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## AMBIENT POLLEN CONCENTRATIONS AND EMERGENCY DEPARTMENT VISITS FOR ASTHMA AND WHEEZE

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### Abstract

**Background**—Previous studies report associations between aeroallergen exposure and asthma exacerbations. Aeroallergen burdens and asthma prevalence are increasing worldwide and are projected to increase further with climate change, highlighting the importance of understanding population-level relationships between ambient pollen concentrations and asthma.

**Objective**—To examine short-term associations between ambient concentrations of various pollen taxa and emergency department (ED) visits for asthma and wheeze in the Atlanta metropolitan area between 1993 and 2004.

**Methods**—We assessed associations between the three-day moving average (lag 0-1-2) of Betulaceae (except *Alnus*), Cupressaceae, *Quercus*, Pinaceae (except *Tsuga*), Poaceae, and *Ambrosia* pollen concentrations and daily asthma and wheeze ED visit counts, controlling for covarying pollen taxa and ambient pollutant concentrations.

**Results**—We observed a 2–3% increase in asthma and wheeze ED visits per standard deviation increase in *Quercus* and Poaceae pollen and a 10–15% increased risk on days with the highest concentrations (comparing the top 5% of days to the lowest 50% of days). A standard deviation increase in Cupressaceae concentrations was associated with a 1% decrease in ED visits. The association for *Quercus* pollen was strongest for children age 5 to 17 years. Effects of *Ambrosia* pollen on asthma exacerbations were difficult to assess in this large-scale temporal analysis due to possible confounding by the steep increase in circulating rhinoviruses every September.

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**Conclusion**—Poaceae and *Quercus* pollen contribute to asthma morbidity in Atlanta. Altered *Quercus* and Poaceae pollen production due to climate change could affect allergen-induced asthma morbidity in the southeastern United States.

### Keywords

pollen; asthma exacerbation; wheeze; pollinosis; aeroallergens; bioaerosols; ozone; climate change; epidemiology

## INTRODUCTION

Previous epidemiological studies have reported associations between ambient pollen levels and various measures of asthma morbidity (1–6). However, the specific pollen taxa implicated have not been consistent across studies, which may be partially attributable to geographic differences in the prevalence of plant species, their related allergens, pollen concentrations and allergic sensitization profiles of the populations under study. In addition, determining the shape of the exposure-response curve for highly skewed pollen distributions and controlling adequately for time and meteorology in time-series studies present methodological challenges and may explain differences in results among studies (7).

The incidence of asthma and other allergic respiratory diseases has increased dramatically worldwide in the last three decades (8). Projected changes in pollen production due to climate change magnify the importance of understanding relationships between asthma exacerbations and pollen concentrations (9). Improved understanding of specific exposure-outcome relationships can facilitate a wide range of adaptation activities that may reduce the associated health impacts (10).

We investigated short-term associations between pollen levels and asthma exacerbations in the metropolitan Atlanta area using a large time series of over 400,000 emergency department (ED) visits for asthma and wheeze between 1993 and 2004. We assessed associations for four tree taxa (Betulaceae, Cupressaceae, *Quercus* and Pinaceae), Poaceae (grasses), and *Ambrosia* (ragweeds). The large sample size allowed for tight control of time trends and temperature as well as secondary analyses in which we explored the shape of the dose-response, confounding among the pollen taxa, age-specific effects and confounding and effect modification by ambient pollutant concentrations.

## METHODS

### Pollen Data

Airborne pollen concentrations were measured by the Atlanta Allergy and Asthma Clinic (AAAC), a member of the National Allergy Bureau, between January 1, 1993 and December 31, 2004 (Figure 1). The monitoring site was moved once on January 1, 2000; pollen was sampled from the same rooftop height at both locations and away from vegetation, air conditioners and building vents. National Allergy Bureau Certified AAAC staff analyzed air samples five days per week (Sunday-Thursday) using a Rotorod sampler (Model 40). The Rotorod was set to spin for 30 seconds every 10 minutes and pollen was collected on a plastic I rod (dimensions: 23 mm × 1.59 mm) coated with silicone grease. After each 24-hr sampling period, the I rod was placed in a stage adapter and stained with Calberla's solution. As per Rotorod manufacturer instructions, the entire surface (using 3 and 1/3 longitudinal sweeps) was examined microscopically at 400X magnification, and counts of individual pollen taxa were converted to concentration (pollen grains/m<sup>3</sup> of air). Since pollen grains deposit on the rods in a random manner along the collector surface (11), during peak pollen

seasons, counts were obtained from one longitudinal sweep over the rod, with concentration conversion calculations adjusted accordingly.

