Title: Association of Wildfire Air Pollution and Health Care Use for Atopic Dermatitis and Itch

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KEY POINTS

Question: How does short-term exposure to wildfire-associated air pollution affect the frequency of outpatient visits for atopic dermatitis (AD) and itch?

Findings: In this ecological study of 8,049 dermatology clinic visits, wildfire-associated air pollution exposure was associated with significantly increased rates of weekly pediatric and adult AD appointments and pediatric itch appointments.

Meaning: Short-term exposure to poor air quality due to a wildfire was associated with measurable effects on patient skin health and increased healthcare utilization for the management of skin disease.

ABSTRACT

Importance: As the frequency and intensity of wildfires increase, the resulting emission of air pollutants may affect the development of and healthcare utilization for chronic inflammatory skin diseases, such as atopic dermatitis (AD).

Objective: To assess the impact of wildfire-associated air pollution on clinic visits for AD or itch and prescribed medications for AD management.

Design: An ecological study was performed to assess the effects of air pollution associated with the California Camp Fire in November 2018 on healthcare utilization at dermatology clinics in an urban city 175 miles from the wildfire source.

Setting: An academic tertiary care hospital system in San Francisco.

Participants: Pediatric and adult patients with AD and/or itch seen in 2015, 2016, and 2018, from October to February of the following year.

Exposures: Wildfire-associated air pollution was assessed using three metrics: fire status, concentration of particulate matter ($PM_{2.5}$), and satellite-based smoke plume density scores.

Main Outcomes and Measures: Primary outcomes were weekly clinic visits for AD or itch. Secondary outcomes were weekly numbers of topical and systemic medications prescribed for AD management in adults.

Results: In this study, data on 8,049 dermatology clinic visits and 4,147 patients (average age: 44.5 years; percent female: 56%) were analyzed. The rate for weekly pediatric itch clinic visits during the Camp Fire is 1.82 (95% CI: 1.20, 2.78) times the rate for non-fire weeks at lag 0 (the current week), adjusted for temperature, relative humidity, patient age, and total patient load at clinics. The adjusted rate ratios for weekly pediatric and adult AD clinic visits are 1.49 (95% CI: 1.07, 2.07) and 1.15 (95% CI: 1.02, 1.30), respectively. In addition, a 10 $\mu g/m^3$ weekly increase

in $PM_{2.5}$ concentration is associated with a 7.7% increase in weekly pediatric AD visits (95% CI: 1.9, 13.7). Air pollution was associated with significantly increased rates of prescribed systemic medications.

Conclusions and Relevance:

Short-term exposure to wildfire-associated air pollution is associated with increased healthcare utilization for AD and itch. These results provide a better understanding of the impact of poor air quality on skin health and can guide medical providers' counseling of patients with skin disease and public health practice.

INTRODUCTION

Air pollution is a global public health issue: in 2015, exposure to ambient particulate matter less than 2.5 microns in diameter ($PM_{2.5}$) contributed to 4.2 million deaths and 103.1 million disability-adjusted life-years.[1] It is a complex mixture of gaseous molecules and suspended solid and liquid particles that negatively affects multiple organ systems, contributing to the development and exacerbation of respiratory, cardiovascular, neurologic, and other diseases.[2–5] The effects of air pollution on skin health, however, are relatively underexplored.

Atopic dermatitis (AD), often referred to as eczema, is a chronic inflammatory skin disease characterized by itching and erythematous, scaly skin lesions, attributable to an underlying skin barrier defect and increased immune response to allergens.[6,7] The incidence of AD has been increasing in industrialized countries, and it affects approximately 15% to 20% of children worldwide.[8,9] Potential pathways through which air pollution can contribute to the development and exacerbation of AD include: activation of the aryl hydrocarbon receptor pathway,[10,11] generation of reactive oxygen species,[12–14] and induction of a pro-inflammatory response.[11,15–18] The epidemiological evidence for a relationship between air pollution and AD is somewhat mixed; some studies report null findings,[19–23] but many others report evidence of a positive association.[24–32]

Epidemiology studies on skin diseases have primarily focused on chronic exposure to pollution, but the connection between acute exposure to outdoor air pollution and cutaneous diseases like AD is becoming increasingly important to understand as environmental conditions change. An increase in the frequency and severity of wildfires is contributing to a recent trend of increased $PM_{2.5}$ concentrations in the United States (U.S.) after a decades-long reduction in air pollution.[4,33–36] Most of the largest wildfires in the U.S. since the middle of the last century have

all occurred within the past decade.[37,38] For example, the Camp Fire in Northern California during November 2018 was the deadliest and most destructive wildfire in modern California history.[39] Internationally, wildfires that recently occurred in Brazil and Australia garnered global media attention, as millions of people were exposed to hazardous levels of air pollutants.[38,40]

In addition to directly harming patients' health, increased outdoor air pollution attributable to wildfires has systems-level effects. It is associated with increased healthcare services use and spending due to a greater number of emergency room visits for urgent health conditions, such as myocardial infarction.[41,42] As wildfire frequency and intensity increase across the world, we sought to determine the impacts of wildfire associated air pollution on skin health and healthcare utilization. The California Camp Fire posed a unique opportunity to study short term impacts, since particulate matter generated by the fire caused a significant spike in air pollution concentrations for a brief period of time in San Francisco, California, 175 miles from the site of the wildfire.[39] This study examines the impacts of short-term exposure to increased ambient air pollution during a wildfire on clinic visits for AD or itch in order to inform patient care and public health practice.

METHODS

In this retrospective study, we collected environmental data for the city of San Francisco and clinical data for patients seen at the University of California, San Francisco (UCSF)'s dermatology clinics. We collected data for the weeks before, during, and after the Camp Fire (October 2018 – February 2019) as well as for the corresponding dates from previous years when there were no large wildfires in close proximity to San Francisco (October 2015 – February 2016 and October 2016 – February 2017). The study was approved by the UCSF Institutional Review Board.

Exposure Assessment

We gathered data for the daily 24-hour average $PM_{2.5}$ concentrations (μg /m^3) from the Bay Area Air Quality Management District (BAAQMD)'s air quality monitoring station in San Francisco, which meets the U.S. Environmental Protection Agency validation requirements.[43] For all zip codes in San Francisco, we collected the average daily smoke plume density score, ranging from 0 to 3, from the National Oceanic and Atmospheric Administration (NOAA) Hazard Mapping System (HMS) for Fire and Smoke.[44] The HMS displays geospatial distribution of smoke plumes with 4-kilometer resolution by integrating visible band satellite imagery data. We found insignificant spatial variation in daily smoke plume scores across zip codes in San Francisco. Therefore, for our analysis, we calculated city-wide, population-weighted average scores to characterize daily smoke plume density by using the number of residents in each zip code, which is published online by the 2010 U.S. Census Bureau.[45] Daily mean temperature and relative humidity for San Francisco were obtained from the NOAA Local Climatographic Data[46], as prior studies have shown that these factors may affect AD symptoms.[24,25]

Patient data

Using specific codes from the *International Statistical Classification of Diseases and Related Health Problems, Tenth Revision* (*ICD-10*), we identified outpatients for whom a dermatologist indicated a diagnosis of AD or itch at a clinic visit during the time periods assessed. The *ICD-10* codes used for eczema/AD were L30.9, L20.82, L20.84, L20.9, H01.139, H01.136 L, H01.133 R, L28.0 and for itch were L29.9 and L29.8. Patients were excluded from this group if they resided outside of San Francisco (around 25% of the original group). Other extracted information included patients' age, sex, and race/ethnicity, prescribed medications list

for AD patients, and the daily total number of dermatology clinic visits for any skin health-related concern. The medications data for pediatric AD patients were excluded due to low counts.

