Peat Bog Wildfire Smoke Exposure in Rural North Carolina Is Associated with Cardio-Pulmonary Emergency Department Visits Assessed Through Syndromic Surveillance

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Abbreviations:

CI: Confidence Interval

AOD: Aerosol Optical Depth

AQI: Air Quality Index

ICD-9-CM Codes: International Statistical Classification of Diseases and Related Health Problems

ED: Emergency Department

COPD: Chronic Obstructive Pulmonary Disease

URIs: Upper Respiratory tract Infections

RR: Relative Risk

PM2.5: Particulate matter with diameter of 2.5 micrometers and smaller

Abstract

Background: In June 2008 burning deposits of peat produced haze and air pollution far in excess of National Ambient Air Quality Standards, encroaching on rural communities of eastern North Carolina (NC). While the association of mortality and morbidity with exposure to urban air pollution is well established, the health effects associated with exposure to wildfire emissions are less understood.

Objective: To determine the effects of exposure on cardio-respiratory outcomes in the population affected by the fire.

Methods: A population-based study was performed using Emergency Department (ED) visits reported through the syndromic surveillance program NCDETECT. Aerosol optical depth measured by a satellite was used to determine a high-exposure window and distinguish counties most impacted by the dense smoke plume from surrounding reference counties. Poisson log-linear regression with a five day distributed lag was used to estimate changes in the cumulative relative risk (RR).

Results: In the exposed counties significant increases in cumulative RR for asthma (1.65(95% confidence interval [1.25, 2.17]), COPD (1.73[1.06, 2.83]), pneumonia and acute bronchitis (1.59[1.07, 2.34]) were observed. ED visits associated with cardiopulmonary symptoms (1.23[1.06, 1.43]) and heart failure (1.37[1.01, 1.85]) were also significantly increased.

Conclusions: Satellite data and syndromic surveillance were combined to assess the health impacts of wildfire smoke in rural counties with sparse air quality monitoring. This is the first study to demonstrate both respiratory and cardiac effects following brief exposure to peat wildfire smoke.

Introduction

On June 1st, 2008 a lightning strike initiated a fire in the eastern plains of North Carolina (NC). Low humidity and prolonged drought contributed to the spread of the fire into the Pocosin Lakes National Wildlife Refuge where it smoldered through rich deposits of peat. Peat in the refuge was on average 3ft and in places up to 15ft deep. Poor oxygen supply during combustion of carbon in the decomposing vegetation produced massive amounts of smoke in the area. The region exposed to the hazardous levels of air pollution generated by the fire was largely rural, sparsely populated, and economically disadvantaged.

To investigate health effects associated with this fire, we obtained daily emergency department (ED) visits for cardiac and respiratory conditions for eastern NC counties reported through the state-wide syndromic surveillance system. Satellite measurements of aerosol optical depth (AOD) were used to determine a 3 day window of dense plume. Relative risks associated with these days and five lag days were estimated for the counties most impacted by the smoke plume and the surrounding, less impacted, referent counties.

Air pollution is described as a complex mixture of gasses and particles whose toxicity depends on the type of fuel and conditions of combustion. There are more than 100 epidemiological studies demonstrating mortality and morbidity associated with both chronic and acute exposures to air pollution focusing mostly on emissions of burning fossil fuels, from automobiles, diesel engines, and coal or oil fired power plants (Integrated Science Assessment for Particulate Matter 2009). During the episodes of wildfires, affected regions experience acute exposures, with concentrations orders of magnitude larger than observed in urban centers. However, health implications of the exposure to wildfire emissions are less well understood (Naeher et al. 2007). In contrast to health studies of urban air pollution, wildfire studies are constrained by the size and distribution of the exposed population, duration of the episode, and the retrospective accessibility of data on exposure and health outcomes. The most comprehensive studies, conducted for forest fires near large metropolitan areas, reported significant increases in symptoms and exacerbations of underlying respiratory illnesses (Jeffrey et al. 2005; Delfino et al. 2009; Duclos P 1990; Kunzli et al. 2006). Less conclusive results have been found within smaller cohort and convenience sample-based studies and less populated regions (Moore 2006; Mott 2005). The effects of exposure on cardiovascular outcomes have been reported with more varied results (Delfino et al. 2009; Moore 2006; Mott 2005; Sastry 2002; Vedal and Dutton 2006) in part due to lack of statistical power.

