regression models between precipitation during four critical climate periods and quantity of pollen measured in Kansas City, Missouri, from 1997 to 2009: **a** annual *Ambrosia* sum and precipitation in the south, **b** annual Poaceae sum and precipitation in the south during the first critical climate period, **c** annual Poaceae sum and precipitation in the south during the second critical climate period, and **d** annual other (mostly arboreal pollen) sum and precipitation in the east



(Martin et al. 2009; Chamecki et al. 2009). Local and regional sources of pollen have not been separated in this analysis, but the strong influence of weather conditions 200 km from the pollen sampling station in Kansas City, Missouri, indicates at least some regional role in these urban pollen counts.

Qualitative predictions of the severity of an upcoming allergy season could be greatly improved using the critical climate period technique described here. All three pollen types respond strongly to regional precipitation, but in different ways. Because we did not restrict the length of the critical climate

period in our analysis, the predictor variables were precipitation during a long period of time. For example, the critical climate period for the non-*Ambrosia*, non-Poaceae pollen group was 210 days, effectively the entire growing season. If prediction is the ultimate goal, our analysis could be restricted to find a critical climate period prior to August. Based on the correlations with climate, the severity of an upcoming allergy season may be predicted with early-season precipitation data, while short-term severity can be forecast from local weather patterns.

Acknowledgments We thank Julie Commerford for providing cartographic assistance. Jay Portnoy, Julie Landuyt, Freddy Pacheco, Frank Hu, and Minati Dhar provided the original pollen data from Children's Mercy Hospital. Mary Knapp provided data from three weather stations. Konza Prairie Biological Station provided weather data from Kansas. We appreciate helpful discussions with Doug Goodin and John Harrington Jr. This research was supported by grant BCS-0821959 from the National Science Foundation to K.K.M. The data collection has been supported at times by Marriion-Merrill-Dow and the Kansas City Allergy Society and throughout its history by Children's Mercy Hospital.