Statistical Analysis

Exposure, outcome (counts), and covariate data were aggregated on a weekly basis for analysis. This involved calculating the weekly sum of clinic visits and prescribed medications, the weekly average $PM_{2.5}$ concentration, smoke plume density score, temperature, relative humidity, and age of patients, and weekly proportion of patients whose sex is male or female. Poisson regression models are used to look at the role of cofactors on mean counts with extensions to cover overdispersed data that are said to display extra-Poisson variation. Here, however, the counts reflect visit and medication counts from week-to-week and display underdispersion. We thus used a generalized Poisson regression model, based on the generalized Poisson distribution,[47,48] to assess the effects of exposure to wildfire-associated air pollution on clinic visits for AD and itch symptoms and prescribed AD medications. Each outcome was analyzed separately in models that only included one type of exposure assessment data (fire status, smoke plume density, or $PM_{2.5}$) and compared data from the year of the Camp Fire to previous control years: 2015-2016 and 2016-2017. Fire status is a binary exposure variable to indicate whether or not a fire was occurring during a given week. To account for potential delays in seeking care during a wildfire and developing symptoms following exposure, we used 4 1-week, cumulative exposure lags that were analyzed independently. In addition, the models included an offset variable, log of the weekly total number of dermatology clinic visits for any skin health-related concern, to adjust for differences in the total number of available clinic appointments per week both within and across years. This offset accounted for changes in clinic

capacity, such as the number of practicing dermatologists and total patient load. Lastly, the models included a holiday week indicator variable that accounted for weeks which had national holidays, such as Thanksgiving.

The primary outcomes of interest are the weekly total number of adult and pediatric clinics visits for AD or itch. We conducted sensitivity analyses using simple exposure lags and combined 2-week exposure lags for the fire status metric. For each outcome, we report rate ratios (RR) and 95% confidence intervals (CI). Two-tailed *P* values were calculated, and a *P* value less than 0.05 was considered statistically significant. Data management and statistical analyses were conducted using *SAS software and STATA (Barbara, please add version).*

RESULTS

Environmental conditions

The California Camp Fire started in November 8, 2018 and was contained 17 days later, on November 25.[49] Due to prevailing wind patterns, the burning caused a 9-fold increase in average weekly $PM_{2.5}$ concentration in San Francisco during a two-week period (November 8 - 21, 2018), compared to baseline before and after, peaking during the second week of the fire (**Figure 1)**. The smoke plume density score, a measurement of increased haziness of atmospheric conditions attributable to the wildfire, achieved maximum values during the start of the 2 weeks. During the period of the Camp Fire, average temperature in San Francisco was similar to baseline, and the relative humidity decreased during this time (**Table 1**). With the exception of the Thanksgiving holiday week, the total number of appointments for AD and itch increased during the second week of the Camp Fire and following few weeks, compared to the preceding weeks.

Study population

Patient demographics, numbers of visits, and medications are summarized in **Table 2**. The study population included 3,448 unique adult patients and 699 unique pediatric patients, with a total of 6,439 AD visits and 1,610 itch visits across all 3 time periods. The number of appointments and medications generally increased over the years. There were slightly more female patients (56%) than male patients (44%) seen overall. During the Camp Fire, 88% of the adult patients who presented with itch were not previously diagnosed with AD, compared to 59% and 51% during the same 2 weeks in 2015 and 2016, respectively .

Air pollution and AD visits

The results from the generalized Poisson regression, adjusting for temperature, humidity, and patient age, demonstrated significant and positive associations between exposure to wildfire-associated air pollution and weekly clinic visits for AD in both adult and pediatric patients (**Figure 2**). The rate of weekly pediatric and adult AD clinic visits during the Camp Fire are, respectively, 1.49 (95% CI: 1.07 - 2.07) and 1.15 (95% CI: 1.02 - 1.30) times the rate for non-wildfire weeks at lag 0. Rate ratios for smoke plume density and $PM_{2.5}$ exposures correspond to a 1 unit increase in the weekly average NOAA smoke plume density score and a 10 $\mu g/m^3$ increase in weekly average $PM_{2.5}$ concentration. A 1 unit increase in the average weekly NOAA score is associated with 1.12 (95% CI: 1.04 – 1.22) times more average weekly adult AD clinic visits. A 10 $\mu g/m^3$ increase in weekly average $PM_{2.5}$ concentration is associated with 5.1% (95% CI: 0.8 – 9.7%) increase in the average weekly pediatric AD clinic visits.

The effect sizes are larger for the pediatric patient population compared to adults and largest at lag 0 for all three exposure metrics: fire status, weekly average NOAA smoke plume score and $PM_{2.5}$ concentration. The 1-week exposure lags estimate delayed effects of exposure by representing a fixed amount of passing time. For example, cumulative lag 1 includes

pollution exposure during a given week and from the week prior, and cumulative lag 2 includes pollution exposure during a given week and from the previous two weeks. The rate ratios generally tend to decrease from lag 0 to lag 4 for all three exposure metrics.

Air pollution and visits for itch symptoms

The adjusted rate ratios for average weekly pediatric itch visits for fire status, average weekly $PM_{2.5}$ concentration, and average weekly smoke plume density score are 1.82 (95% CI: 1.20 – 2.77), 1.08 (95% CI: 1.02 – 1.14), and 1.55 (95% CI: 1.15 – 2.09), respectively (**Figure 3A**). Similar to the results for pediatric AD visits, the rate ratios for pediatric itch visits generally are largest for lag 0 and decrease from lag 0 to lag 4. However, the effect size is larger for pediatric itch visits compared to pediatric AD visits.

The adjusted rate ratios for adult itch visits are greater than 1 across all lags in the three exposure metrics. However, unlike the results for pediatric itch visits, these do not achieve statistical significance (**Figure 3B**).

Air pollution and AD medications for adults

Medication data were assessed separately as topical and systemic agents; the latter are generally prescribed for the treatment of more severe AD. The results show a positive, significant association between air pollution exposure and weekly number of systemic medications prescribed for treatment of AD in adult patients for certain lags **(Figure 4).** For the topical medications outcome, the adjusted rate ratios are greater than 1 but not statistically significant, except for lag 0 for the smoke plume density metric.

All adjusted and unadjusted results are reported in **eTable 1** and **eTable 2** in the Supplement, respectively. Sensitivity analyses were performed for all outcomes and exposure metrics using simple exposure lags and 2-week combined lags fire status exposure. They

generated results that are overall similar to those from the primary analysis (**eTable 2** in the Supplement).

DISCUSSION

For this study, we assessed the effects of the California Camp Fire, which caused a unique short-term spike of air pollution in San Francisco, on healthcare utilization for skin disease. We found that wildfire-associated air pollution was associated with significantly increased rates of weekly visits for AD for pediatric and adult patients at an academic medical center's dermatology clinics, adjusting for temperature, relative humidity, patient volume, and patient age. In addition, wildfire smoke exposure was associated with a significantly increased rate of clinic visits for itch among pediatric patients and rate of systemic immunosuppressive medications for treatment of AD in adult patients. Overall, our findings indicated that both pediatric and adult patients experienced exacerbations of AD and itch symptoms, as measured by healthcare utilization rates, in association with short-term exposure to increased air pollution.

We used three different metrics to characterize pollution exposure—fire status, $PM_{2.5}$, and smoke plume density—and obtained consistent results across these metrics for each outcome. In addition, we used lags to investigate delayed effects possibly due to patients' slow onset of symptoms or decisions to wait to seek care to minimize travel during episodes of poor air quality. The highest rate ratios for all outcomes are generally seen at exposure lags 0-2, which means that short-term exposure to air pollution is associated with rapid effects on the rates of weekly clinic visits and prescribed medications.

