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Effects of Daily Pollen Concentrations on Primary Asthma Emergency Department Visits in Atlanta, GA

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Abstract

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By Adam Sole

Introduction: Asthma is currently one of the most prevalent chronic respiratory illnesses across the globe. It is also a disease that is not distributed evenly across the population, with some groups more burdened than others. Asthma exacerbations have many causes, one of which is through exposure to allergens. This study aims to quantify the effects of pollen on emergency department visits for asthma in the city of Atlanta, Georgia, and to determine effects across population sub-groups and over time.

Methods: Measurements of daily pollen concentrations were obtained for the period 1993 to 2018. Counts of emergency department visits for asthma were sourced from individual hospitals early in the study period (1993-2004), and from the Georgia Hospital Association more recently (2005-2018). Time series regression using quasi-Poisson models was employed to investigate the association of daily total pollen concentrations with asthma emergency department visits. Analyses were run for each of three pollen types (tree, weed, grass) within their respective pollen seasons, and across race, age, and temporal stratifications.

Results: Regression estimates showed a statistically significant increase in risk of primary asthma emergency department visits for tree pollen of 3.4% (95% CI: 2.7-4.1) per standard deviation increase in pollen concentration. Significant associations were not observed for grass or weed pollens. Black residents of Atlanta had a greater risk associated with a one standard deviation increase in tree pollen concentration of 2.9% (95%CI: 2.4-3.5) per standard deviation compared to the White population at 1.2% (95% CI: 0.4-1.9). Young people (0-17) and adults (18-64) were shown to have significant associations ($P<0.05$) between asthma and tree pollen, while no association was found in the elderly (65+). Temporal analysis of tree pollen showed decreasing risks over each of the three decades within the study period.

Conclusion: This analysis shows an elevated risk of primary asthma emergency department visits associated with an increase in concentration of tree pollen. It also indicated differential vulnerability across subgroups. The health impacts of pollen are an increasing concern in the context of climate change, which can act to increase pollen production and/or lengthen the pollen season.

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Introduction

Asthma is a chronic condition which effects the airways and lungs, causing inflammation as well as a narrowing of the respiratory passages (NHLBI, 2020). The condition can result in symptoms including wheeze, coughing, and tightness in the chest, with severity of the symptoms ranging from mild to severe (NHLBI, 2020). While the exact cause of the condition is unknown, it is hypothesized that a majority of cases are the result of viral infections or exposure to aeroallergens during childhood while the immune system is still in development (ALA, 2020). A genetic component is also shown to play some role in the development of asthma, with a child having a roughly 25% chance of developing asthma for each parent with the condition(Thomsen, 2015). While there is no cure for asthma, its symptoms can typically be managed through avoidance of respiratory triggers present in an individual case and the use of medication including a rescue inhaler (AAFA, 2021).

Asthma is a highly prevalent condition impacting roughly seven percent of children under eighteen years of age, and eight percent of adults aged eighteen and above (AAFA, 2021). These numbers currently position it as the leading chronic disease in children (AAFA, 2021). Black Americans can been seen to bear the highest burden of asthma, being five times more likely to require an emergency department visit for asthma and three times more likely to die from it than white Americans. In total the condition was responsible for 1.6 million emergency department visits in the United States in 2018 alone (AAFA, 2021). In total the prevalence of the disease has shown to be on the rise. From the years 2001 to 2017, the number of Americans with asthma increased to 25 million, representing a 25% increase in the total number of cases (CDC, 2021). Like with asthma as a whole, the exact cause of the rise is unknown; it is hypothesized that rapid changes in environmental conditions such as increases in industrialization and the resulting rise in exposure to air pollutants are largely responsible (Selgrade et. al. 2006) (Ozdemir et. al. 2018).