We selected several pollen taxa *a priori* for evaluation in epidemiologic analyses based on allergenic potential and prevalence in Atlanta, including Betulaceae (birches, hornbeam, hophornbeam, and hazelnut, but excluding alder), Cupressaceae (junipers, cedars, and bald cypress), *Quercus* (oaks), Pinaceae (pines, spruces, fir, except hemlock). Pinaceae was selected as a “control” pollen taxon as it is thought to only infrequently cause serious allergic responses (12, 13). We also included Poaceae (grasses), and *Ambrosia* (ragweeds). For our main epidemiologic analyses, the two days (Friday-Saturday) of missing pollen data each week were estimated using linear interpolation. In a model validation exercise, imputations for Tuesdays and Wednesdays were reasonably correlated with corresponding measured pollen levels, with Spearman correlation coefficients ranging from 0.65 (Cupressaceae) to 0.84 (*Quercus*). In sensitivity analyses, we excluded the Friday-Saturday imputed data from the epidemiologic models.

### Ambient Air Pollution Data

Monitoring data from available monitoring networks in the study area were used to create daily, population-weighted spatial average pollutant concentrations for 8-hour maximum ozone; 1-hour maximum carbon monoxide (CO), nitrogen dioxide (NO<sub>2</sub>), and sulfur dioxide (SO<sub>2</sub>); and 24-hour average particulate matter less than 10 μm (PM<sub>10</sub>) and 2.5 μm (PM<sub>2.5</sub>) in diameter, as described in detail elsewhere (14). We have examined associations between ED visits and these air quality metrics in previous analyses (15).

### Emergency Department Visit Data

We obtained individual-level data on ED visits for the 20-county (7964 sq. mile) Atlanta population through computerized billing records collected from 41 acute care hospitals for the 1993–2004 time period (Figure 1) (16). For each patient visit, hospitals provided the date of admission, International Classification of Diseases 9<sup>th</sup> Revision (ICD-9) diagnostic codes, patient date of birth and residential ZIP code.

We defined ED visits for asthma and wheeze as all visits with a primary or secondary ICD-9 code indicating asthma (493.0–493.9) or wheeze (786.09 before October 1, 1998; 786.07 beginning October 1, 1998) that did not also have a code for an external injury or poisoning (E800–E999) (15). Asthma ED visits were grouped into three age categories: 0–4 years, 5–17 years, and 18+ years. We identified ED visits for acute upper respiratory infections (URI; 460.0–466.0) without a concurrent ICD code for asthma or wheeze. We also created a control outcome group for finger wounds (883) because these visits were unlikely to be causally related to pollen levels. The study protocol was approved by the Emory University Institutional Review Board.

### Analysis

We examined associations between pollen concentrations and asthma ED visits using a case-crossover design matched on same-day temperature, a strong confounder (15). Because the exposure (i.e., ambient pollen) was shared among all patients, we implemented the analysis in Poisson regression using indicator variables for month, year, and maximum temperature (lag 0) as well as their interactions (17). Conceptually this is analogous to creating strata in which case days (day of the ED visit) are matched to control days in the same calendar month with the same temperature (exact degree Celsius). Models included indicator variables for hospital, day-of-week and holidays, cubic polynomial terms for lag 1–2 minimum temperature and lag 0-1-2 average dew point. All models also included control for the potential confounding effect of upper respiratory infections (URI) by including a term

for the logarithm of the age-specific daily count of URI ED visits. Primary analyses assessed associations between continuous three-day moving average pollen levels (average of today [lag 0], yesterday [lag 1], and two days ago [lag 2]) and asthma ED visits. Analyses were limited to the relevant pollen season for each taxon: Betulaceae (February-May); Cupressaceae (January-April); *Quercus* (February-May); Pinaceae (February-June); Poaceae (March-June); and *Ambrosia* (August-November). Months outside of these seasons were excluded due to minimal variation in concentrations.

We conducted several secondary analyses including examination of the shape of the dose-response relationship using distributional categories, single-day lag models (lag 0 through lag 7), age-specific effects, confounding by ambient air pollutants, and effect modification by ozone, a known pulmonary irritant. We also created a multi-pollen model to assess whether individual tree pollen results were confounded by each other; although the tree pollen taxa did not peak at exactly the same time each year, airborne levels were correlated between taxa within calendar month, creating the potential for confounding. The multi-tree pollen model time period (January– June of every year) captured the peak concentration periods for all four tree taxa.

Although the case-crossover approach inherently controls for all time-invariant risk factors (e.g., socio-economic status, race), it is vulnerable to confounding by factors which vary within the time-windows selected, here months (18). An example of within-month trends in asthma exacerbations is the steep increase that occurs at the beginning of the school year every September due to circulating rhinoviruses (19). In sensitivity analyses we added control for within-month trends by including a cubic polynomial on day-of-season (with “season” defined for each pollen taxa as described above). We also conducted analyses excluding days with imputed pollen values and stratified analyses by study year to assess whether associations were driven by a small number of influential years. All analyses were carried out using SAS statistical software V9.2 (SAS Institute, Inc., Cary, NC, USA).