Pruritus is a key symptom of AD;[7] however, most of the adult patients seen for itch during the Camp Fire were not previously diagnosed with AD. This suggests that air pollution exposure may affect the skin health of a wider range of patients beyond just those diagnosed with

AD. Alternatively, these patients may have subclinical AD, not previously diagnosed. In either case, clinicians can broadly counsel patients to use articles of clothing to cover their skin and emollients to optimize their skin barrier to prevent risk of skin irritation during short-term episodes of poor air quality. In addition, the significant, positive associations between air pollution and number of prescribed systemic immunosuppressive medications for treatment of AD in adults suggest that patients with more severe skin disease were particularly affected by poor air quality or that exposure to air pollution increased the severity of existing AD, requiring the initiation of systemic therapy. Longitudinal studies with small samples of schoolchildren in Korea similarly found increased patient-reported AD symptom severity in association with exposure to particulate matter.[29,30]

The roles of environmental factors in the development and exacerbation of AD have been of great clinical concern because understanding them informs chronic disease management. On a molecular level, air pollution contributes to AD pathogenesis through many mechanisms, including the aryl hydrocarbon pathway, oxidative stress, and inflammation.[50–52] However, the link between air pollution exposure and AD has been unclear due to conflicting epidemiological evidence. This study addresses gaps in previous epidemiology studies[20,23] that have examined PM_{10} instead of $PM_{2.5}$, the latter of which overall causes more harmful health effects,[53] and relied on patient-reported outcome data instead of physician-confirmed diagnoses. It also supports findings from studies on long-term $PM_{2.5}$ exposure and AD, including indoor air pollution and AD severity in children,[54] AD prevalence among adults,[55] and prenatal pollution exposure.[27] Regarding healthcare utilization, two studies[56,57] found that outpatient visits for eczema and dermatitis in China were positively associated with air pollution in areas with

continuously high background levels. This study is the first to show that the association holds true for short-term exposure to increased air pollution in an area with low background levels.

The findings of this study should be contextualized within the contemporary progression of climate change. It increases the risk for wildfires in California and other areas around the world, which can then result in exposures to high concentrations of air pollution, even in regions where background levels are usually low.[58,59] Both patients with AD and the general public will benefit from understanding the negative skin health effects of climate change. This study suggests that clinics serving affected communities may experience increased visits for skin disease exacerbations, which negatively affect patient quality of life and increase healthcare expenditures. Public health researchers have reported that people with skin of color and from low-income communities experience disproportionately increased exposure to air pollution.[60,61] Additional study of air pollution and skin health disparities is needed. A better understanding of the skin health implications of climate change will improve clinical management and inform public health education practice and policies on healthcare resource utilization.

Limitations

This study has some limitations. First, this was an observational study, so no direct causal inference can be made; however, unlike most ecological analyses, this study was strengthened by the inclusion of individual-level covariate data. Second, the study population was restricted to patients living in San Francisco and seeking care at dermatology clinics affiliated with one healthcare system. This limits the generalizability of our results, and further research could include more study participants over a larger geographic area affected by wildfires. It is interesting to note that this study found significant associations for visits at clinics located around 175 miles from the origin of the fire; observed effects are anticipated to be even

larger at clinics closer to the origin. Third, this study was not able to include environmental exposure data on an individual patient level, and there were limitations to the publicly available pollution datasets. However, this study analyzed three exposure metrics and found consistent results for all three metrics. Fourth, identification of study subjects via *ICD-10* codes could be subject to selection bias.

CONCLUSIONS

This study shows that short-term exposure to wildfire-associated air pollution impacts skin health and is associated with increased clinic visits for AD and itch. These results highlight the relationship between air quality and skin health, which, especially in an era of climate change, assists clinicians and public health practitioners better understand the prevention and treatment of cutaneous diseases and associated healthcare utilization rates.

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Figure and Table Titles:

-**Figure 1**: Environmental conditions and clinic visits for AD and itch before, during, and after the Camp Fire.

-**Table 1:** Descriptive statistics for environmental conditions of time periods included in analysis.

-**Table 2**: Summary characteristics of the analysis population (visits and patients).

-**Figure 2:** Adjusted generalized Poisson regression results for weekly AD clinic visits according to exposure metric.

A: Pediatric AD visits

B: Adult AD visits

-**Figure 3:** Adjusted generalized Poisson regression results for weekly itch clinic visits according to exposure metric.

A: Pediatric itch visits

B: Adult itch visits

-**Figure 4:** Adjusted generalized Poisson regression results for weekly prescribed AD medications for adults according to exposure metric.

A: Systemic medications

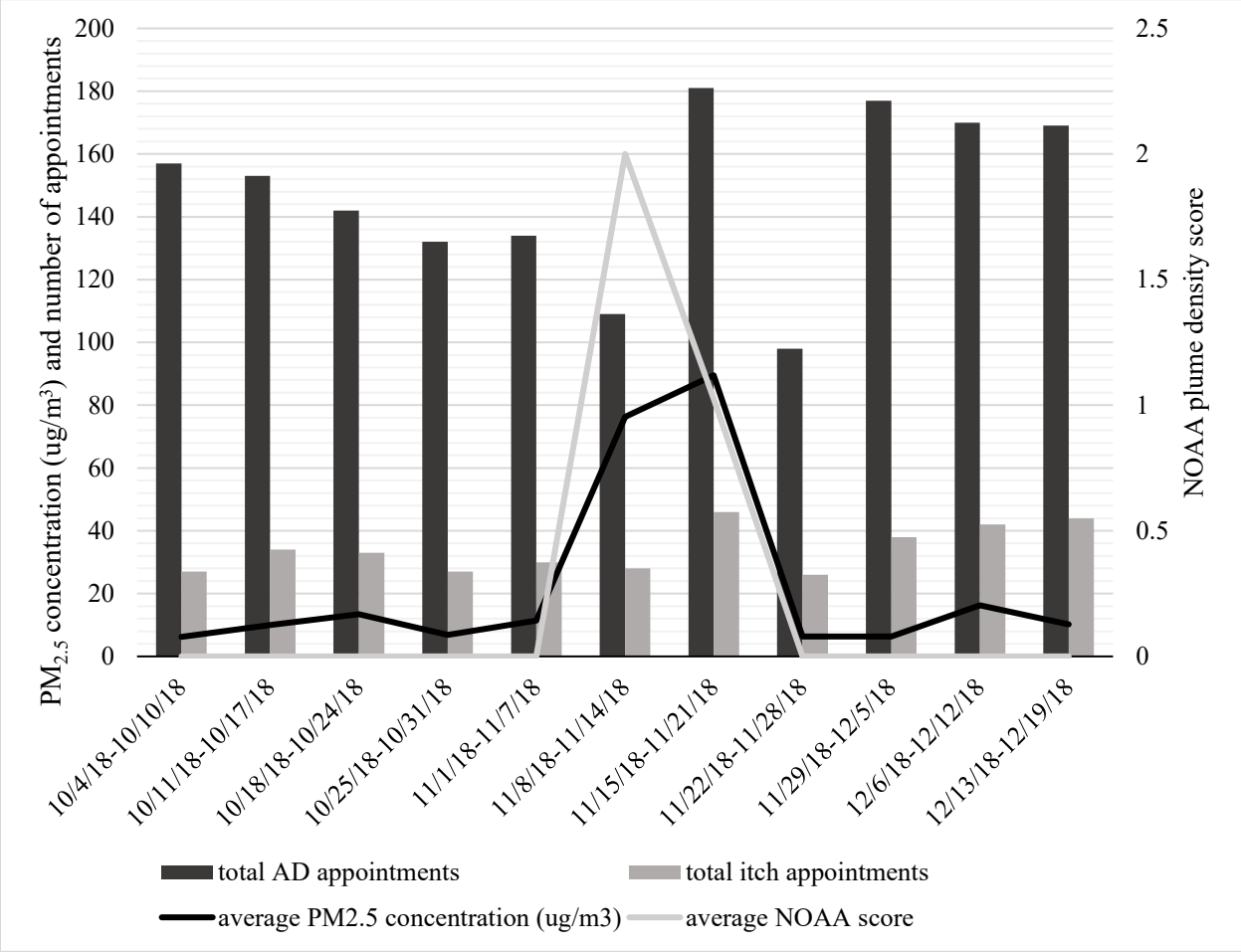
B: Topical medications

-**Supplementary eTable 1:** Adjusted generalized Poisson regression results for all outcomes according to exposure metric. Models included covariates, temperature, humidity, and patient age, an offset for total patient load, and an indicator variable for weeks with a holiday.