One potential respiratory trigger is exposure to pollen. Pollen is the male fertilizing agent of flowers and plants. It consists of tiny grains released by plants that are carried from plant to plant by insects, small animals, and the wind. Pollen is given off by all flowers and plants, but the main allergenic species of pollen are those that derive from trees, weeds and grasses. These classes of plants release lighter pollens that are more easily carried by the wind and this lighter nature allows these species of pollen to function as potent aeroallergens (AAAI). Even these lighter pollens are too large to penetrate the smaller airways where the asthmatic response occurs, leading to uncertainty regarding the mechanisms by which pollen allergies trigger asthmatic response (Taylor et. al. 2007). A leading hypothesis is that these larger pollen grains are shattered while still in nature, and the smaller particles are what penetrate the smaller airways and trigger an immune response (Taylor et. al. 2007). While pollen itself is not particularly harmful, it is responsible for a type of immune response known as a hypersensitivity reaction. In this type of reaction, the body mistakenly identifies a non-harmful substance such a pollen, pet dander, or peanuts as a harmful substance. This causes the recruitment of a large quantity of immune cells known as granulocytes, which are responsible for causing inflammation in allergic responses(Gao et. al. 2017).

Among individuals suffering from asthma, pollen allergies are often a comorbidity. Childhood asthmatics have been found to suffer from pollen allergies in 80-90% of cases, with 40-50% of adult onset asthmatics also suffering from pollen allergies(Taylor et. al. 2007). This statistic provides one possible explanation for the association that has been proven between asthma related emergency department visits and hospitalizations. For example, analyses in London and Atlanta have both found positive associations between days of increased pollen concentration and increased rates of asthma exacerbation resulting in emergency care; the London study included data from 2005-2011 and the Atlanta study1993-2004 (Osborne et. al. 2017) (Darrow et. al. 2012). A recent meta-analysis of pollen studies also cited twelve separate studies as providing strong evidence that short-term pollen exposure is associated with a significant increase in the risks associated with asthmatic symptoms (Kitinoja et. al. 2020). The meta analysis produced an effect estimate of an average 2% increase in allergic and asthmatic symptoms per 10 grains/m^3 increase in pollen exposure (Kitinoja et. al. 2020).

Anthropogenic climate change and its resulting environmental effects have served to exacerbate a number of environmental hazards, with pollen being heavily impacted by a number of climate-related processes. Increased temperature and carbon dioxide levels have both been shown experimentally to cause increases in pollen production (Kim et. al. 2018) (Ziska et. al. 2019). Studies in North America have also shown significant shifts in pollen metrics including increased daily pollen extremes, earlier pollen season start date, and increased total pollen season length over the time frame of 1990-2018 (Anderegg et. al. 2021). Temperature was shown to have a greater impact on these metrics, with carbon dioxide concentrations also being significantly associated (Anderegg et. al. 2021). These changes in pollen metrics are likely to continue to worsen as the effects of climate change continue to take effect, with temperatures and atmospheric carbon dioxide levels both on the rise, and expected to continue rising for the foreseeable future. These factors coupled with the rapid increase in asthma prevalence signal a greater need to understand the underlying relationship between pollen and exacerbation of asthmatic symptoms in order to properly combat the disease in the near future.

The changes in pollen metrics related to climate change bring about an increased importance in the tracking of pollen and asthma metrics. This study will seek to build on the work of Darrow et. al. (2012) to provide an up to date quantification of pollen concentrations as they relate to asthma related emergency departments in the Atlanta area. This study will use data form 1993 up to 2018. It will also view this increase through a lens of climate change to explore how the effects of pollen concentrations on primary asthma visits have changed over time. The study will also seek to explore impacts along demographic lines. This study will specifically seek to estimate the differential risks felt by racial groups and age categories in Atlanta.

Methods

Pollen Data

Measurements for daily pollen concentrations between 1993 and 2018 – recorded as grams of pollen per cubic meter of air – were taken by the Atlanta Allergy and Asthma Clinic and provided by partners at the US Centers for Disease Control and Prevention. Measurements were taken from a single monitoring station in Marietta Georgia, which is part of the Metro-Atlanta area. The pollen monitoring station was moved once on January 1st, 2000. Measures were taken 5 days a week (Sunday-Thursday) on a rooftop away from ventilation and vegetation. Individual pollen types were grouped in accordance with the source of the pollen, as tree pollen, weed pollen, grass pollen, or unidentified pollen. These pollen source categories were chosen due to the fact that the majority of allergic responses to pollen are caused by these three categories (AAFA, 2021).