## RESULTS

### Descriptive Statistics

Over the 1993–2004 time period there were 400,819 ED visits for asthma and wheeze (0–4 years=108,147 visits, 5–17 years=91,386 visits, and 18+ years= 201,286 visits). ED visits are further described in Table E1 in the Online Repository. Raw data plots shown in Figure E1 in the Online Repository demonstrate recurrent seasonal patterns of ED visits. Ambient pollen concentrations were highly skewed with concentrations that were low or zero for large parts of the year (e.g., Figure 2 presents daily pollen time-series for 2004). Descriptive statistics (Table 1) for each pollen taxon for the months included in epidemiologic analyses show that concentrations differed among taxa by orders of magnitude. Table 2 displays overall Spearman correlation coefficients among the three-day average pollen concentrations and pollutant concentrations; three-day average concentrations of *Quercus*, Pinaceae and Betulaceae pollen levels were strongly correlated ( $r=0.68-0.77$ ).

### Single-Taxon Models

Risk ratios and 95% confidence intervals for associations between continuous (i.e., linear) three-day moving average pollen levels for the six pollen taxa and asthma ED visits for all ages combined are presented in Table 3. Relative risks were scaled to approximate standard deviation increases in the season-specific pollen data (see Table 3). We observed positive associations for Betulaceae, *Quercus*, Pinaceae, and Poaceae pollen, a negative association for Cupressaceae, and no association for *Ambrosia*.

## Multi-Taxon Models

Because tree pollen levels were correlated between taxa (see Table 2 and Figure 2), we examined whether results from the single-taxon models were confounded by covarying pollen types. Among the tree taxa, the *Quercus*-asthma relationship was strongest; the effects of Betulaceae and Pinaceae were consistent with the null when controlling for *Quercus* pollen (Table 3). These results suggest that the positive associations observed in the single-taxon models for Betulaceae and Pinaceae were likely due to covarying *Quercus* pollen concentrations. Based on observed positive associations, we also modeled *Quercus* and Poaceae together in the same model. Results shown in Table 3 demonstrate independent associations for these two taxa.

## Categorical Exposure

We investigated the potential for a non-linear dose-response, with a focus on the top end of the pollen distributions. We examined effects of the 50–75<sup>th</sup> percentile, 75–90<sup>th</sup> percentile, 90–95<sup>th</sup> percentile and 95–100<sup>th</sup> percentile relative to the 0–50<sup>th</sup> percentile of pollen concentrations within the pre-defined pollen season for each taxon. Concentration percentiles are shown in Table 1, and median concentrations for each category are shown on the x-axis in Figure 3. Because of the apparent confounding of the Pinaceae and Betulaceae effects by *Quercus* described above, Betulaceae and Pinaceae results are adjusted for *Quercus* pollen concentrations.

We observed positive associations for *Quercus* and Poaceae, with a pattern of progressively stronger risk ratios for higher concentrations relative to the lowest concentrations (Figure 3). For Poaceae pollen, statistically significant elevated risks were observed for all concentration categories above the 50<sup>th</sup> percentile, whereas for *Quercus*, associations were only observed for concentrations above the 90<sup>th</sup> percentile (relative to the bottom 50%). There was little evidence of associations with other pollen taxa. Risk ratios for the highest category of Betulaceae and *Ambrosia* (95–100%ile) were elevated but not significant. Because only *Quercus* and Poaceae were associated with ED visits in the primary analyses, secondary analyses focused exclusively on *Quercus* and Poaceae.

## Assessment of Lag Structure

We assessed the lag structure of the pollen-asthma associations using single-day lag models of lags 0 through 7. Figure 4 presents the results of these analyses for *Quercus* and Poaceae pollen. For *Quercus*, the strongest associations were observed for lags 2–4; whereas for Poaceae, the strongest association was for lag 0. The three-day moving average (of lags 0, 1, and 2) exposure window yielded stronger associations than any single-day lag.

## Age-Specific Effects

We examined age-stratified associations using the continuous three-day moving average pollen levels for *Quercus* and Poaceae pollen (Figure 5). The magnitude of associations differed by age group, with the strongest associations for *Quercus* occurring in school-aged children 5 to 17 years (RR=1.046; 95% CI=1.033–1.059 per standard deviation increase) and the strongest associations for Poaceae occurring in adults 18 years or older (RR=1.030; 95% CI=1.017–1.043). Further stratification of the adult age group into 18–39 (N=96,622), 40–59 (N=67,227) and 60+ (N=37,437) age groups showed similar results as the overall adult age group (results not shown).

## Assessment of Confounding and Effect Modification by Air Pollution

We examined whether ozone, CO, NO<sub>2</sub>, SO<sub>2</sub>, PM<sub>10</sub>, or PM<sub>2.5</sub> concentrations confounded the observed pollen-asthma associations by controlling for the three-day moving average of

these pollutants. The observed pollen-asthma associations were nearly identical to those without controlling for these pollutants, indicating that these air pollutants are not confounders of the observed associations with pollen. Likewise, pollen did not affect the estimated associations between these pollutants and asthma and wheeze ED visits, as previously reported (15).

We also assessed effect modification of the *Quercus* and Poaceae pollen associations by ozone by including interaction terms between ozone and pollen (three-day moving average concentrations of both). Interaction terms for *Quercus* and Poaceae were not significant. However, there was limited variation in ozone concentrations over the narrow windows when pollen concentrations peaked.