-**Supplementary eTable 2:** Unadjusted generalized Poisson regression results for all outcomes according to exposure metric. Models included an offset for total patient load and an indicator variable for weeks with a holiday.

-**Supplementary eTable 3:** Sensitivity analyses for simple exposure lags and 2-week exposure lags for fire status exposure using generalized Poisson regression. Models included covariates, temperature, humidity, and patient age, an offset for total patient load, and an indicator variable for weeks with a holiday.

Figure 1: Environmental conditions and clinic visits for AD and itch before, during, and after the Camp Fire.



Appointment visits represent the sum of adult and pediatric clinic visits for AD or itch on a weekly basis. Environmental conditions represent the average weekly concentration of $PM_{2.5}$ and smoke plume density score.

Abbreviations: AD, atopic dermatitis; $PM_{2.5}$, particulate matter less than 2.5 microns in diameter; NOAA: National Oceanic and Atmospheric Administration

Table 1: Descriptive statistics for environmental conditions of time periods included in analysis.

	2015-2016[a]	2016-2017[a]	2018-2019[a]	Camp Fire[b]
$PM_{2.5}$				
Mean (SD)	8.2 (2.4)	8.2 (3.2)	17.4 (24.1)	82.9 (9.3)
Median	8.2	9	9.5	82.9
Range	3.8 - 12.4	2.5 - 12.6	5.4 - 89.5	76.3 - 89.5
Plume density score				
Mean (SD)	0 (0.1)	0 (0)	0.17 (0.52)	1.5 (0.7)
Median	0	0	0	1.5
Range	0 - 0.2	0 - 0.1	0 - 2	1.0 - 2
Temperature				
Mean (SD)	56.5 (6.0)	55.9 (5.4)	57.2 (4.0)	57.6 (2.1)
Median	55.7	53.9	56.4	57.6
Range	45.9 - 68.3	50.4 - 64.6	51.6 - 64.4	56.1 - 59.1
Relative Humidity				
Mean (SD)	74.1 (6.3)	73.2 (5.0)	70.9 (9.0)	60.3 (16.6)
Median	73.1	74.3	72.1	60.3
Range	62.1 - 86	62.1 - 81.4	48.6 - 83.9	48.6 - 72

[a] Data for these time periods encompass 18 weeks from October of the first year to February of the second year. [b] Data in this column encompass the 2 weeks of the Camp Fire in November 2018.

Abbreviations: AD, atopic dermatitis; $PM_{2.5}$, particulate matter less than 2.5 microns in diameter; SD, standard deviation.

Table 2: Summary characteristics of the study population (visits and patients).[a]

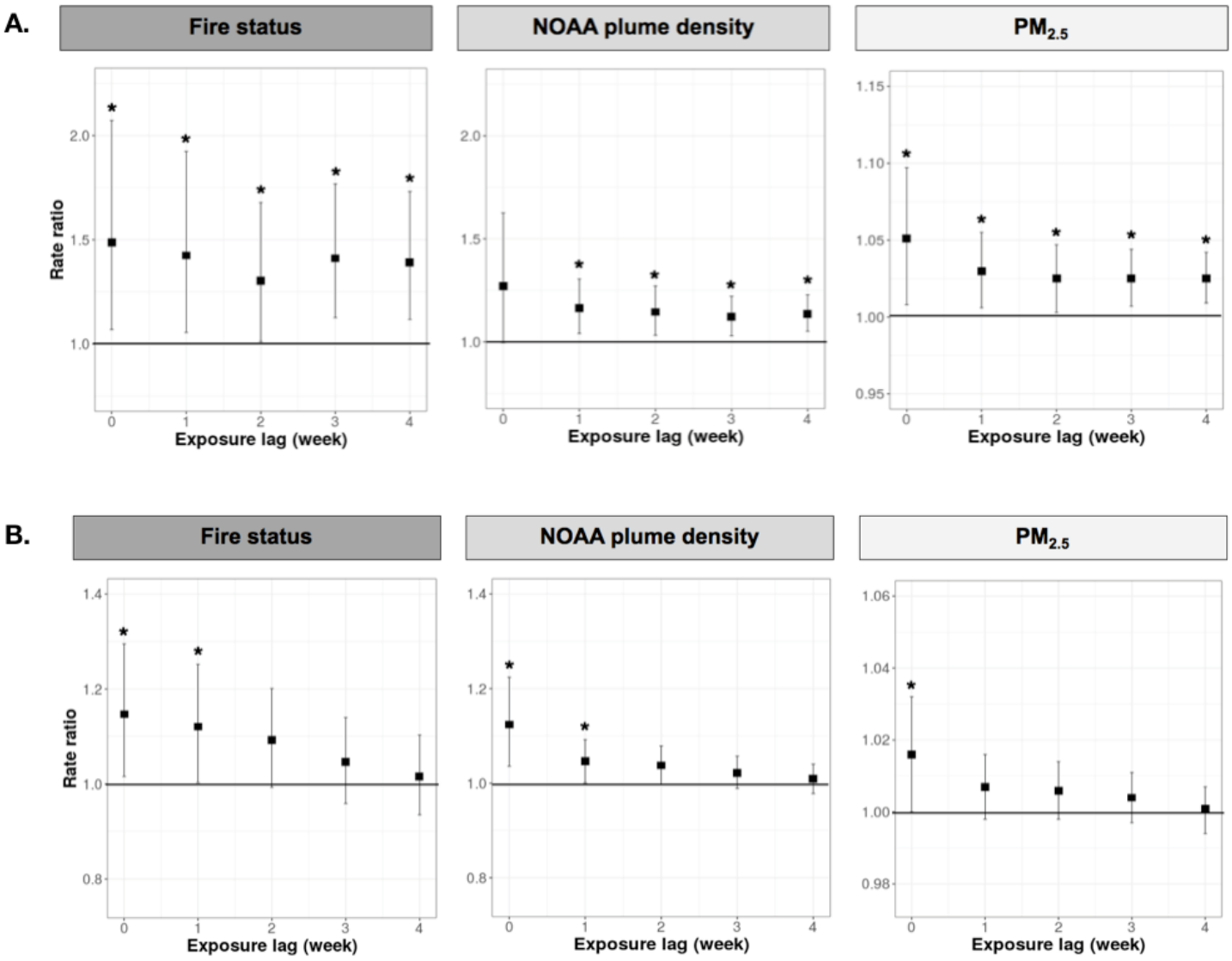
Characteristic	Total[b]	2015-2016[c]	2016-2017[c]	2018-2019[c]
Total AD appointments	6,439	1,739	2,145	2,555
Adult AD appointments	5,529 (85.9)	1,477 (84.9)	1,790 (83.4)	2,262 (88.5)
Pediatric AD appointments	910 (14.1)	262 (15.1)	355 (16.6)	293 (11.5)
Total itch appointments	1,610	539	508	563
Adult itch appointments	1,319 (81.9)	460 (85.3)	422 (83.1)	437 (77.6)
Pediatric itch appointments	291 (18.1)	79 (14.7)	86 (16.9)	126 (22.4)
Total adult AD medications	3,464	928	1,145	1,391
Systemic medications	508 (14.7)	107 (11.5)	186 (16.2)	215 (15.5)
Topical medications	2,956 (85.3)	821 (88.5)	959 (83.8)	1,176 (84.5)
Total all skin concerns appointments	66,642	19,796	21,887	24,959
Adult all skin concerns appointments	56,575 (84.9)	17,037 (86.1)	18,421 (84.2)	21,117 (84.6)
Pediatric all skin concerns appointments	10,067 (15.1)	2,759 (13.9)	3,466 (15.8)	3,842 (15.4)
Total patients	4,147	1,100	1,300	1,747
Adult patients	3,448 (83.1)	905 (82.3)	1,073 (82.5)	1,470 (84.1)
Pediatric patients	699 (16.9)	195 (17.7)	227 (17.5)	277 (15.9)
Adult patients seen for itch but not diagnosed with AD[d]	120 (66.0)	33 (58.5)	31 (50.9)	56 (88.6)
Pediatric patients seen for itch but not diagnosed with AD[d]	10 (8.7)	2 (8.3)	2 (8.3)	3 (9.5)
Age of all patients, mean (SD), y	44.6 (21.1)	44.8 (21.5)	44.3 (20.3)	44.5 (21.3)
Adult patients	51.9 (4.6)	52.7 (4.4)	51.6 (5.4)	51.4 (4.2)
Pediatric patients	7.5 (2.0)	8.0 (2.1)	7.6 (2.2)	6.9 (1.7)
Proportion Female – All patients	0.56	0.59	0.55	0.55