Climate related changes and past land use practices are expected to increase the risk of wildfires in upcoming decades (Quadrennial Fire Review: Final Report 2009). In addition to the forests, particular concerning is the vulnerability of large deposits of peat bogs to wildfires. Peat soil accounts for approximately 2% of global land cover, mostly in the Boreal regions, where it has been traditionally harvested for energy. In draught conditions peat bogs are exceptionally susceptible to ignition, can smolder indefinitely, and are notoriously difficult to extinguish. Although less common then forest fires, they have an important impact on regional climate and ecosystems. In 1997, Indonesian peat fires released the equivalent of 13-40% of the mean annual global carbon emissions from fossil fuels, and contributed to the largest annual increase in atmospheric CO_2 in four decades (Page 2002). Despite their large impact on the environment, significantly less is known about the associated health effects. One study of Indonesian fires reported more than 500 haze-related deaths, 290,000 cases of asthma exacerbations, 58,000 cases of bronchitis, and 1,440,000 cases of acute respiratory infection between September and November 1997 (Kunii O et al. 2002).

Methods

Daily counts of ED visits were obtained from the NC Disease Event Tracking and Epidemiologic Collection Tool (NCDETECT 2010), a statewide, early event detection and public health surveillance system which records daily ED visits from 111 of 114 civilian NC EDs. We considered visits for selected cardiovascular and respiratory outcomes by adults throughout the eastern portion of the state, as well as county of residence, gender, age, date of admission, and discharge ICD-9-CM codes for all visits. Prior to the analysis, outcomes of interest were defined through ICD-9-CM codes for asthma [493], chronic obstructive pulmonary disease [491 - 492], pneumonia and acute bronchitis [481, 482, 485, 486, and 466], upper respiratory tract infections (URIs) [465], heart failure [428], cardiac dysrythmia [427], myocardial infarction [410, 411.1] and symptoms involving the respiratory system and other chest symptoms [786]. For respiratory related outcomes the population was stratified into two age groups: 19-64, and 65 and older. The small numbers of ED visits for respiratory-related events in those younger than 19 precluded analysis of this subgroup. Cardiac outcomes were also stratified into two age groups: 45-64 and 65 and older. Age of 45 was used to differentiate ischemic heart disease related to atherosclerosis, from coronary artery spasm seen in a younger population. The Human Subjects Institutional Review Board of the University of North Carolina at Chapel Hill, East Carolina University, and the Environmental Protection Agency approved the study.

The study period was defined as the time between the onset of the wildfire through mid-July when controlled flooding, increased humidity, and the first rainfall largely contained the fire (June 1st through July 14th, 2008). During this period, average daily temperatures ranged from 69 to 86^{o}F with overnight lows always below 75^{o}F (See Supplemental Material, Figure 1). For most of the period, winds blew from the west and smoke affected only a few sparsely populated neighboring counties. However, on June 10th easterly winds directed the smoke plume inland, exposing a large portion of eastern and central NC for a three day period (Figure 1A-C). On June 12th, the maximum one-hour concentration of fine particulate matter ($PM_{2.5}$) exceeded 200μg/m^3 at ground-based monitors located 200 kilometers from the fire. We defined June 10th, 11th, and 12th as a window of high exposure and estimated risks associated with the exposure days and one to five lag days relative to the non-exposed days of the six week study period. The relative risks for lags 0 -5 was summarized to define cumulative risk of exposure.

County-level exposure to the plume was classified using AOD, measured by instruments aboard a Geostationary Operational Environmental Satellite. AOD is a unit-less measure with scale from 0 to 2 of the atmospheric scattering and absorption of light by aerosols where larger values indicate higher concentration of particles in the atmosphere and lower visibility. Half-hour, 4 x 4 km resolution grid maps of AOD were averaged over the available day time hours. AOD has been shown to be a good surrogate for boundary layer fine particulate matter concentrations, and a predictor of the Air Quality Index, a nationally uniform index for reporting daily air quality (Al-Saadi et al. 2005; AQI 2009; Engel-Cox et al. 2004; Wang and Christopher 2003). Typical background levels of AOD for this region were well below 0.5. Based on the sharp difference between the high density plume and background, we chose an AOD of 1.25 and greater as an indicator of the high density plume. Counties with a minimum of 25% of the geographic area exceeding this threshold were defined as exposed to the smoke plume for each day in the high exposure window (Figure 1). The satellite's operational algorithm considers high AOD values created by strong reflectance from clouds as unreliable and removes them from the standard data product. The dense smoke plume was, at times, classified as a cloud, resulting in missing AOD values on the interior of the plume. We considered such values as right censored and classified the respective grid cells as exposed to the plume.