Emergency Department Visit Data

Hospital data, also from 1993-2018 was included, sourced from ~45 individual hospitals early in the study period(1993-2004), and from the Georgia Hospital Association more recently (2005-2018). The data format was counts of emergency department visits in the 20 county Metro-Atlanta area where asthma was the primary reason for the visit. Some hospitals were unable to provide data over the entire study period due to lack of operation or lack of participation. The dataset also included counts by race and age of the admitted patients, where age was stratified into categories of 0-17 years, 18-64 years, and 65+years. The final hospital dataset was provided by the ENVISION team at Emory University, after approval by Emory's Internal Review Board.

Analysis

Time series regression was employed to investigate the association of daily total pollen concentrations and primary asthma emergency department visits. A quasi-poisson regression model was run, with each category of pollen (Tree, Weed, Grass, or Unidentified) as the exposure variable in order to examine the effects of each type on primary asthma ED visits. Pollen concentrations are highly seasonal, and so the model for each pollen type was run in the corresponding pollen season (Table 1). In order to further control for time and seasonality in the models, indicator variables for elapsed calendar month-by-year were included in the regression model. Risk ratios with 95% confidence intervals were determined for each individual pollen category. To standardize the effect estimates, all estimates are presented per one standard deviations change in a given pollen category. Secondary analysis also was completed to evaluate differential impacts of pollen concentrations by race, age, and over time (roughly decade by decade). Time stratification was run in decade intervals to analyze changes in overall risk ratios over time. Time stratified analysis was used to attempt to draw conclusions on possible impacts of anthropogenic causes of climate change on pollen related primary asthma hospitalizations. A secondary analysis was also run to determine potential effects of confounding by temperature. Temperature was selected as a possible confounder since it can increase production of pollen as well as increase asthma exacerbations (Kim et. al. 2018) (Romaszko-Wojtowicz et. al. 2020). All analyses were run using R coding software.

Results

Descriptive Statistics

The mean number of primary asthma emergency department visits over the study period was 67, and standard deviation of 34.4. Pollen concentrations varied greatly by category, with tree pollen often exhibiting values an order of magnitude greater than the others. Full descriptive statistics for each pollen category can be seen in table 1. Daily total pollen concentrations and asthma hospitalizations exhibited similar seasonality (Figure 1). Counts of both pollen concentrations and asthma hospitalizations both typically occurred in the spring to summer months. Counts of primary asthma emergency department visits also show an apparent increase over much of the study period. Across the entire study period primary asthma visits exhibited a mean of 67.1 and standard deviation of 34.6. Analysis was also run to determine the exact start and end dates of each pollen season in ten-year intervals within the study period (Table 2). Following Manangan et. al. (2021) The start date was defined as the first date of the year in which pollen concentration was above 1g/m^3 for three consecutive days. The end date was defined as the first day in which three consecutive pollen concentrations were measured under 1g/m^3 after the maximum day within the season. Results of this analysis support previous studies suggesting that anthropogenic climate change is serving to increase the total length of pollen seasons (Manangan et. Al. 2021)(Anderegg et. al. 2021); in all cases, the pollen season length in 2015 was longer than in 1995, especially for tree pollen. .