### Sensitivity Analyses

Risk ratios for Cupressaceae and *Ambrosia* but not the other taxa were sensitive to inclusion of a cubic polynomial to smoothly control for within-month trends. In this analysis, the negative association between Cupressaceae and asthma and wheeze ED visits shown in Table 3 was no longer evident. Conversely, inclusion of the cubic polynomial in the *Ambrosia* model induced a negative association between *Ambrosia* and asthma ED visits. Similarly, omission of control for URI visits led to a slight downward bias in the effect estimate for *Ambrosia*, but not the other pollen taxa.

Sensitivity analyses excluding days with imputed pollen concentrations led to similar results as the primary analyses. Results excluding imputed pollen values and results from spatial subanalyses restricted to hospitals within 10 miles (16 km) or 6 miles (10km) of the pollen monitoring showed similar patterns to the primary analyses (see Table E2 and Figure E2 in Online Repository). Year-stratified analyses showed similar associations across years, suggesting that results were not attributable to a small number of influential years. For both *Quercus* and Poaceae, risk ratios were elevated (i.e., above 1.00) for 9 of the 12 study years. Finally, models assessing relationships between pollen levels and ED visits for finger wounds, a control outcome group, did not suggest any systematic bias in the modeling approach; the risk ratio for *Quercus* was 0.997 (95% CI=0.987,1.007) and for Poaceae was 1.003 (95% CI=0.989,1.018).

## DISCUSSION

Overall, these results suggest that ambient pollen, in particular *Quercus* and Poaceae pollen, independently contribute to asthma morbidity in Atlanta. We observed a 2–3% increased risk of asthma ED visits per standard deviation increase in pollen levels and a corresponding 10–15% increase in risk on days with the highest concentrations (comparing the top 5% of days to the lowest 50% of days) for *Quercus* and Poaceae pollen. The magnitudes of association observed are similar to those reported in studies of air pollution health impacts and other population-level studies of ambient pollen levels and asthma morbidity (2, 15, 20). We also observed a negative association between Cupressaceae pollen concentrations and asthma and wheeze ED visits. However, when smooth control for within-month trends was added to the model, the association was consistent with the null.

In this analysis, we observed consistent independent associations for *Quercus* and Poaceae pollen, whereas the associations for Betulaceae and Pinaceae were not evident when *Quercus* pollen levels were controlled. *Quercus* pollen concentrations were highest of all pollen taxa examined, reaching a three-day average maximum concentration of 3,793 grains/m<sup>3</sup>. Pinaceae concentrations were also high, but Pinaceae pollen is thought to be less frequently allergenic (13). Although Betulaceae pollen is considered highly allergenic (21), it is possible that the aggregate population response to Betulaceae pollen was dwarfed by the

population response to *Quercus* pollen, as *Quercus* pollen concentrations were orders of magnitude higher than Betulaceae, even when Betulaceae pollen concentrations were peaking. Further, pollen measurements were available from only one monitor and differing degrees of measurement error among the pollen taxa, due to local vegetation impacts for example, could have distorted our results. Of the lag periods examined, our *a priori* three-day moving average yielded the strongest risk ratios. It is possible that asthma exacerbations are greatest when pollen concentrations remain elevated for several consecutive days, leading to development of a full allergic response in susceptible individuals.

The null association observed between ambient *Ambrosia* pollen levels and ED visit counts for asthma and wheeze was unexpected given that *Ambrosia* pollen is known to be highly allergenic and is a major cause of hay fever (13, 21). However, there is evidence to suggest that our results for *Ambrosia* were confounded. *Ambrosia* pollen levels increased steeply every September around the same time, or just after steep increases in daily asthma ED visits (see Figure E1, Online Repository). Previous studies have also noted September increases in asthma exacerbations, attributing the pattern to circulating rhinoviruses (19). Unfortunately we did not have an accurate population-level measure of circulating rhinoviruses to include as a covariate in our models; few ED visits indicated rhinovirus (ICD-9 079.3), and URI visits are likely a poor surrogate. Nonetheless, controlling for URI visits slightly increased the effect estimate for *Ambrosia* suggesting that a better surrogate might allow positive associations to be observed between *Ambrosia* and asthma ED visits. The strong increasing trend in asthma visits every September may also explain sensitivity of the *Ambrosia* results to control for within-month time trends. For these reasons, our *Ambrosia* results should be interpreted cautiously. Results from previous time-series and case-crossover studies of *Ambrosia* may also be confounded by this back-to-school effect (20). Although there is a corresponding spring and summer decrease in the number of asthma ED visits, the trend is not as strong as the September increase and does not coincide with dramatic increases or decreases in other pollen taxa. Effect estimates for the spring and summer pollen taxa (i.e., trees and grasses) were not sensitive to within-month time trend control, suggesting that the results for these taxa were not confounded.

