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Spatial proximity to wildfires as a proxy for measuring $PM_{2.5}$: A novel method for estimating exposures in rural settings

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Abstract

Background: : Climate change impacts humans and society both directly and indirectly. Alaska, for example, is warming twice as fast as the global mean, and researchers are starting to grapple with the varied and inter-connected ways in which climate change affects the people there. With the number of wildfires increasing in Alaska as a result of climate change, the number of asthma cases has increased, driven by exposure to small particulate matter. However, it is not clear how far away smoke from wildfires can affect health. In this study, we hope to establish a relationship between proximity to wildfires and asthma in locations where direct $PM_{2.5}$ measurement is not easily accomplished.

Methods: : In this study, we examined whether proximity to wildfire exposure is associated with regional counts of adults with asthma, calculated using Behavioral Risk Factor Surveillance System (BRFSS) survey data and US Census data. We assigned "hotspots" around population centers with a range of various distances to wildfires in Alaska.

Results: : We found that wildfires are associated with asthma prevalence, and the association is strongest within 25 miles of fires.

Conclusions: : This study highlights the fact that proximity to wildfires has potential as a simple proxy for actual measured wildfire smoke, which has important implications for wildfire management agencies and for policy makers who must address health issues associated with wildfires, especially in rural areas.

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Supplementary materials
Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.joclim.2023.100219.

Declaration of Competing Interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Keywords

Climate change; Human health; Asthma; Alaska

1. Introduction

Alaska is warming faster than any other US state, at a rate twice the global mean [1], experiencing warmer winters, decreased summer sea ice, and a dramatic increase in wildfires [2]. In Alaska, major fire years, in which more than a million acres burn, are occurring more frequently—with eight major fire years in the 40-year period from 1950 through 1989, and 11 in the years from 1990 through 2018 [3]. Given a changing climate, the number of these fires is predicted to increase [4], owing to an expected longer fire season [5] and a greater potential risk of more frequent lightning [6].

Asthma is a chronic condition marked by episodic inflammatory response of the airways that go to the lungs [7,8]. Of Alaskans, 9.9% reported current asthma in 2019 [9], higher than the US average of 7.8% [10]. Asthma is a complex, multifactorial disease, with known triggers such as dust or allergens like mold or dander [7,11], as well as tobacco smoke, poor diet, and air pollution [12–15]. Prior research has demonstrated a strong relationship between asthma and particulate matter in smoke created by wildfires [16,17], such as those that are rapidly increasing in Alaska [17,18]. Measurement of pollution exposure is difficult in Alaska because there are only nine pollution monitoring stations [19]. Given the risk of increased wildfires in Alaska and the sparsity of pollution monitoring, the state presents a unique setting to explore novel methods of assigning exposure and measuring the relationship between exposure to wildfire and developing asthma, in order to create a framework for discussion, to support future studies, and to develop intervention measures.

The relationship between wildfire and asthma has been explored many times throughout the United States outside of Alaska, demonstrating a relationship between wildfire and asthma using measures such as more frequent physician visits [20], emergency department visits [21–23], and hospitalization [24]. Only one study has considered the impacts of wildfire in Alaska: In a study of the effects of wildfires on admissions to emergency departments in the somewhat more populous areas of Anchorage, Fairbanks, and the Matanuska–Susitna Valley, Hahn et al.[24] found higher odds of an emergency department visit for asthma on the day of a wildfire, with effects lasting up to four days after smoke exposure. But there is scant literature on exposure in more rural areas, and prior research looking at exposure in rural locations distant from real-time monitoring stations has necessarily used time- and computing-intensive processes to interpolate satellite data to generate exposure data [25].

Our study looked at the effect of wildfires on counts of asthma in the 11 Alaska Behavioral Health System (BHS) regions from 2007 through 2017 using mapped wildfire boundaries and population center data from the Alaska Bureau of Labor and Statistics to describe the relationship between exposure based on proximity to wildfires and to measure the correlations between this exposure and region-specific asthma counts.

2. Methods

Our outcome of interest is current asthma status for residents of each of the 11 Alaskan BHS regions [26]. These regions have a minimum population of 20,000 in order to provide adequate denominators for research while maintaining personal privacy. Alaska BHS region data identified the percentage of people aged 18 and over with current (prevalent) asthma as those who answered yes to both of the following questions: "Have you ever been told by a doctor [nurse or other health professional] that you have asthma?" and "Do you still have asthma?" [27].

Estimates of the prevalence of asthma in the US were obtained from surveys such as the Behavioral Risk Factor Surveillance System (BRFSS), National Health and Nutrition Examination Surveys, and National Health Interview Surveys [8].