The study population resided in 42 contiguous counties in eastern NC. One sparsely populated county (Gates County) was significantly impacted by another wildfire and was excluded from this analysis. Counties with smoke exposure on at least two days were considered exposed (18 counties in Figure 1D). The remaining 23 counties, exposed one day (15 counties) or less (8 counties), were used as referent counties. The populations of exposed and referent counties are similar with respect to age structure, ethnicity, population density, and socioeconomic status. Counties in eastern NC are more rural and agricultural with a higher percentage of African-Americans, and of lower socioeconomic status than most of the remaining North Carolina counties. A table with demographic characteristics of the two groups of counties is included in the online supplement (See Supplemental Material, Table 1).

We applied a Poisson regression model to daily counts of ED visits for combined and individual cardiovascular and respiratory outcomes separately with explanatory variables indicating days within the three-day window of dense smoke and subsequent 5 days of lagged exposure. This was done for both exposed and referent counties. The effects of exposure on outcomes at lags was estimated using an unconstrained distributed lag model (Peng 2008). A number of published studies (Pope et al. 2008; Braga et al. 2001), have determined that air pollution produces immediate and delayed effects on morbidity and mortality and that the time to adverse outcome may vary by pollutant and health outcomes. From the perspective of public health, in this study, we were interested in the total burden on human health associated with the wildfire episode. Inference on delay between the exposure and effect is not appropriate for this study without personal exposure measurements. Here the results are summarized in terms of the cumulative relative risk (cRR), i.e. cumulative risk over lags 0-5, following exposure (Peng 2008) according to

$$\left[\exp\left(\sum_{i=0}^{5}\beta_i\right)\right]$$

where β_i is the relative risk estimate associated with the ith day following the exposure. Figures 3 and 4 summarize percent change in cRR or excess risk according to (cRR-1)x100%. The analysis was stratified by age and sex in both exposed and reference county cohorts.

Results

Asthma related visits accounted for 44% of all respiratory codes considered, and heart failure accounted for 33% of all cardiac events. Consistent with the distribution of asthma prevalence by sex, the aggregate counts of asthma-related visits occurred in more women (70%) than men, and in those between 18 and 64 years (85%). Cardiac events were substantially more common in those individuals over 65 (67%). The number of clinical events reported for each ICD-9-CM code during the study period is given in Table 1.

The cumulative impact during the three high exposure days and five subsequent lag days resulted in significant increases in ED visits for several outcomes when compared with visits during the remainder of the six week study period in the exposed counties (Figure 3). ED visits for all the respiratory diagnoses were elevated in the exposed counties (cRR= 1.66, 95% confidence interval [CI] 1.38 to 1.99) but not in the referent counties (1.06 [0.89, 1.25]). Among the respiratory outcomes, ED visits for asthma (1.65[1.25, 2.17]), COPD (1.73[1.06, 2.83]), pneumonia and acute bronchitis (1.59[1.07, 2.34]) increased significantly. Visits for URIs (1.68[0.94, 3.00]) also increased but were not statistically significant. We found no changes for respiratory outcomes in the referent counties.

Cumulative relative risk for heart failure related ED visits (1.37 [1.01, 1.85]) was increased in the exposed counties, while visits for myocardial infarction and cardiac dysrhythmias were not increased in exposed or referent counties. Reflecting the increase in cardiac and respiratory events, ED visits associated with cardiopulmonary symptoms (ICD-9-CM 786) were significantly increased (1.23[1.06, 1.43]) in the exposed counties.