References

- Barnes, C., Pacheco, F., Landuyt, J., Hu, F., & Portnoy, J. (2001). The effect of temperature, relative humidity and rainfall on airborne ragweed pollen concentrations. *Aerobiologia*, 17, 61–68.
- Cecchi, L., Malaspina, T. T., Albertini, R., Zanca, M., Ridolo, E., Usberti, I., et al. (2007). The contribution of long-distance transport to the presence of *Ambrosia* pollen in central northern Italy. *Aerobiologia*, 23(2), 145–151. doi:10.1007/s10453-007-9060-4.
- Chamecki, M., Meneveau, C., & Parlange, M. B. (2009). Large eddy simulation of pollen transport in the atmospheric boundary layer. *Journal of Aerosol Science*, 40(3), 241–255. doi:10.1016/j.jaerosci.2008.11.004.
- Craine, J. M., Towne, E. G., Joern, A., & Hamilton, R. G. (2009). Consequences of climate variability for the performance of bison in tallgrass prairie. *Global Change Biology*, 15(3), 772–779. doi:10.1111/j.1365-2486.2008.01769.x.
- Edmonds, R. L. (1979). *Aerobiology: The ecological systems approach*. Stroudsburg, Pennsylvania: Academic Press.
- Garcia-Mozo, H., Perez-Badia, R., Fernandez-Gonzalez, F., & Galan, C. (2006). Airborne pollen sampling in Toledo, central Spain. *Aerobiologia*, 22(1), 55–66. doi:10.1007/s10453-005-9015-6.
- Kinney, P. L. (2008). Climate change, air quality, and human health. *American Journal of Preventive Medicine*, 35(5), 459–467. doi:10.1016/j.amepre.2008.08.025.
- Knapp, A. K., Briggs, J. M., & Koelliker, J. K. (2001). Frequency and extent of water limitation to primary production in a mesic temperate grassland. *Ecosystems*, 4(1), 19–28.
- Mahura, A. G., Korsholm, U. S., Baklanov, A. A., & Rasmussen, A. (2007). Elevated birch pollen episodes in Denmark: Contributions from remote sources. *Aerobiologia*, 23(3), 171–179. doi:10.1007/s10453-007-9061-3.
- Mao, Y. Y., & Huang, S. Q. (2009). Pollen resistance to water in 80 angiosperm species: Flower structures protect rain-susceptible pollen. *New Phytologist*, 183(3), 892–899. doi:10.1111/j.1469-8137.2009.02925.x.
- Martin, M. D., Chamecki, M., Brush, G. S., Meneveau, C., & Parlange, M. B. (2009). Pollen clumping and wind dispersal in an invasive angiosperm. *American Journal of Botany*, 96(9), 1703–1711. doi:10.3732/ajb.0800407.
- Pashley, C. H., Fairs, A., Edwards, R. E., Bailey, J. P., Corden, J. M., & Wardlaw, A. J. (2009). Reproducibility between counts of airborne allergenic pollen from two cities in the East Midlands, UK. *Aerobiologia*, 25(4), 249–263. doi:10.1007/s10453-009-9130-x.
- Pendell, G. G., Hu, F., Portnoy, J., & Barnes, C. (2007). Global climatic change and its impact on oak pollen season in the Midwestern US. *Annals of Allergy, Asthma & Immunology*, 98(1), A107–A107.
- Pendell, G. G., Hu, F., Pacheco, F., Portnoy, J., & Barnes, C. (2008). Seasonal and daily patterns of Cupressaceae pollen in Kansas City. *Journal of Allergy and Clinical Immunology*, 121(2), 81.
- Perez, C. F., Gassmann, M. I., & Covi, M. (2009). An evaluation of the airborne pollen-precipitation relationship with the superposed epoch method. *Aerobiologia*, 25(4), 313–320. doi:10.1007/s10453-009-9135-5.
- Petermel, R., Culig, J., Hrga, I., & Hercog, P. (2006). Airborne ragweed (*Ambrosia artemisiifolia* L.) pollen concentrations in Croatia, 2002–2004. *Aerobiologia*, 22(3), 161–168. doi:10.1007/s10453-006-9028-9.
- Portnoy, J., & Barnes, C. (2003). Clinical relevance of spore and pollen counts. *Immunology and Allergy Clinics of North America*, 23(3), 389–410. doi:10.1016/s0889-8561(03)00028-6.
- Reese, C. A., & Liu, K. B. (2005). Interannual variability in pollen dispersal and deposition on the tropical Quelccaya Ice Cap. *Professional Geographer*, 57(2), 185–197.
- Sikoparija, B., Radisic, P., Pejak, T., & Simic, S. (2006). Airborne grass and ragweed pollen in the southern Panonian Valley—consideration of rural and urban environment. *Annals of Agricultural and Environmental Medicine*, 13(2), 263–266.
- Smith, M., Skjoth, C. A., Myszkowska, D., Uruska, A., Puc, M., Stach, A., et al. (2008). Long-range transport of *Ambrosia* pollen to Poland. *Agricultural and Forest Meteorology*, 148(10), 1402–1411. doi:10.1016/j.agrformet.2008.04.005.
- Smith, M., Emberlin, J., Stach, A., Rantio-Lehtimäki, A., Caulton, E., Thibaudon, M., et al. (2009). Influence of the North Atlantic oscillation on grass pollen counts in Europe. *Aerobiologia*, 25(4), 321–332. doi:10.1007/s10453-009-9136-4.
- Stepalska, D., Szczepanek, K., & Myszkowska, D. (2002). Variation in *Ambrosia* pollen concentration in southern and central Poland in 1982–1999. *Aerobiologia*, 18(1), 13–22.

- Stepalska, D., Myszkowska, D., Wolek, J., Piotrowicz, K., & Obtulowicz, K. (2008). The influence of meteorological factors on Ambrosia pollen loads in Cracow, Poland, 1995–2006. *Grana*, 47(4), 297–304. doi:[10.1080/00173130802492849](https://doi.org/10.1080/00173130802492849).
- Sugita, S. (1994). Pollen representation of vegetation in quaternary sediments: Theory and method in patchy vegetation. *Journal of Ecology*, 82, 881–897.
- Sugita, S. (2007). Theory of quantitative reconstruction of vegetation II: All you need is love. *Holocene*, 17(2), 243–257.
- Towne, E. G. (2002). Vascular plants of Konza prairie biological station: An annotated checklist of species in a Kansas tallgrass prairie. *Sida*, 20, 269–294.
- Weaver, J. E. (1968). *Prairie plants and their environment: A 50 year study in the Midwest*. Lincoln, Nebraska, USA: University of Nebraska Press.
- Ziska, L. H., Epstein, P. R., & Schlesinger, W. H. (2009). Rising CO₂, climate change, and public health: Exploring the links to plant biology. *Environmental Health Perspectives*, 117(2), 155–158. doi:[10.1289/ehp.11501](https://doi.org/10.1289/ehp.11501).