Using US Census GIS shape files [28] and a geographical description from the Alaska Department of Health Services website [26], we created a data file that merged Alaska's boroughs and census areas into the Alaskan BHS regions. Additionally, we obtained Alaska Bureau of Labor and Workforce Development data about each population center in Alaska to provide additional granularity about the specific population for each town or village in each region [29]. For simplicity, we held the population constant at the 2010 level.

We assigned annual fire exposure based on proximity to wildfires as the distance from population centers to fire boundaries and measured the association between people exposed to wildfire smoke and yearly asthma prevalence in the Alaskan BHS regions. Using Alaska Bureau of Labor Statistics data [29], we plotted each village as a point, using a file with an associated 2010 population. We downloaded fire data from the combined fire database for Alaska and plotted all fires for each year from 2007 through 2017 [30]. Then, using the buffer tool in ArcGIS, we created 12 buffers with radii ranging from 5 to 50 miles at 5-mile intervals, and 60 miles and 70 miles from each named population center in Alaska. If a fire occurred within the specified radius of a village, that village was considered fire exposed for that year. As an example of these buffers, supplemental eFig. 1 shows the fires within 25 miles of population areas; any village whose 25-mile buffer had a fire was considered exposed. Next, we summed the populations of all villages in each Alaskan BHS region [26] that were fire exposed. To assign the asthma population, we used the age-adjusted population asthma prevalence percentage for a given year from the BRFSS data and multiplied it by the total population of the BHS region. We then ran a Pearson's correlation examining the relationship between a region's yearly asthma prevalence and the number of fire exposed people in that region for that year.

Data about fire locations were extracted from the Alaska Interagency Coordination Center's combined fire geodatabase, which plots all fire boundaries in space and time for the period of 1940 through 2020 [30]. All steps were performed in accordance with the relevant guidelines and regulations.

3. Results

Examination of the relationship between exposed populations and yearly asthma prevalence showed a positive correlation when including fires within 5 miles of a population center (r = 0.75) up to a radius of 25 miles, at which point the correlation remained relatively flat (r = 0.94). Pearson correlations between population totals of BHS residents for whom a fire occurred within a given radius and the number of that BHS region's population with current asthma are shown in Fig. 1. As increasingly large radii may capture the entire population of the large population centers of Anchorage and Fairbanks, we measured the correlations at all radii excluding those communities. Finally, we tested the correlations both excluding years and places with no fires and treating those values as zeros and including them in the analysis. All correlations are significant at an alpha = 0.05."

4. Discussion

In this study, we found a strong correlation between yearly exposure to fires and higher annual prevalence rates of asthma. Prior research has largely examined point measures of $PM_{2.5}$ smoke and acute effects of wildfire using accurate local monitoring [24,31] in urban population settings where precise measurements are available [32]. We do see evidence that at larger radii, the entire population might be considered exposed, because excluding those communities lowers the correlation. For example, the correlations excluding Anchorage and Fairbanks are lower than those including these larger cities. However, the resulting correlations are still high, and the pattern persists with a fairly consistent effect at a radius of approximately 25 miles." Other research has considered larger areas using computationally intensive modeling that might be ideal for predicting smoke but could be unnecessarily cumbersome for exploratory research [22,33,34]. Our study is the first to use the method of proximity to mapped wildfires to examine effects over a large area, which allows for large area measurement of exposure using a simpler methodology.

In this research, we contribute to the literature by creating a method for an exposure metric based on simple proximity to fires in rural areas, where there is poor direct measurement of pollution by instrumentation and where satellite measurement is currently of poor quality and is computationally intensive. Additionally, this study adds further evidence to the body of literature connecting wildfire smoke to asthma.