Adult patients	0.57	0.60	0.56	0.55
Pediatric patients	0.52	0.53	0.51	0.54

[a] Data are presented as No. (%) unless otherwise indicated. [b] Percentages represent the fraction of data within the combined data from all three time periods. [c] Percentages represent the fraction of data within the respective time period (e.g., 2015-2016, 2016-2017, or 2018-2019), not the combined data. [d] Data represent patients who were seeking care during the 2 weeks of the Camp Fire in November 2018 and the corresponding 2 weeks in 2015 and 2016.

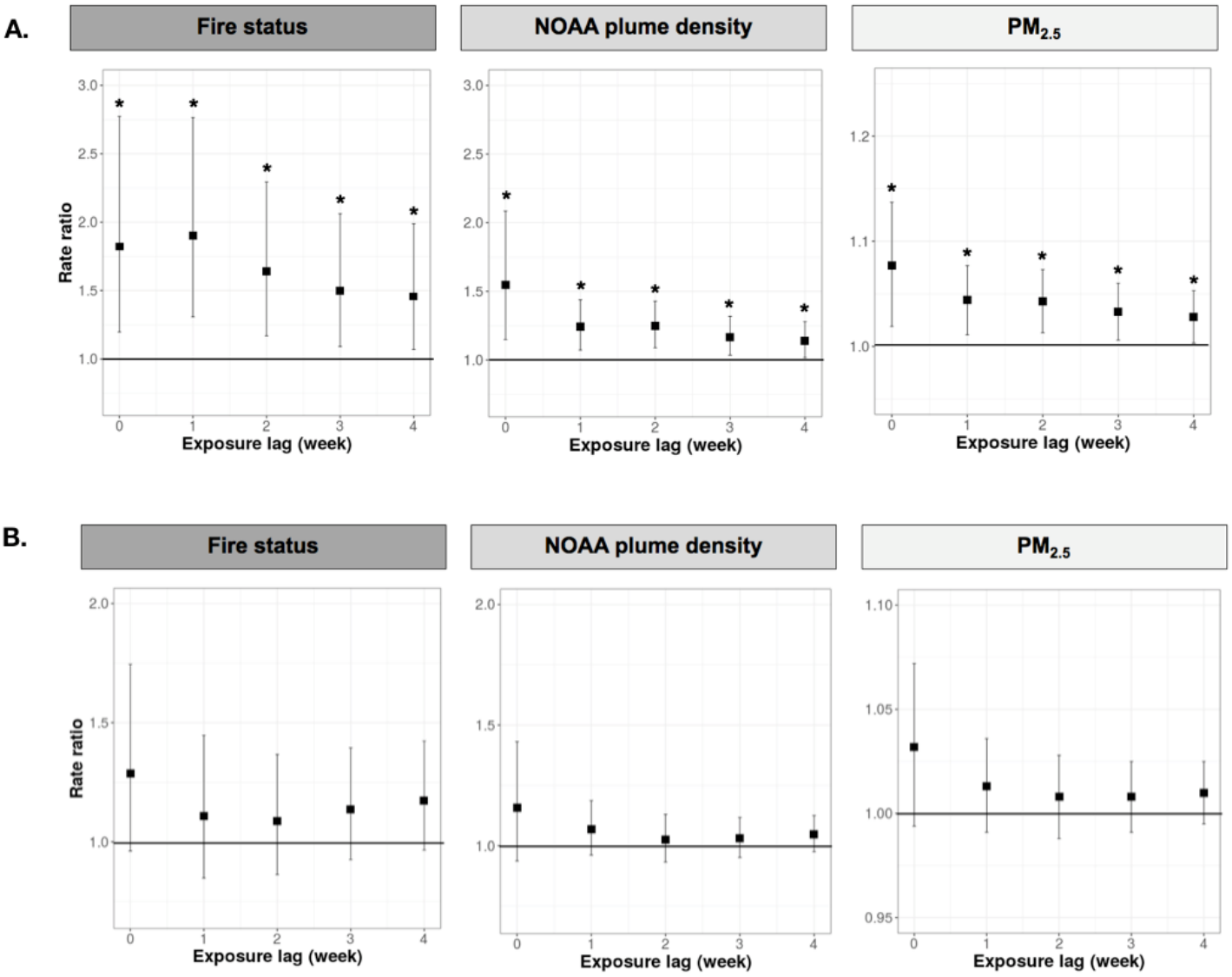
Abbreviations: AD, atopic dermatitis; $PM_{2.5}$, particulate matter less than 2.5 microns in diameter.

Figure 2: Adjusted generalized Poisson regression results for weekly AD clinic visits according to exposure metric. A: Pediatric AD visits; B: Adult AD visits