Positive associations for Poaceae and *Quercus* were observed for all age groups, with the exception of Poaceae pollen in the 0–4 year group. Asthma is difficult to diagnose in children under 5 years (22), and weaker associations in the youngest age group may reflect a less specific outcome group. Respiratory symptoms in early life also tend to be unrelated to allergy (23); thus the respiratory response to an inhalant allergen might be expected to be weaker. Different sensitivities to pollen concentrations, and behavioral management of those sensitivities in adults vs. children, could also explain differences in effects observed between the 5–17 age group and adults (18+). Unfortunately there were no data available on the allergy status of the ED patients. Finer stratification of the adult age group suggested similar patterns between older and younger adults. Some true asthma visits were likely coded as chronic obstructive pulmonary disease (COPD), particularly in the oldest age group (60+); COPD visits were not included in our outcome group unless accompanied by an ICD code for asthma or wheeze. While disease misclassification resulting from the use of ICD codes may have biased true associations toward the null, it would be unlikely to induce spurious associations because coding preferences are likely independent of day-to-day changes in pollen concentrations.

A limitation of our study was the use of one monitoring site to represent city-wide population exposures. Exposure measurement error due to spatial heterogeneity in ambient pollen levels as well as differences between ambient and personal exposures could have biased risk ratios toward the null but would be unlikely to induce a spurious association in this context. Spatial subanalyses of ED visits from hospitals within 10 or 6 miles around the

pollen monitoring stations showed similar patterns of association across pollen taxa despite the loss of precision. Previous studies have indicated that single monitoring sites can be suitable for representing study areas up to 30–40 km wide, especially for geographies like Atlanta for which air flow is not restricted due to mountains or water bodies (24, 25).

Ambient pollutant concentrations are also associated with asthma and wheeze ED visits in this population (15) but were not confounders of the associations with pollen. Effect estimates for pollen were virtually identical between the models including and excluding control for ozone, NO<sub>2</sub>, CO, SO<sub>2</sub>, PM<sub>10</sub>, and PM<sub>2.5</sub>. Clinical and epidemiological reports have suggested that exposure to ozone may enhance the respiratory response to airborne allergens (2, 26, 27). We found no evidence of effect modification for *Quercus* or Poaceae pollen; however, it is important to note the difficulty of assessing this interaction in the current study. Pollen concentrations exhibit sharp peaks at specific times of year, hence there was little variation in ozone concentration during the time periods when concentrations of these taxa were high. For example, ozone concentrations were rarely high in February and March when tree pollen concentrations were peaking, thus limiting our ability to compare days with high tree pollen and high ozone to days with high tree pollen and low ozone.

As our climate changes, the temporal distribution and concentration of ambient pollen will likely be altered. Increased carbon dioxide levels have been shown to increase *Ambrosia* pollen production (28–30). Trends of longer pollen seasons and increased concentrations in response to increasing temperatures have already been observed for specific taxa, including *Quercus* (31). Our results and those of previous investigators suggest that these changes can have implications for asthma morbidity. The most important taxa may differ by region, but in Atlanta, of the taxa we considered, Poaceae and *Quercus* pollen appear to be of particular concern for asthmatics. Additional research is needed to determine if these relationships hold in other locations.

A 10–15% increase in asthma ED visits for the highest pollen concentration days has large public health implications; for a common health outcome and ubiquitous exposure, even modest increases in risk affect large numbers of people. To put these increased risks in context, a 10% increase in ED visits in the later years of our study would represent approximately 16 additional visits per day on the highest concentration days (approximately 6 days per year fell into the top 5% of days for each pollen taxon). However, the affected number of people is likely much greater as we did not capture every ED visit in the study area and the effects of pollen on asthma exacerbation are presumably not limited to those that result in ED visit. In addition, ED visits for asthma represent a heterogeneous mix of individuals with severe or uncontrolled asthma, those without a health insurance or those who use the ED as a source of primary health care; for some of these subgroups, associations with pollen may be stronger or weaker.

As others have noted, additional research on exposure-outcome associations can facilitate a wide range of public health measures to improve primary, secondary, and tertiary prevention of aeroallergen-related disease (10). Primary prevention includes management of allergenic plants, pollen surveillance and warning systems, and building and ventilation strategies. Secondary prevention includes patient education and medical management to reduce the development of allergic disease. Tertiary prevention includes enhanced access to medical care to palliate the symptoms of allergic respiratory disease and reduce the severity of exacerbations when they occur.

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## ABBREVIATIONS

<b>AAAC</b>	Atlanta Allergy and Asthma Clinic
<b>ED</b>	Emergency Department
<b>ICD-9</b>	International Classification of Diseases 9 <sup>th</sup> Revision
<b>URI</b>	Upper Respiratory Infections
<b>RR</b>	Risk Ratio