This study does have limitations. The BRFSS survey data are annual, so assigning temporality to exposure and outcome is difficult, and the exposure data are ecologic in that they define simple proximity to fire as exposure. Because the outcome data are annual and aggregated to the health region, we were unable to look at the specific effects of a fire on a region or to estimate other potential causes of asthma. These data limitations likewise restrict our analysis to a correlation, especially given asthma is a multifactorial disease. Also, because of the distribution of populations, a large radius will likely capture an entire population which makes for a less useful correlation. Excluding these large population centers weakens the measure of correlation slightly, but the remaining correlations are still strong. However, the effective radius for this method will have a limit and that will have to be considered in future research using this technique. Additionally, the distribution of fire effects is unlikely to be concentric because of weather, wind, and natural features—an issue that could be addressed in future work by incorporating additional data sets. That said, we feel that these limitations are outweighed by the simplicity of our exposure model and its potential for exploratory data analysis that can support future work and provide support for health policy makers working on programs that address the common yet costly disease of asthma, as well as extending this research to additional outcomes associated with fires such as emergency department visits where $PM_{2.5}$ cannot be directly measured. This work can contribute to policy discussions about health resource allocation for rural communities affected by fires and inform clinicians and patients about asthma management in locations where smoke is not explicitly measured because of a lack of adequate pollution monitoring.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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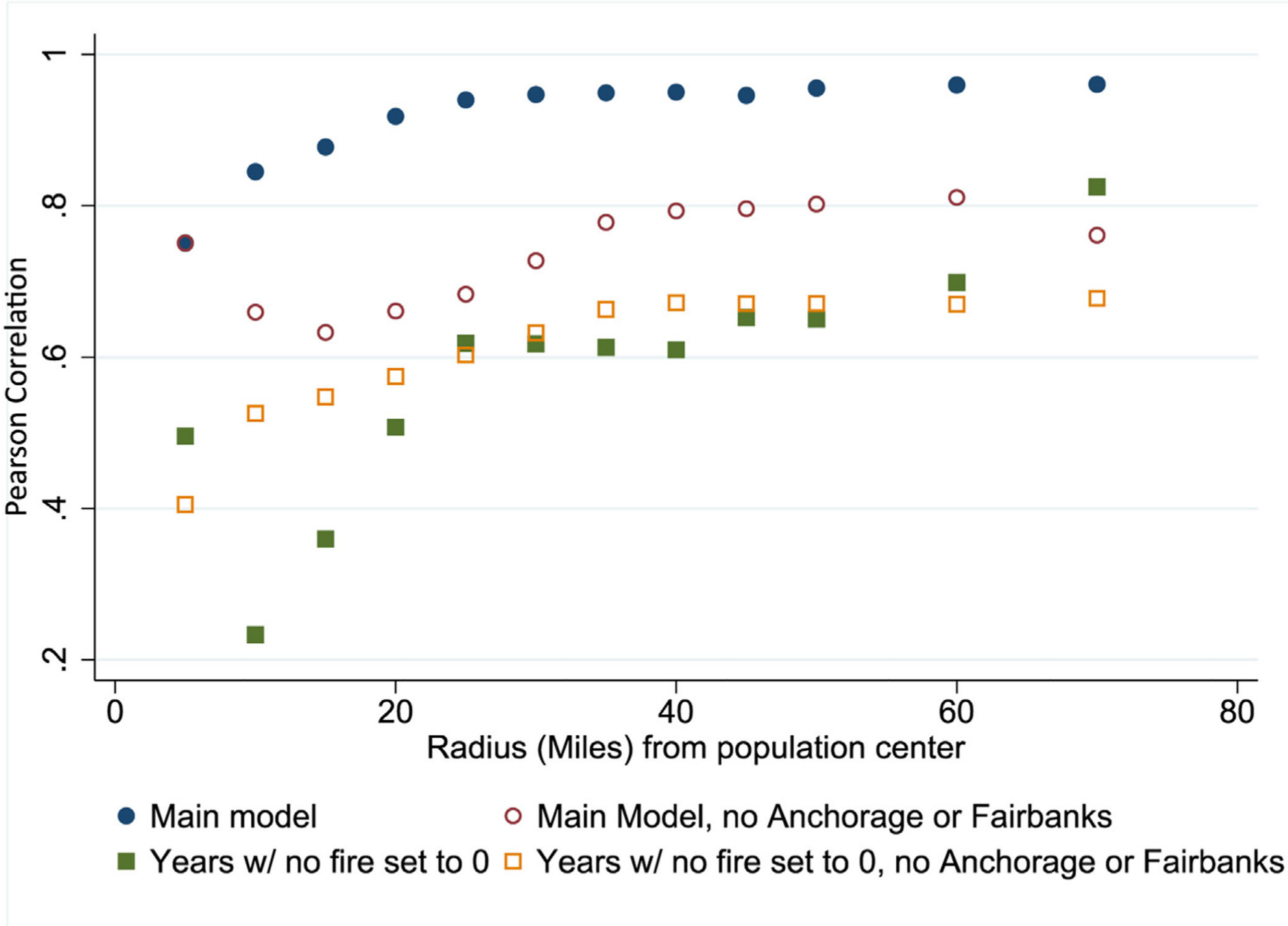

Fig. 1.

Pearson's correlation between the number of people aged 18 and over in Alaskan BHS regions who reported prevalent asthma and the total number of people living in a BHS region who were exposed to fire at radii ranging from 5 to 70 miles from all village centroids.