Age and sex had varying effects on respiratory outcomes and the analysis reflected higher uncertainty due to lower counts of events in these subgroups. Visits for asthma, pneumonia, acute bronchitis and URI increased to a greater extent among women than men in exposed counties (Figure 4A). In contrast, visits related to COPD were only elevated in men. There were more ED visits for asthma, COPD, pneumonia and acute bronchitis among those younger than 65 in the exposed counties (Figure 4B). There were no differences in ED visits for cardiovascular events stratified by age or sex, possibly because the smaller number of visits for these ICD-9-CM codes diminished the power to observe effects in these subgroups.

Discussion

This is the first population-based health study of peat bog fire exposures utilizing a syndromic surveillance system with a nearly comprehensive record of health outcomes from an entire geographic region. We determined relative risk of cardio-respiratory outcomes cumulative over the lag days 0 through 5 of the exposure to smoke. The study demonstrated that exposure to smoke from the wildfire increased ED visits for asthma, COPD, pneumonia, acute bronchitis and heart failure in a sparsely populated non-urban area. The study also demonstrates the utility of syndromic surveillance in assessment of health burden during widespread environmental events. In turn, such assessments should help guide development of strategies and the allocation of resources for the public health response.

Consistent with the results from other studies, asthma related outcomes were most prevalent, especially among adult women. A surprising and important observation is the statistically significant association between smoke exposure and an increase in ED visits for heart failure, as well as the trend towards a positive association with acute coronary syndrome (myocardial infarction and unstable angina). We restricted the cardiovascular clinical endpoints to acute coronary syndrome, which included myocardial infarction and unstable angina (ICD-9 410 and 411.1), and heart failure (ICD-9 428) and excluded hypertensive heart disease.

Although previous studies have shown positive associations between ambient concentrations of $PM_{2.5}$ and ED visits and hospitalization for heart failure (Wellenius et al. 2005; Wellenius et al. 2006; Brook et al. 2010; Dominici et al. 2007), to our knowledge this is the first study that has reported ED visits for heart failure associated with wildfire exposure. However, epidemiologic studies in areas with high residential wood burning suggest have suggested an increased risk of cardiovascular mortality and morbidity may be in part due to wood smoke emissions (Sanhueza et al. 2009; Schwartz et al. 1993). Our study demonstrated an increased percent change in relative risk of 37%. In comparison to the rest of the state, counties of eastern NC are among the poorest and least healthy counties, characterized by higher prevalence of hypertension, diabetes, ischemic heart disease, and heart failure (NCSCHS 2009). These are clinical conditions that are known to be associated with individuals more vulnerable to the health effects of ambient air particle pollution and may have contributed to the large number of events in this relatively sparse population (Wellenius et al. 2005; O'Neill et al. 2007; O'Neill et al. 2005).

Unlike the hot canopy forest fires often seen in the western portion of the country, Pocosin fire was not associated with high temperatures and heat waves. Instead, a prolonged drought lead to the unusually dry conditions in the region which allowed for rapid spread of fire across the peat bogs following a lightning strike. Therefore, it is not surprising we did not observe long-term linear trends or seasonality for the principal respiratory and cardiac diagnoses during this study period as shown for visits for asthma (Figure 2). However, at least three types of misclassification in exposure could have occurred in the study. First, any days with elevated PM levels outside the three day window, were misclassified into periods and could have resulted in a bias towards the null hypothesis. Second, some of the referent counties were exposed to emissions from the fire at some point during the six week period, though not to the extent of the exposed counties, also potentially resulting in bias toward the null hypothesis. Finally, a degree of mis classification at the individual level may occur due to differencies in exposure between county groups. According to the 2000 Census information exposed counties are demographically similar to, but more rural, then referent counties, which may have resulted in a higher exposure (see Supplemental Material, Table 1). However no individual data was available for the analysisAwell documented risk of increased morbidity and mortality due to air-pollution is largely based on central site monitoring and time-series of health outcomes within major urban centers. Rural and remote areas are often not studied because of sparse population and lack of monitoring data. The type and availability of monitoring most often found in sparsely populated areas, such as in this study, provides limited information about the geographic scope of exposure times of environmental events. Air pollution monitors collect data at irregular temporal resolution (e.g. every 24 hrs or every 3 days or every 6 days) and do not provide comprehensive information regarding the geographic scope of the exposure, depending on monitor location, wind direction, terrain (e.g. differences in elevation). Developing new methods for assessing exposure will be increasingly more important as wildfires and other environmental events become more frequent. Several computer models for atmospheric pollutant dispersion already exist but are difficult to validate against sparse ground measurements. In this study we used satellite-derived measurements of AOD to define spatial boundaries of the smoke plume. This allowed us to capture the geographic extent of ED visits in the region and thereby increase statistical power. Such exposure assessment however allows us to associate changes in relative risk to the exposure period but not to the concentration of air pollutants.