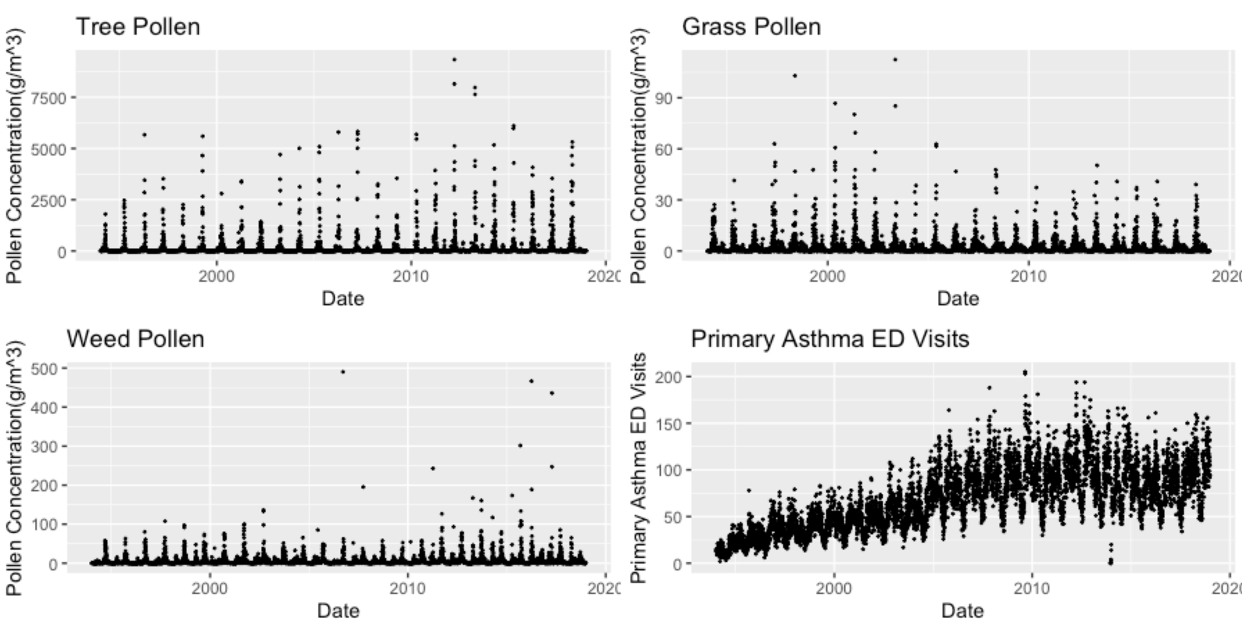

Figure 1: counts of pollen concentrations for each category and primary asthma emergency department visits

Pollen	Months	Mean	Standard Deviation	Max	Min
Tree	January-May	326.79	814.5	9336.2	0
Grass	May-August	4.25	8.7	112.4	0
Weed	August-December	9.90	20.3	490.2	0

Table 1: Descriptive statistics of each pollen category. "Months" indicates the calendar months (pollen season) in which each analysis was run.

	Start Date	End Date	# of Days in Season
1995 Tree	1/12	7/05	174
2005 Tree	1/13	7/12	180
2015 Tree	1/21	11/04	287
1995 Grass	3/29	6/12	75
2005 Grass	4/14	7/18	95
2015 Grass	3/29	7/01	94

	Start Date	End Date	# of Days in Season
1995 Weed	3/28	11/1	218
2005 Weed	4/12	11/28	230
2015 Weed	3/26	11/02	221

Table 2: Start and end date for pollen seasons in ten year intervals over the study period

Individual Pollen Models

Linear models were run in order to determine risk ratios as well as 95% confidence intervals for each pollen category within their own individual pollen season. Estimates were standardized by standard deviations of their own pollen concentrations to create estimates for a one standard deviation increase in concentration. A significant positive association was found between tree pollen increases and primary asthma emergency department visits, with an estimated increased risk of 3.4% (95% CI: 2.7-4.1) per standard deviation increase in pollen. Point estimates for weed and grass pollen were also elevated but not significant (P>0.05, Figure 2).