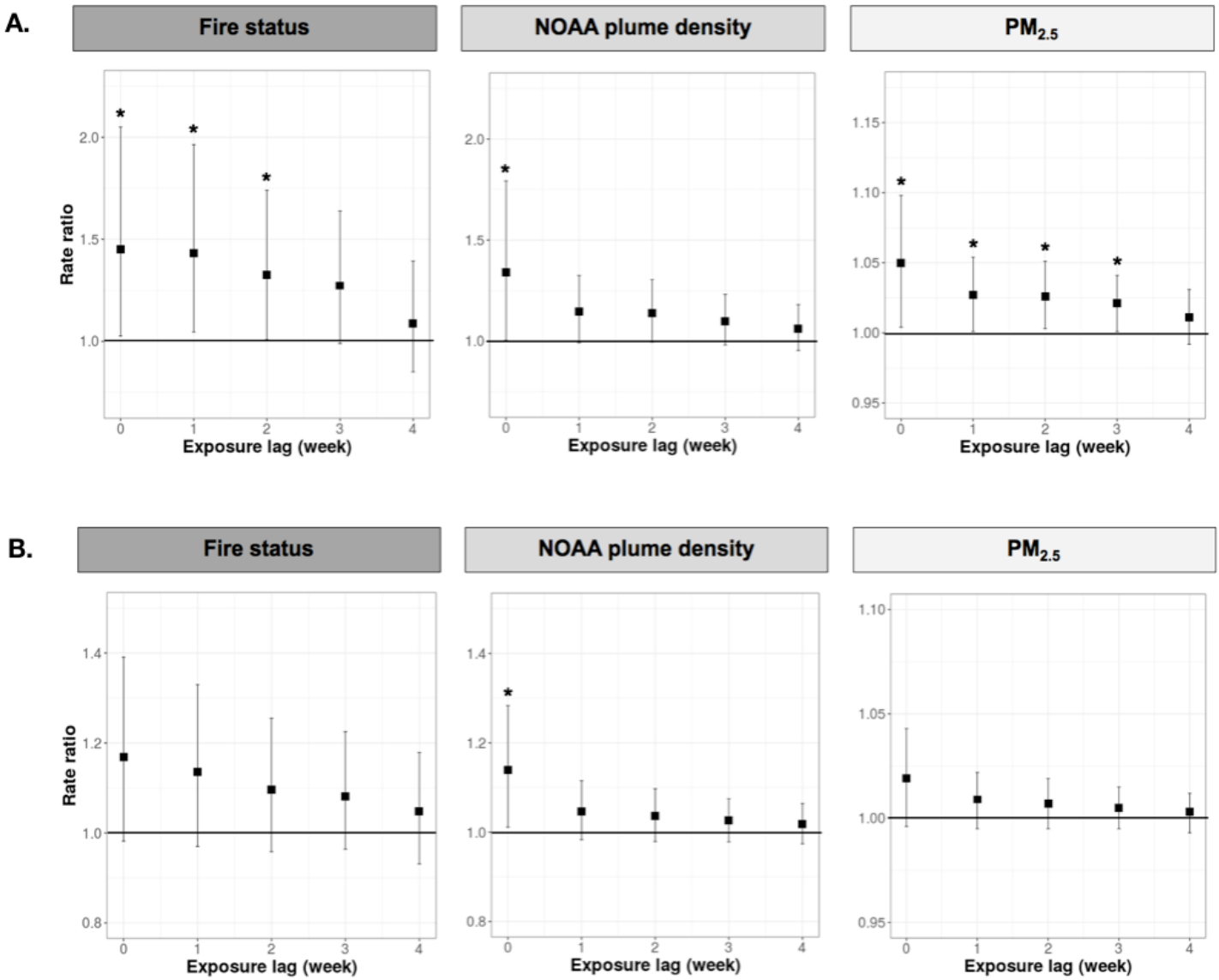
Squares represent the point estimate adjusted for temperature, humidity, patient age, and total patient load, error bars represent 95% confidence intervals, lags represent cumulative exposure to air pollution, and * represents results with $P<0.05$. The horizontal line at a rate ratio of 1 represents the null hypothesis. Abbreviations: AD, atopic dermatitis; $PM_{2.5}$, particulate matter less than 2.5 microns in diameter; NOAA: National Oceanic and Atmospheric Administration.

Figure 3: Adjusted generalized Poisson regression results for weekly itch clinic visits according to exposure metric. A: Pediatric itch visits; B: Adult itch visits



Squares represent the point estimate adjusted for temperature, humidity, patient age, and total patient load, error bars represent 95% confidence intervals, lags represent cumulative exposure to air pollution, and * represents $P<0.05$. Lags represent cumulative exposure to air pollution, and * represents $P<0.05$. Abbreviations: AD, atopic dermatitis; $PM_{2.5}$, particulate matter less than 2.5 microns in diameter; NOAA: National Oceanic and Atmospheric Administration.

Figure 4: Adjusted generalized Poisson regression results for weekly prescribed AD medications for adults according to exposure metric. A: Systemic medications; B: Topical medications



Squares represent the point estimate adjusted for temperature, humidity, patient age, and total patient load, error bars represent 95% confidence intervals, lags represent cumulative exposure to air pollution, and * represents $P<0.05$. Lags represent cumulative exposure to air pollution, and * represents $P<0.05$. Abbreviations: AD, atopic dermatitis; $PM_{2.5}$, particulate matter less than 2.5 microns in diameter; NOAA: National Oceanic and Atmospheric Administration.

eTable 1: Adjusted generalized Poisson regression results for all outcomes according to exposure metric. Models compared data from 2018-2019 to previous years, included covariates, temperature, humidity, and patient age, an offset for total patient load, and an indicator variable for weeks with a holiday. Bold values represent results with $P<0.05$. Abbreviations: CI = confidence interval; C = cumulative; AD = atopic dermatitis; $PM_{2.5}$ = particulate matter less than 2.5 microns in diameter.

Outcomes	Exposures	Lags	Rate Ratio	95% CI Lower Bound	95% CI Upper Bound	*P*-value
Pediatric AD	Fire status	C0	**1.488**	**1.069**	**2.072**	**0.019**
		C1	**1.425**	**1.055**	**1.924**	**0.021**
		C2	**1.302**	**1.011**	**1.678**	**0.041**
		C3	**1.411**	**1.126**	**1.768**	**0.003**
		C4	**1.390**	**1.117**	**1.731**	**0.003**
Pediatric AD	$PM_{2.5}$	C0	**1.051**	**1.008**	**1.097**	**0.020**
		C1	**1.030**	**1.006**	**1.055**	**0.013**
		C2	**1.025**	**1.003**	**1.047**	**0.025**
		C3	**1.025**	**1.007**	**1.044**	**0.006**
		C4	**1.025**	**1.009**	**1.042**	**0.003**
Pediatric AD	Plume score	C0	1.272	0.996	1.625	0.054
		C1	**1.165**	**1.041**	**1.305**	**0.008**
		C2	**1.145**	**1.032**	**1.271**	**0.011**
		C3	**1.121**	**1.029**	**1.221**	**0.009**
		C4	**1.137**	**1.052**	**1.228**	**0.001**
Adult AD	Fire status	C0	**1.147**	**1.016**	**1.295**	**0.027**
		C1	**1.121**	**1.003**	**1.252**	**0.044**
		C2	1.092	0.993	1.201	0.070
		C3	1.046	0.959	1.140	0.309
		C4	1.016	0.935	1.103	0.714
Adult AD	$PM_{2.5}$	C0	**1.016**	**1.001**	**1.032**	**0.049**
		C1	1.007	0.998	1.016	0.138
		C2	1.006	0.998	1.014	0.158
		C3	1.004	0.997	1.011	0.325
		C4	1.001	0.994	1.007	0.826

Adult AD	Plume score	C0	**1.124**	**1.036**	**1.224**	**0.007**
		C1	**1.046**	**1.001**	**1.092**	**0.043**
		C2	1.038	0.997	1.079	0.067
		C3	1.022	0.989	1.057	0.198
		C4	1.009	0.978	1.040	0.582
Pediatric itch	Fire status	C0	**1.822**	**1.197**	**2.773**	**0.005**
		C1	**1.900**	**1.307**	**2.764**	**0.001**
		C2	**1.638**	**1.169**	**2.294**	**0.004**
		C3	**1.500**	**1.091**	**2.062**	**0.013**
		C4	**1.458**	**1.070**	**1.988**	**0.017**
Pediatric itch	$PM_{2.5}$	C0	**1.077**	**1.019**	**1.137**	**0.008**
		C1	**1.044**	**1.011**	**1.077**	**0.008**
		C2	**1.043**	**1.013**	**1.073**	**0.005**
		C3	**1.033**	**1.006**	**1.060**	**0.015**
		C4	**1.028**	**1.003**	**1.053**	**0.028**
Pediatric itch	Plume score	C0	**1.548**	**1.149**	**2.085**	**0.004**
		C1	**1.242**	**1.072**	**1.439**	**0.004**
		C2	**1.247**	**1.089**	**1.429**	**0.001**
		C3	**1.169**	**1.036**	**1.319**	**0.011**
		C4	**1.141**	**1.017**	**1.279**	**0.024**
Adult itch	Fire status	C0	1.287	0.961	1.745	0.091
		C1	1.108	0.848	1.447	0.452
		C2	1.086	0.862	1.367	0.486
		C3	1.135	0.925	1.394	0.226
		C4	1.172	0.965	1.423	0.110
Adult itch	$PM_{2.5}$	C0	1.032	0.994	1.072	0.098
		C1	1.013	0.991	1.036	0.241
		C2	1.008	0.988	1.028	0.457
		C3	1.008	0.991	1.025	0.359
		C4	1.010	0.995	1.025	0.207
Adult itch	Plume score	C0	1.158	0.937	1.431	0.174
		C1	1.068	0.961	1.187	0.224
		C2	1.026	0.932	1.130	0.601
		C3	1.031	0.951	1.117	0.458
		C4	1.047	0.975	1.125	0.208
Systemic medications	Fire status	C0	**1.450**	**1.026**	**2.050**	**0.035**
		C1	**1.433**	**1.046**	**1.964**	**0.025**
		C2	**1.325**	**1.009**	**1.740**	**0.043**