Central reporting of ED visits and the high rate of case identification afforded by the NCDETECT syndromic surveillance system contributed to the strength of the associations found in this study. Syndromic surveillance systems were developed to detect epidemics and monitor outbreaks in near real-time (Buehler et al. 2008). The program is implemented at the state level and the median rate of hospital participation in the US is 35%, and ranges between 2 and 100%. Most states report chief complaint data alone but a few, including NC, report diagnostic ICD-9-CM codes. NC has a uniquely comprehensive program with 98% of its hospitals participating. Two other studies of health effects of wildfires in California and Florida (Jeffrey et al. 2005; Sorenset et al. 1999) used syndromic surveillance data and reported increases in respiratory outcomes, asthma, respiratory complaints, eye irritation, and smoke inhalation for respiratory-related chief complaints. The strength of evidence found in the present study further supports efforts to expand automated surveillance system for near-real time delivery of information and health advisories during emergencies. While ICD-9-CM codes are not as timely as chief complaints, they can provide more specific measurements of health outcomes and should be added into syndromic surveillance systems in other states.

Peat fires burn significantly more biological mass, produce massive amounts of smoke, and are notoriously more difficult to extinguish than hot canopy forest fires or grassland fires (Page 2002; See et al. 2007; Soja et al. 2004; Muraleedharan et al. 2000). One study of peat fire particle composition reported carbonaceous particles, particularly organic carbon, NO3-, and SO4(2-) as major components of PM2.5, while the less abundant constituents included ions such as NH4+, NO2-, Na+, K+, organic acids, and metals such as Al, Fe, and Ti (See et al., 2007). Another study reported CO, CO2, and CH4 to be the most abundant gaseous emissions (Muraleedharan et al. 2000). Although, emissions from peat fires may differ from forest fires in chemical composition, it is not known if they differ in toxicity.

Population growth and land use alterations are the primary bases for increased wildfire events worldwide. Additional stress is created by earlier snow melts, rising temperatures, cumulative effects of the current drought and other climate-related changes (Quadrennial Fire Review: Final Report 2009; Westerling et al. 2006). Recent peat fires around Elektrogorsk, Russia exemplify the synergistic effect of these factors and their impact on health and economy in the region (Reilly 2010). Unprecedented hot and dry weather in Russia last year, eased the spread of fires in swamps long ago drained to harvest energy from peat. The smoke obstructed ground, as well as air travel, and resulted in numerous health advisories (Williams 2010). Peat bogs have been exploited for energy use in many parts of the world leaving vest areas of dried wetlands and swamps particularly vulnerable to droughts. It is expected, therefore, that the risk of peat fires is likely to increase in upcoming decades (Quadrennial Fire Review: Final Report 2009).

Conclusion

A consistent increase in relative risk in the exposed counties for nearly all outcome categories is striking and persuasive in comparison to the referent counties and has potentially significant public health implications. The precision of relative risk estimates in this study is attributed to the use of comprehensive population health data from the NC public surveillance program as well as the use of spatially and temporally dense satellite measurements of aerosol optical depth. The region of the state most affected by the smoke was sparsely populated with few available air quality monitors. Therefore, traditional exposure assessment based on monitoring and hospital admissions data alone would not provide us with enough information to assess the true risk. Both data sources used in this paper are readily available to state and local public health officials and lend themselves to the application of traditional statistical methods. In the near future, public health officials may benefit from dashboard-like visualization tools that allow end users to overlay environmental data with healthcare data in order to improve event characterization capabilities and response efforts. Mitigation of exposure and raising public awareness would be expected to decrease the burden to the health care system, and improve the wellbeing of the public.