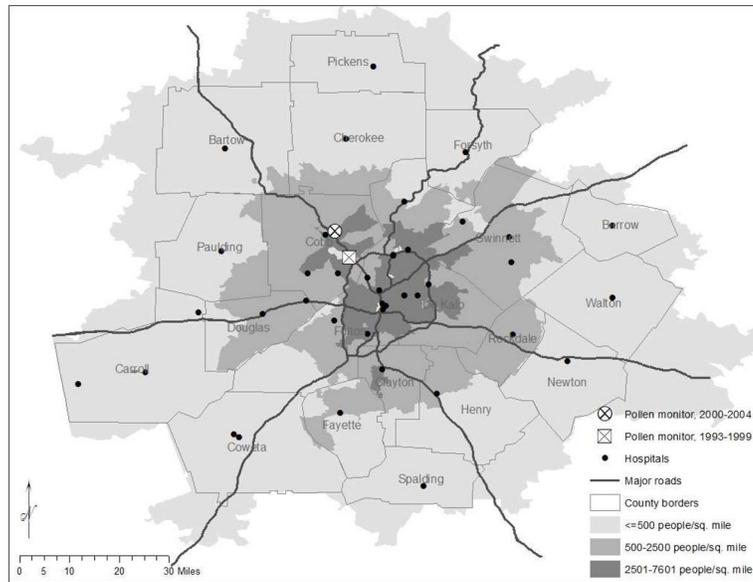
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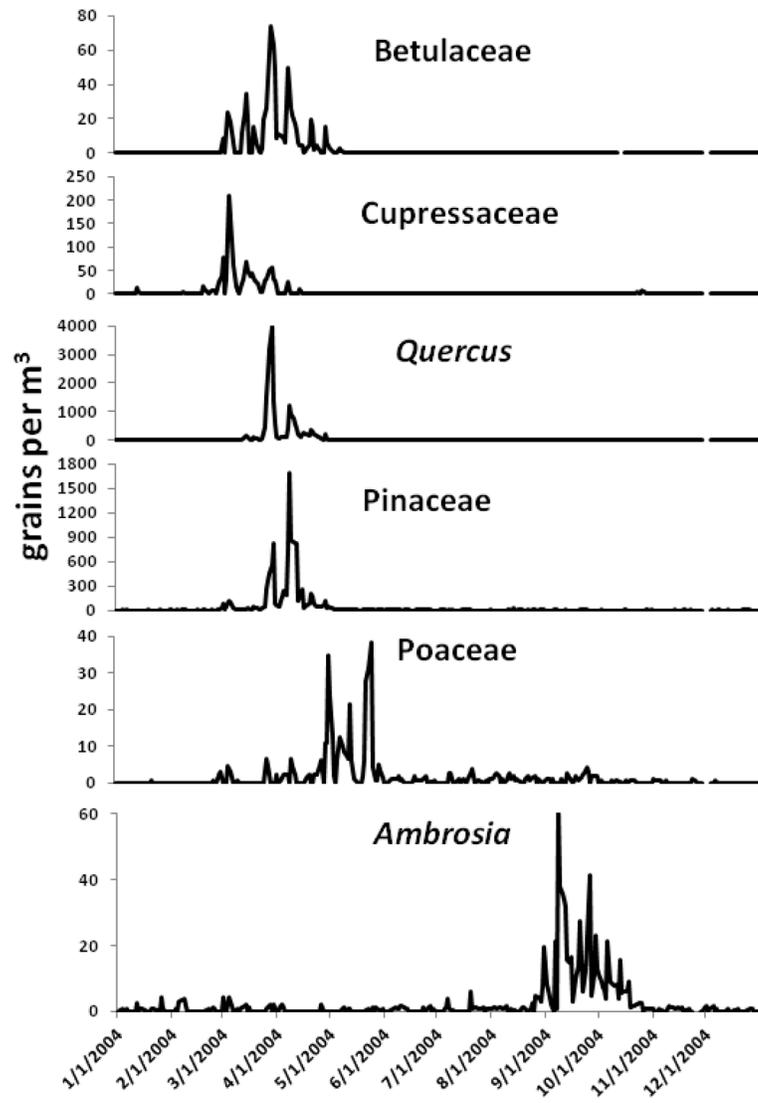
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**Clinical implications**

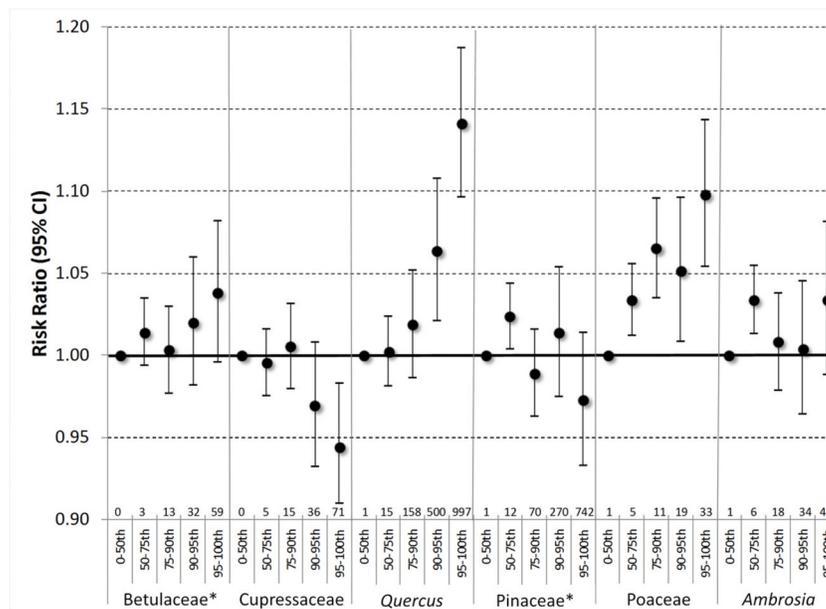
Pollen levels contribute to asthma emergency department visit risk. Increased patient education and access to treatment, aeroallergen surveillance, and early warning systems may be relevant adaptation measures under a changing climate.