		C3	1.273	0.989	1.639	0.061
		C4	1.089	0.851	1.393	0.497
Systemic medications	$PM_{2.5}$	C0	**1.050**	**1.004**	**1.098**	**0.031**
		C1	**1.027**	**1.001**	**1.054**	**0.043**
		C2	**1.026**	**1.003**	**1.051**	**0.030**
		C3	**1.021**	**1.001**	**1.041**	**0.045**
		C4	1.011	0.992	1.031	0.238
Systemic medications	Plume score	C0	**1.342**	**1.005**	**1.793**	**0.046**
		C1	1.146	0.991	1.325	0.066
		C2	1.139	0.995	1.305	0.060
		C3	1.099	0.981	1.231	0.103
		C4	1.061	0.954	1.181	0.275
Topical medications	Fire status	C0	1.169	0.982	1.391	0.079
		C1	1.136	0.970	1.330	0.113
		C2	1.096	0.958	1.255	0.182
		C3	1.081	0.964	1.225	0.220
		C4	1.048	0.931	1.179	0.439
Topical medications	$PM_{2.5}$	C0	1.019	0.996	1.043	0.099
		C1	1.009	0.995	1.022	0.208
		C2	1.007	0.995	1.019	0.281
		C3	1.005	0.995	1.015	0.349
		C4	1.003	0.993	1.012	0.587
Topical medications	Plume score	C0	**1.139**	**1.011**	**1.283**	**0.032**
		C1	1.047	0.983	1.115	0.151
		C2	1.037	0.979	1.097	0.218
		C3	1.026	0.978	1.075	0.297
		C4	1.018	0.974	1.064	0.422

eTable 2: Unadjusted generalized Poisson regression results for all outcomes according to exposure metric. Models compared data from 2018-2019 to previous years, included an offset for total patient load, and an indicator variable for weeks with a holiday. Bold values represent results with $P<0.05$. Abbreviations: CI = confidence interval; C = cumulative; AD = atopic dermatitis; $PM_{2.5}$ = particulate matter less than 2.5 microns in diameter.

Outcomes	Exposures	Lags	Rate Ratio	95% CI Lower Bound	95% CI Upper Bound	*P*-value
Pediatric AD	Fire status	C0	1.317	0.954	1.818	0.094
		C1	1.326	0.978	1.796	0.069
		C2	**1.298**	**1.002**	**1.683**	**0.049**
		C3	**1.383**	**1.099**	**1.741**	**0.006**
		C4	**1.352**	**1.083**	**1.687**	**0.008**
Pediatric AD	$PM_{2.5}$	C0	**1.041**	**1.000**	**1.085**	**0.047**
		C1	**1.028**	**1.003**	**1.053**	**0.025**
		C2	**1.027**	**1.004**	**1.049**	**0.019**
		C3	**1.027**	**1.009**	**1.046**	**0.004**
		C4	**1.025**	**1.009**	**1.042**	**0.002**
Pediatric AD	Plume score	C0	**1.128**	**1.007**	**1.399**	**0.046**
		C1	**1.129**	**1.006**	**1.267**	**0.040**
		C2	**1.130**	**1.014**	**1.258**	**0.026**
		C3	**1.121**	**1.026**	**1.226**	**0.012**
		C4	**1.130**	**1.044**	**1.224**	**0.003**
Adult AD	Fire status	**C0**	**1.101**	**1.012**	**1.239**	**0.042**
		C1	1.079	0.990	1.214	0.102
		C2	1.059	0.958	1.170	0.263
		C3	1.042	0.951	1.141	0.374
		C4	1.024	0.940	1.116	0.592
Adult AD	$PM_{2.5}$	**C0**	**1.013**	**1.001**	**1.027**	**0.046**
		C1	1.007	0.997	1.017	0.101
		C2	1.005	0.997	1.014	0.225
		C3	1.004	0.997	1.011	0.293
		C4	1.002	0.996	1.009	0.496
Adult AD	Plume score	C0	1.049	0.964	1.141	0.268
		C1	1.034	0.987	1.083	0.162
		C2	1.029	0.987	1.074	0.181
		C3	1.019	0.983	1.055	0.307
		C4	1.012	0.980	1.045	0.470
Pediatric itch	Fire status	C0	**1.728**	**1.161**	**2.572**	**0.007**

		C1	**1.864**	**1.294**	**2.686**	**0.001**
		C2	**1.640**	**1.179**	**2.282**	**0.003**
		C3	**1.518**	**1.108**	**2.079**	**0.009**
		C4	**1.475**	**1.088**	**2.001**	**0.012**
Pediatric itch	$PM_{2.5}$	C0	**1.073**	**1.018**	**1.131**	**0.009**
		C1	**1.045**	**1.013**	**1.078**	**0.006**
		C2	**1.044**	**1.015**	**1.074**	**0.003**
		C3	**1.034**	**1.008**	**1.060**	**0.010**
		C4	**1.028**	**1.004**	**1.051**	**0.021**
Pediatric itch	Plume score	C0	**1.407**	**1.089**	**1.820**	**0.009**
		C1	**1.237**	**1.070**	**1.431**	**0.004**
		C2	**1.249**	**1.091**	**1.430**	**0.001**
		C3	**1.175**	**1.043**	**1.324**	**0.008**
		C4	**1.145**	**1.023**	**1.281**	**0.018**
Adult itch	Fire status	C0	1.214	0.914	1.613	0.181
		C1	1.097	0.839	1.435	0.497
		C2	1.067	0.847	1.344	0.581
		C3	1.131	0.920	1.390	0.242
		C4	1.179	0.974	1.428	0.092
Adult itch	$PM_{2.5}$	C0	1.026	0.988	1.064	0.181
		C1	1.013	0.991	1.036	0.254
		C2	1.007	0.987	1.028	0.480
		C3	1.007	0.991	1.024	0.390
		C4	1.009	0.995	1.024	0.201
Adult itch	Plume score	C0	1.095	0.904	1.326	0.354
		C1	1.061	0.954	1.180	0.277
		C2	1.026	0.931	1.130	0.607
		C3	1.029	0.949	1.115	0.487
		C4	1.049	0.977	1.127	0.187
Systemic medications	Fire status	C0	**1.469**	**1.046**	**2.063**	**0.026**
		C1	**1.457**	**1.053**	**2.016**	**0.023**
		C2	**1.370**	**1.034**	**1.815**	**0.028**
		C3	**1.364**	**1.054**	**1.763**	**0.018**
		C4	1.139	0.881	1.474	0.321
Systemic medications	$PM_{2.5}$	C0	**1.054**	**1.008**	**1.101**	**0.021**
		C1	**1.028**	**1.000**	**1.056**	**0.046**
		C2	**1.028**	**1.003**	**1.054**	**0.029**
		C3	**1.025**	**1.004**	**1.047**	**0.018**
		C4	1.016	0.996	1.035	0.112