<u>Disclaimer</u>: The research described in this article has been reviewed by the National Health and Environmental Effects Research Laboratory, US Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and the policies of the Agency nor does mention of trade names or commercial products constitute endorsement or recommendation for use. The NC Public Health Data Group and NC DETECT do not take responsibility for the scientific validity or accuracy of methodology, results, statistical analyses, or conclusions presented.

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Tables and Figure Legends

			Total	<65	≥65	Female	Male
Exposed Counties	Respiratory Outcomes	All†	4702	3485	1217	2963	1739
		Asthma (ICD-9 493)	2081	1775	306	1463	618
		Chronic Obstructive Pulmonary Disease (ICD-9 491, 492)	647	314	333	317	330
		Pneumonia and Acute Bronchitis (ICD-9 481, 482, 485, 486, 466)	1053	607	446	575	478
		Upper Respiratory Infections (ICD-9 465)	444	189	255	202	242
	Cardiac outcomes	All‡	6078	2037	4041	3357	2721
		Myocardial Infarction (ICD-9 410, 411)	444	189	255	202	242
		Heart Failure (ICD-9 428)	1817	579	1238	1068	749
		Cardiac Dysrhythmias (ICD-9 427)	1756	538	1218	937	819
	Respiratory/Other chest Symptoms(786)		7716	5752	1964	4532	3184
Referent Counties	Respiratory Outcomes	All†	6074	4347	1727	3819	2255
		Asthma (ICD-9 493)	2199	1886	313	1591	608
		Chronic Obstructive Pulmonary Disease (ICD-9 491, 492)	1158	558	600	601	557
		Pneumonia and Acute Bronchitis (ICD-9 481, 482, 485, 486, 466)	1815	1146	669	1039	777
		Upper Respiratory Infections (ICD-9 465)	490	429	61	344	146
	Cardiac Outcomes	All‡	7999	2704	5295	4279	3720
		Myocardial Infarction (ICD-9 410, 411)	674	334	340	288	386
		Heart Failure (ICD-9 428)	2374	740	1634	1337	1037
		Cardiac Dysrhythmias (ICD-9 427)	2580	785	1795	1381	1199
	Respiratory/Other chest Symptoms(786)		10102	7801	2301	5968	4134

Table 1. Total counts of emergency department visits in the exposed and referent counties by outcomes , age group, and gender, between June 1 and July 14, 2008. Minimum age for respiratory and cardiac outcomes was 18 and 45 respectively.

†All Respiratory ICD-9 Codes: 465, 466, 480, 481, 482, 483, 484, 485, 486, 490, 491, 492, 493
‡All Cardiac ICD-9 Codes: 410, 411, 413,415, 416, 417, 420, 421, 422, 423, 424, 425, 426, 427, 428, 429, 434, 435, 444, 445, 451

Figure Legends

Figure 1. Aerial maps showing counties impacted by the Evans Road Fire at the Pocosin Lakes National Wildlife Refuge on June 10th, 11th, and12th (Panels A, B, and C respectively) as measured by satellite AOD images. Panel D shows assignment of counties as exposed or referent.

Figure 2. Daily counts of asthma related ED visits in the exposed counties. Arrows represent the 3 days of high exposure (red) and subsequent 5 lags (grey).

Figure 3. Percent change in cumulative relative risk and 95% confidence intervals by discharge diagnosis category for exposed and reference North Carolina counties during the 3 day period of high exposure compared with the entire six week study period. Dark circles denote exposed counties and open circles denote referent counties. The grey line indicates the null hypothesis of no change in the cumulative relative risk.

Figure 4. Percent change in cumulative relative risk and 95% confidence intervals by discharge diagnosis category, age, and gender for exposed and reference North Carolina counties during the 3 day period of high exposure compared with the entire six week study period. Panel (a) Dark and open squares denote ED visits by females in exposed and referent counties, respectively. Dark and open diamonds denote ED visits by males in exposed and referent counties, respectively. Panel (b) Dark and open squares denote ED visits by those under 65 in exposed and referent counties, respectively. Dark and open diamonds denote ED visits for those 65 and older in exposed and referent co unties, respectively. The grey line indicates the null

hypothesis of no change in the cumulative relative risk. Confidence interval extending out of the figure region reaches 1816% in excess risk (19.16 cumulative Relative Risk) see Supplemental Material, Table 4.

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