**Figure 1.**  
Twenty-county Atlanta study area

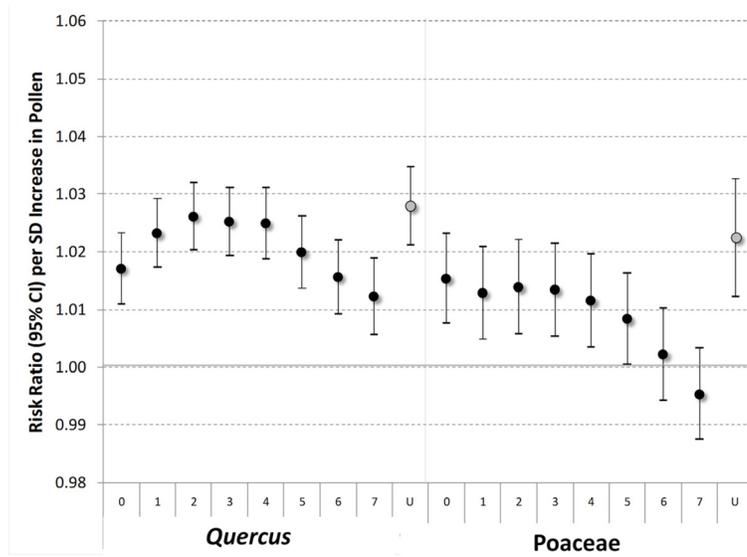


**Figure 2.**  
Daily time series of pollen concentrations (grains/m<sup>3</sup>) for 2004

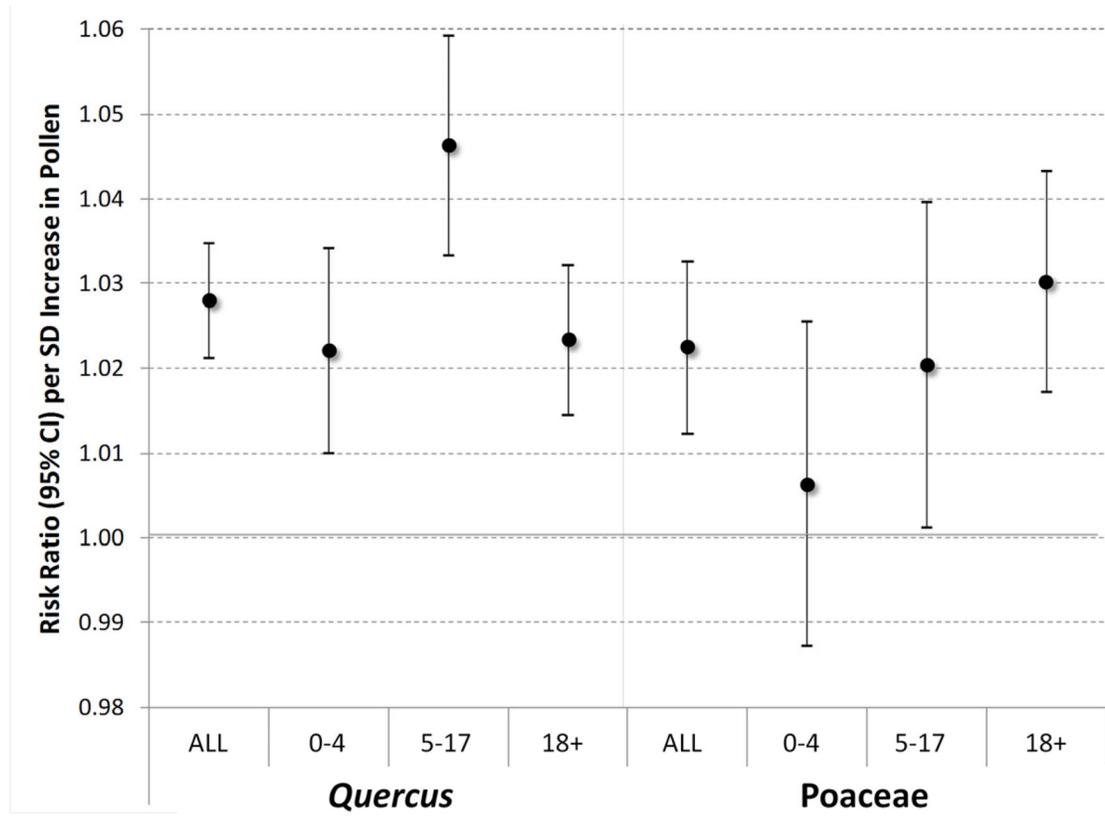


**Figure 3. Risk ratios and 95% confidence intervals for categories of three-day moving average pollen levels**

Numbers above the x-axis indicate median pollen concentrations for each category. Risk ratios for Betulaceae and Pinaceae\* are controlled for *Quercus* concentrations



**Figure 4. Risk ratios and 95% confidence intervals of models assessing lag 0 through lag 7 and three-day moving average pollen levels**  
 Risk ratios from the *a priori* model assessing three-day moving average pollen levels are shown in gray, and denoted by a “U” on the x-axis.