Systemic medications	Plume score	C0	**1.302**	**1.048**	**1.616**	**0.017**
		C1	**1.148**	**1.011**	**1.303**	**0.033**
		C2	**1.144**	**1.015**	**1.290**	**0.027**
		C3	**1.116**	**1.009**	**1.234**	**0.032**
		C4	1.082	0.986	1.188	0.096
Topical medications	Fire status	C0	1.163	0.985	1.374	0.075
		C1	1.131	0.966	1.324	0.125
		C2	1.100	0.962	1.259	0.163
		C3	1.072	0.948	1.213	0.269
		C4	1.042	0.927	1.171	0.490
Topical medications	$PM_{2.5}$	C0	1.020	0.997	1.042	0.084
		C1	1.009	0.996	1.023	0.183
		C2	1.007	0.995	1.019	0.248
		C3	1.005	0.995	1.015	0.351
		C4	1.002	0.993	1.011	0.632
Topical medications	Plume score	C0	**1.118**	**1.004**	**1.245**	**0.042**
		C1	1.047	0.984	1.115	0.149
		C2	1.036	0.978	1.098	0.227
		C3	1.026	0.978	1.076	0.302
		C4	1.015	0.972	1.060	0.496

eTable 3: Sensitivity analyses for simple exposure lags and 2-week exposure lags for fire status exposure using generalized Poisson regression. Models compared data from 2018-2019 to previous year, included covariates, temperature, humidity, and patient age, an offset for total patient load, and an indicator variable for weeks with a holiday. Bold values represent results with $P<0.05$. Abbreviations: CI = confidence interval; S = simple; AD = atopic dermatitis; $PM_{2.5}$ = particulate matter less than 2.5 microns in diameter.

Outcomes	Exposures	Lags	Rate Ratio	95% CI Lower Bound	95% CI Upper Bound	*P*-value
Pediatric AD	Fire status	S0	**1.488**	**1.067**	**2.072**	**0.019**
		S1	**1.543**	**1.112**	**2.142**	**0.009**
		S2	1.088	0.753	1.572	0.654
		S3	1.260	0.941	1.687	0.121
		S4	1.297	0.946	1.778	0.107
		S0,2,4	**1.580**;1.181; 1.410	**1.136**;0.826; 1.030	**2.198**;1.688; 1.930	**0.007**;0.362; 0.032
Pediatric AD	$PM_{2.5}$	S0	**1.051**	**1.008**	**1.097**	**0.020**
		S1	**1.057**	**1.008**	**1.109**	**0.023**
		S2	1.004	0.958	1.052	0.863
		S3	1.035	0.995	1.076	0.085
		S4	1.029	0.986	1.073	0.195
Pediatric AD	Plume score	S0	**1.272**	**1.003**	**1.645**	**0.044**
		S1	**1.271**	**1.070**	**1.509**	**0.006**
		S2	1.073	0.807	1.426	0.629
		S3	1.108	0.927	1.325	0.261
		S4	1.200	0.991	1.451	0.061
Adult AD	Fire status	S0	**1.147**	**1.016**	**1.295**	**0.027**
		S1	1.063	0.929	1.215	0.374
		S2	1.015	0.886	1.163	0.829
		S3	0.967	0.862	1.084	0.561
		S4	0.909	0.808	1.021	0.108
		S0,2,4	**1.141**;1.011; 0.915	**1.013**;0.887; 0.817	**1.287**;1.152; 1.026	**0.029**;0.869; 0.130
Adult AD	$PM_{2.5}$	S0	**1.016**	**1.000**	**1.032**	**0.056**

		S1	1.008	0.988	1.027	0.442
		S2	1.002	0.985	1.019	0.832
		S3	0.997	0.982	1.012	0.697
		S4	0.987	0.971	1.002	0.098
Adult AD	Plume score	S0	**1.124**	**1.033**	**1.224**	**0.007**
		S1	1.041	0.968	1.119	0.275
		S2	1.012	0.914	1.122	0.814
		S3	0.988	0.921	1.060	0.735
		S4	0.947	0.880	1.019	0.145
Pediatric itch	Fire status	S0	**1.822**	**1.197**	**2.773**	**0.005**
		S1	**1.775**	**1.121**	**2.810**	**0.014**
		S2	1.277	0.766	2.130	0.348
		S3	0.984	0.614	1.579	0.948
		S4	0.985	0.604	1.606	0.951
		S0,2,4	**1.884**;1.398; 1.087	**1.236**;0.845; 0.679	**2.874**;2.314; 1.740	**0.003**;0.192; 0.728
Pediatric itch	$PM_{2.5}$	S0	**1.077**	**1.019**	**1.137**	**0.008**
		S1	**1.081**	**1.010**	**1.156**	**0.024**
		S2	**1.029**	**1.002**	**1.051**	**0.043**
		S3	1.003	0.942	1.068	0.925
		S4	1.001	0.937	1.069	0.977
Pediatric itch	Plume score	S0	**1.548**	**1.149**	**2.085**	**0.004**
		S1	**1.317**	**1.029**	**1.685**	**0.029**
		S2	1.311	0.886	1.940	0.176
		S3	0.986	0.739	1.317	0.925
		S4	0.974	0.717	1.324	0.867
Adult itch	Fire status	S0	1.287	0.961	1.725	0.091
		S1	1.080	0.782	1.491	0.640
		S2	0.884	0.631	1.238	0.473
		S3	1.120	0.855	1.465	0.411
		S4	1.223	0.928	1.611	0.152
		S0,2,4	1.317;0.931; 1.246	0.986;0.670; 0.948	1.759;1.293; 1.637	0.062;0.668; 0.115
Adult itch	$PM_{2.5}$	S0	1.032	0.994	1.072	0.098
		S1	1.011	0.966	1.057	0.648
		S2	0.988	0.946	1.032	0.590
		S3	1.011	0.975	1.049	0.541
		S4	1.021	0.983	1.060	0.279
Adult itch	Plume score	S0	1.080	0.907	1.286	0.389

		S1	1.080	0.907	1.286	0.389
		S2	0.859	0.678	1.088	0.207
		S3	1.049	0.887	1.242	0.575
		S4	1.122	0.948	1.327	0.181
Systemic medications	Fire status	S0	**1.450**	**1.026**	**2.050**	**0.035**
		S1	1.346	0.915	1.980	0.132
		S2	1.121	0.753	1.670	0.573
		S3	1.039	0.734	1.472	0.828
		S4	0.714	0.474	1.077	0.109
		S0,2,4	1.416;1.080; 0.827	0.998;0.720; 0.564	2.009;1.621; 1.214	0.051;0.709; 0.332
Systemic medications	$PM_{2.5}$	S0	**1.050**	**1.004**	**1.098**	**0.031**
		S1	1.045	0.989	1.104	0.118
		S2	1.018	0.968	1.070	0.490
		S3	1.010	0.963	1.059	0.679
		S4	0.954	0.901	1.009	0.100
Systemic medications	Plume score	S0	**1.331**	**1.046**	**1.695**	**0.020**
		S1	1.174	0.957	1.438	0.123
		S2	1.147	0.838	1.571	0.391
		S3	1.026	0.834	1.263	0.808
		S4	0.875	0.682	1.121	0.290
Topical medications	Fire status	S0	1.169	0.982	1.391	0.079
		S1	1.060	0.873	1.288	0.556
		S2	1.004	0.828	1.217	0.966
		S3	1.002	0.846	1.186	0.985
		S4	0.953	0.798	1.138	0.594
		S0,2,4	1.166;0.999; 0.950	0.978;0.882; 0.799	1.390;1.215; 1.130	0.086;0.995; 0.562
Topical medications	$PM_{2.5}$	S0	1.019	0.996	1.043	0.099
		S1	1.009	0.981	1.037	0.541
		S2	0.999	0.975	1.024	0.967
		S3	1.001	0.978	1.024	0.943
		S4	0.991	0.967	1.015	0.438
Topical medications	Plume score	S0	**1.139**	**1.011**	**1.283**	**0.032**
		S1	1.030	0.926	1.145	0.590
		S2	0.996	0.861	1.152	0.958
		S3	0.998	0.902	1.105	0.974

		S4	0.978	0.874	1.096	0.706