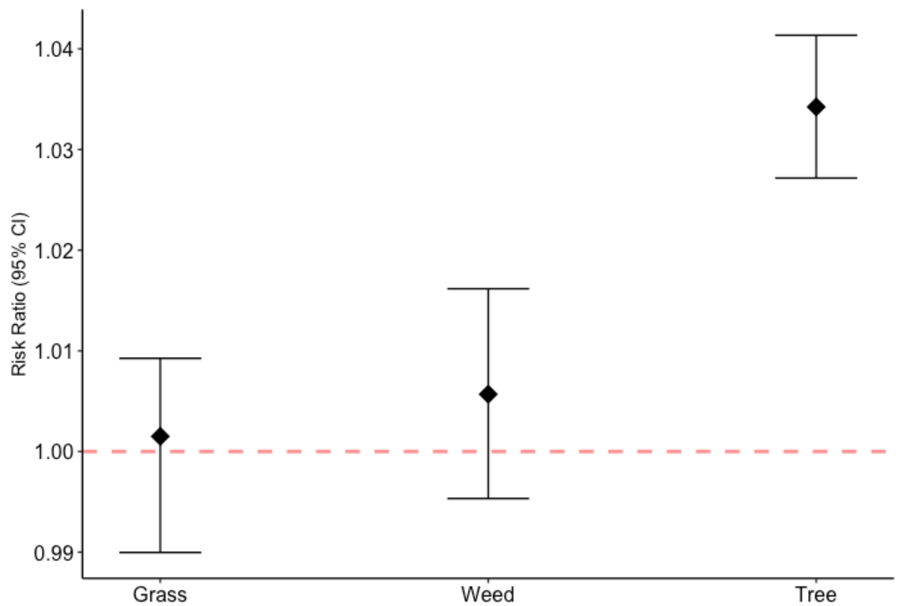

Figure 2: Risk ratios and 95% confidence intervals for primary asthma emergency department visits for a one standard deviation increase in each pollen category. Analysis was limited to each pollen category's respective pollen season.

Race-Stratified Models

In order to explore the effects of pollen concentrations on different races, models were run using primary asthma emergency department visits stratified by race. There were positive associations for both the Black (RR 1.029 95% CI: 1.024-1.035) and White population (RR

1.012 95% CI: 1.004-1.019), with the former significantly higher (Figure 3). Grass and weed pollen were once again found to have no association.

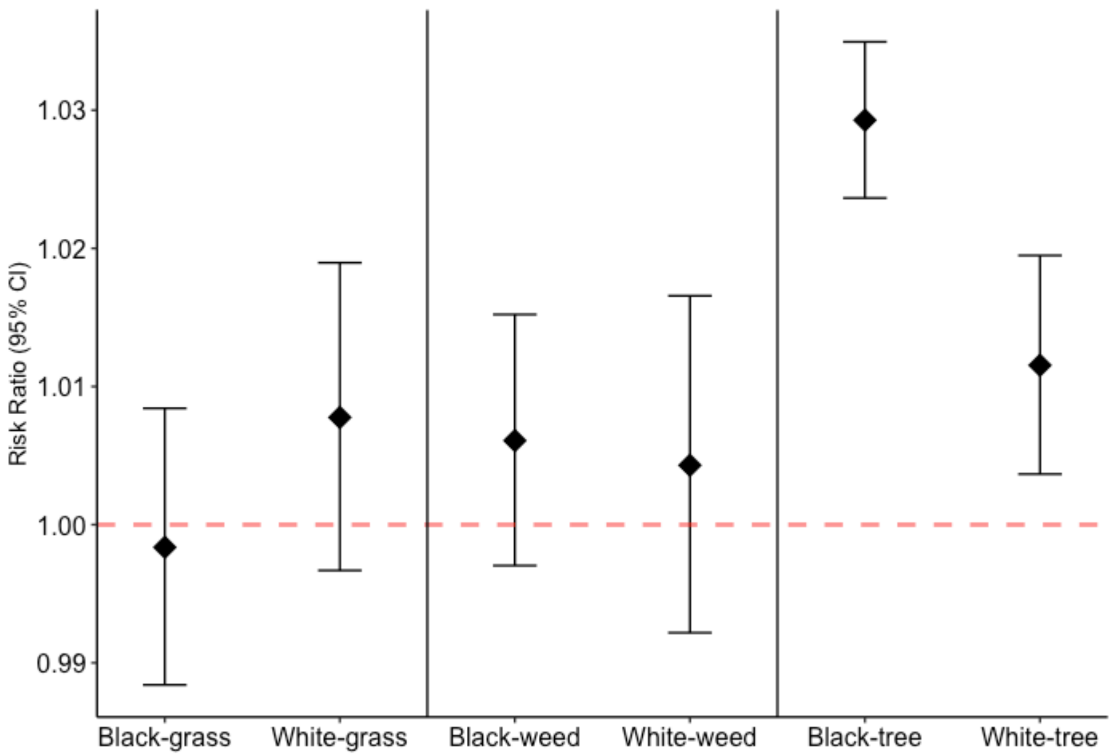

Figure 3: Risk ratios and 95% confidence intervals for primary asthma emergency department visits for a one standard deviation increase in each pollen category, stratified by race. Analysis was limited to each pollen category's respective pollen season.