**Figure 5.** Age-specific risk ratios and 95% confidence intervals for three-day moving average pollen levels

**Table 1**

Descriptive statistics of three-day moving average pollen concentrations (in grains/m<sup>3</sup>) from the Atlanta Allergy and Asthma Clinic, 1993–2004.

Pollen	Months	N <sup>*</sup>	Mean ± SD	Percentiles					
				50 <sup>th</sup>	75 <sup>th</sup>	90 <sup>th</sup>	95 <sup>th</sup>	Max	
<b>Betulaceae</b>	Feb-May	1423	8.1 ± 17.6	1.2	7.2	26.3	38.6	177.5	
<b>Cupressaceae</b>	Jan-Apr	1408	10.0 ± 21.2	2.4	9.9	27.4	46.0	183.2	
<b>Quercus</b>	Feb-May	1423	123.0 ± 333.8	5.1	71.6	390.9	692.0	3793.2	
<b>Pinaceae</b>	Feb-Jun	1782	74.1 ± 219.9	4.9	33.3	193.1	412.1	2753.4	
<b>Poaceae</b>	Mar-Jun	1443	6.1 ± 9.1	2.9	7.9	15.9	21.8	73.8	
<b>Ambrosia</b>	Aug-Nov	1426	8.9 ± 13.8	2.4	11.6	27.5	39.4	128.4	

\* Number of days included in analysis

**Table 2**  
Spearman correlation coefficients between three-day moving average pollen and pollutant concentrations

	Betulaceae	Cupressaceae	Quercus	Pinaceae	Poaceae	Ambrosia	Ozone	CO	NO <sub>2</sub>	SO <sub>2</sub>	PM <sub>10</sub>	PM <sub>2.5</sub>
Betulaceae	1											
Cupressaceae	0.47	1										
Quercus	0.77	0.44	1									
Pinaceae	0.68	0.34	0.74	1								
Poaceae	0.33	-0.19	0.43	0.48	1							
Ambrosia	-0.30	-0.22	-0.32	-0.33	0.02	1						
Ozone	0.15	-0.26	0.16	0.26	0.58	0.01	1					
CO	0.01	0.05	-0.02	-0.06	-0.10	-0.03	0.14	1				
NO <sub>2</sub>	0.18	0.15	0.15	0.10	0.04	0.00	0.26	0.58	1			
SO <sub>2</sub>	-0.04	0.08	-0.06	-0.10	-0.19	-0.13	0.04	0.32	0.43	1		
PM <sub>10</sub>	-0.02	-0.26	-0.03	0.03	0.34	0.11	0.67	0.45	0.43	0.14	1	
PM <sub>2.5</sub>	-0.10	-0.25	-0.09	-0.03	0.26	0.12	0.58	0.42	0.39	0.12	0.89	1

Correlation coefficients are for all days between Jan 1, 1993, and December 31, 2004, except PM<sub>10</sub> (began Jan 1, 1996) and PM<sub>2.5</sub> (began Aug 1, 1998)

**Table 3**

Associations between three-day moving average pollen levels and asthma and wheeze emergency department visits

Pollen taxa	per unit (grains/m <sup>3</sup> )	Single-Taxon Models			Multi-Tree Pollen Model*			Quercus- Poaceae Model**		
		Risk Ratio (95% CI)	P-Value	Risk Ratio (95% CI)	P-Value	Risk Ratio (95% CI)	P-Value	Risk Ratio (95% CI)	P-Value	
Betulaceae	20	1.022 (1.013–1.032)	<0.001	1.004 (0.993–1.016)	0.439	n/a		n/a		
Cupressaceae	25	0.986 (0.975–0.996)	0.007	0.988 (0.978–0.998)	0.024	n/a		n/a		
Quercus	300	1.028 (1.021–1.035)	<0.001	1.028 (1.020–1.037)	<0.001	1.026 (1.019, 1.033)		<0.001		
Pinaceae	200	1.007 (1.001–1.013)	0.015	0.995 (0.988–1.001)	0.123	n/a		n/a		
Poaceae	10	1.022 (1.012–1.033)	<0.001	n/a		1.019 (1.008, 1.029)		<0.001		
Ambrosia	15	1.001 (0.990–1.013)	0.849	n/a		n/a		n/a		

\* Multi-pollen results are from the model including all four tree pollen taxa together for the season January through June of every year

\*\* Quercus-Poaceae results are from the model including both Quercus and Poaceae for the season March through May of every year