Age-Stratified Models

For tree pollen, positive associations for primary asthma hospitalizations were found for tree pollen in the children (0-17) and adults (18-64) categorizations, but not in the elderly for tree pollen (Figure 4). For grass pollen there were increasing effects with age and the opposite for weed pollen, though none of the associations were significant.

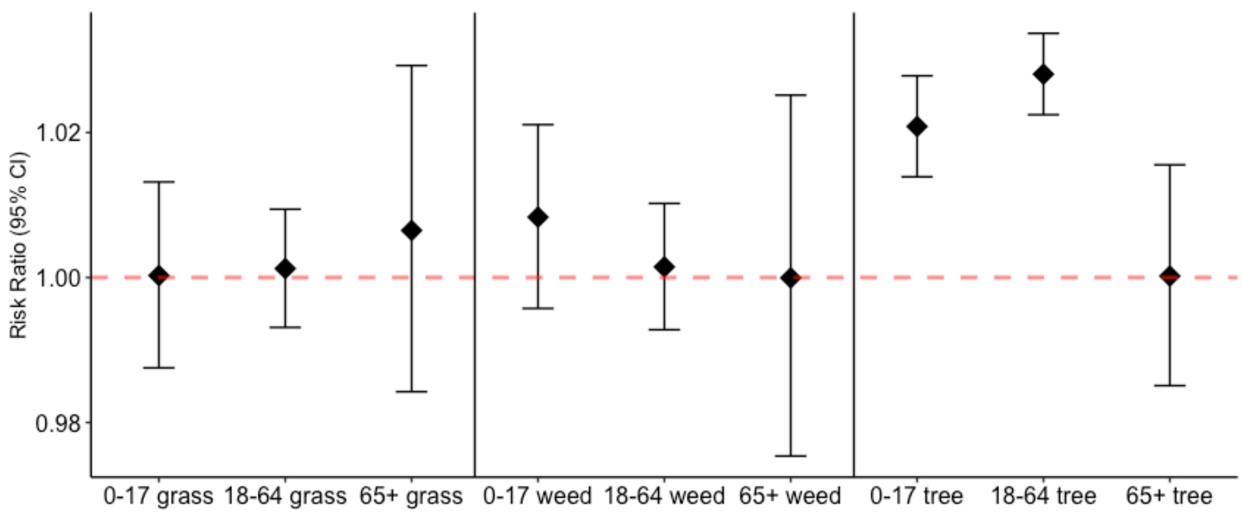

Figure 4: Risk ratios and 95% confidence intervals for primary asthma emergency department visits for a one standard deviation increase in each pollen category, stratified by age group. Analysis was limited to each pollen category's respective pollen season.

Time-Stratified Models

The dataset was stratified into decades (1993-1999, 2000-2009, 2010-2018) to explore how the association between pollen concentrations and primary asthma hospitalizations may have shifted in Atlanta over the study period. Each pollen category was run in its individual pollen season for each of the three time periods. Pollen seasons for each category remained the same across each time period. Tree pollen estimates were highest in earliest period, and lowest in the most recent period, and all were significant at the 5% level (Figure 5). The was no clear pattern for the other two pollen types.

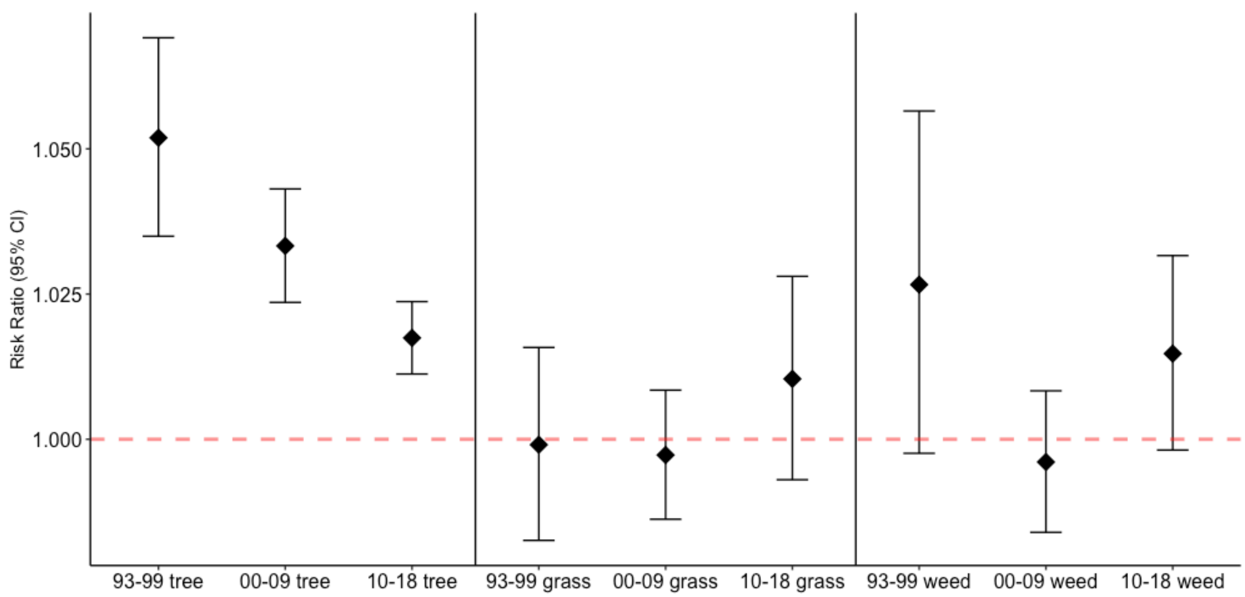

Figure 5: Risk ratios and 95% confidence intervals for primary asthma emergency department visits for a one standard deviation increase in each pollen category, stratified by decade within the study period. Analysis was limited to each pollen category's respective pollen season.

Assessment of Confounding by Temperature

Same day maximum temperature was explored as a confounder due to its association with both pollen concentrations and asthma morbidity. Observed associations changed minimally with the inclusion of temperature in the model. There was also no change in significance for any pollen model after the inclusion of temperature in the model (Table 3).

	Risk Ratio	P-Value
Tree Pollen w/o Temp	1.034(1.027-1.041)	<0.001
Tree Pollen w/ Temp	1.034(1.027-1.041)	<0.001
Grass Pollen w/ Temp	1.001(0.990-1.009)	0.8
Grass Pollen w/o Temp	1.003(0.993-1.016)	0.45
Weed Pollen w/ Temp	1.005(0.995-1.016)	0.28
Weed Pollen w/o Temp	1.006(0.995-1.016)	0.30

Table 3: Risk ratios and 95% confidence intervals for individual pollen models with and without inclusion of same-day maximum temperature.

Discussion

The results of this study suggest that tree pollen has the greatest association with asthma related emergency department visits in the Atlanta area. A 3.4% (95% CI: 2.7-4.1) increase in the risk of primary asthma visits was predicted for each standard deviation increase in tree pollen concentrations. This number showed a slight increase from previous studies in Atlanta, which saw a 2-3% increase for Quercus, a pollen species originating from oak trees which is highly prevalent in Atlanta (Darrow et. al. 2012). A similar time series analysis of tree pollen on asthma hospitalizations in Canada analyzing increases by interquartile range also produced similar estimates of 2-3% increases for each tree species studied (Dales et. al. 2008). This indicates that the The risk is of great concern considering the amount of pollen recorded on high-pollen days compared to average days. While an outlier, the maximum tree pollen concentration recorded (9336 g/m^3) is roughly ten standard deviations above the mean value of 143 g/m^3.

Results of no significant association for grass pollen and primary asthma emergency department visits were unexpected compared to estimates from the Darrow et. Al. (2012) study. That study found estimates for Poaceae, a grass pollen, to be similar to estimates for tree pollen. One possible explanations may be a difference in methods; unlike that study, this study grouped all grass pollens together. The inclusion of less allergenic pollen species may have watered down the effects of grasses as a whole. Differences in modeling strategy and confounder control may also be a factor.

Race stratified estimates showed positive associations with tree pollen and primary asthma visits in both the White and Black population of Atlanta, but the latter population was estimated to have a higher risk per unit. This may partially be explained by differences in socioeconomic status within the city. In Atlanta 33% of black residents live below the poverty, while only 7.4% of white residents live below the poverty line (ACS, 2017). This difference in socioeconomic status may leave black residents at a higher risk of exposure to increased pollen counts due to housing conditions which provide less adequate shelter from environmental factors. The difference in socioeconomic status may also be reflected in differential access to medical care, leaving a larger portion of the black population with less options for treatment prior to emergency department visits (McMaughan et. al. 2020).

Age stratified estimates showed positive associates with tree pollen for the 0-18 and 18-64 age group, with no association for the 65+ age group for any pollen type. Adults with asthma were estimated to have a slightly higher risk associated with increased pollen concentrations than children. This can possibly be explained by behavioral factors. It is possible that parents are quicker to take their children to the emergency department for lesser symptoms than adults choosing to hospitalize themselves. This would partially explain the decreased association, as the association between increased tree pollen and primary asthma visits would likely still be positive, but not as extreme as expected. Null results in the 65+ age group for tree pollen were also surprising, but not entirely unexpected. Lifestyle factors may play a role in the decreased association. The 65+ age group largely consists of retired individuals. This may in turn cause this age group to be less exposed to daily fluctuations in ambient pollen concentrations due to lack of need to exit the home every day. This decrease in exposure may mean that daily fluctuations in pollen concentrations have less of an impact on this age group than others which are typically forced outdoors for school and work on a near-daily basis.

The results of the decade-stratified models were perhaps the most surprising. It was initially expected that risk of primary asthma related emergency department visits would have increased as time progressed due to increasing asthma rates (CDC, 2021) and pollen production (Anderegg et. al. 2021), but the opposite result was seen. Risks were actually observed to have have decreased with each decade of the study period. This is possibly due to better identification and treatment of asthma and allergies as time has progressed. Increased ease of access to information regarding daily pollen counts may also play a role, as individuals are now better able to prepare for exposure on days in which pollen counts are more extreme.

Limitations of this study include the one pollen monitoring station available for use. The use of one monitoring site for a larger area may have misrepresented the true spatial variation of pollen concentrations. This may have impacted effects due to differing levels of exposure within the study population on any given day. Once pollen measurement has been expanded in Atlanta, future studies should explore associations on a smaller scale to provide estimates which more accurately reflect exposure levels for the entire study population. The potential for a non-linear, dose-dependent response has also been explored in previous studies and found significant exposures for some pollen types at higher percentile values. Due to time constraints, a similar analysis was unable to be performed in this study. Similar studies also explored the possible effects of air pollution as a potential confounder, but found no evidence of confounding. A similar analysis of confounding for air pollution in the updated study period was planned, but unable to be completed due to lack of data and time constraints. This study also grouped pollen types together by source rather than exploring individual species. This may have impacted some estimated effects by watering down the effects of more allergenic, but less prevalent species such as the poaceae species of grass pollen, which was shown to have a high effect similar to tree pollen in previous studies.

This study provides updated metrics for the associations of pollen concentrations with primary asthma hospitalizations in Atlanta. It also adds additional considerations of race, age, and temporality, which have been largely unexplored in similar previous studies. The results of this study are important for consideration in future climate change mitigation efforts in the city of Atlanta. The urban sprawl of Atlanta has created an urban heat island, which can increase temperatures and exacerbate the effects felt by climate change (Dixon & Mote, 2003). A common technique to combat the urban heat island effect is through the increase of greenspace, largely through the planting of trees (Bowler et. al. 2010). Increasing temperatures have been experimentally shown to increase the production of pollen, as well as lengthening the overall pollen season (Kim et. al. 2018) (Anderegg et. al. 2021). Increased concentrations of atmospheric CO_2 associated with climate change also serve to increase pollen production (Ziska et. al. 2019). These combined effects will serve to expose the population to more days at increased pollen levels, as well as more days of pollen exposure overall. The effects measured in this study show that these increases could have a significant impact on the respiratory health of the population of Atlanta. Due to the higher association of tree pollen concentrations with primary asthma hospitalizations, great care should be taken when planning the expansion of greenspace. Efforts should be made to make use of low or no pollen producing trees in future tree planting efforts within Atlanta.

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