Science of the Total Environment 610–611 (2018) 802–809

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

The health impacts and economic value of wildland fire episodes in the U.S.: 2008–2012

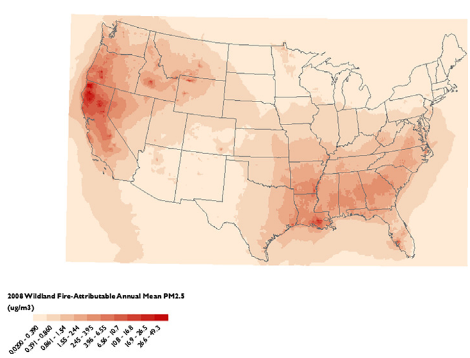
Neal Fann [a,*], Breanna Alman [a], Richard A. Broome [b], Geoffrey G. Morgan [c], Fay H. Johnston [d], George Pouliot [e], Ana G. Rappold [e]

[a] Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, 109 T.W. Alexander Drive, Research Triangle Park, NC 27711, USA
[b] Sydney South West Area Health Service, New South Wales, Australia
[c] University Center for Rural Health, University of Sydney, New South Wales, Australia
[d] Menzies Institute for Medical Research, University of Tasmania, Australia
[e] U.S. Environmental Protection Agency, Office of Research and Development, Research Triangle Park, NC, USA

HIGHLIGHTS

- Wildland fires adversely affect air quality and health in the U.S.
- Between 2008 and 2012, fires increased $PM_{2.5}$ levels in the Northwest and Southeast.
- We estimate thousands of premature deaths and illnesses from these episodes.
- The economic value of these impacts is in the tens to hundreds of billions of US$.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 24 April 2017
Received in revised form 25 July 2017
Accepted 2 August 2017
Available online xxxx

Keywords:
Health impact assessment
Source apportionment
$PM_{2.5}$
Ozone
CMAQ
Wildland fires
Wildfires

ABSTRACT

Introduction: Wildland fires degrade air quality and adversely affect human health. A growing body of epidemiology literature reports increased rates of emergency departments, hospital admissions and premature deaths from wildfire smoke exposure.
Objective: Our research aimed to characterize excess mortality and morbidity events, and the economic value of these impacts, from wildland fire smoke exposure in the U.S. over a multi-year period; to date no other burden assessment has done this.
Methods: We first completed a systematic review of the epidemiologic literature and then performed photochemical air quality modeling for the years 2008 to 2012 in the continental U.S. Finally, we estimated the morbidity, mortality, and economic burden of wildland fires.
Results: Our models suggest that areas including northern California, Oregon and Idaho in the West, and Florida, Louisiana and Georgia in the East were most affected by wildland fire events in the form of additional premature deaths and respiratory hospital admissions. We estimated the economic value of these cases due to short term exposures as being between $11 and $20B (2010$) per year, with a net present value of $63B (95% confidence intervals $6–$170); we estimate the value of long-term exposures as being between $76 and $130B (2010$) per year, with a net present value of $450B (95% confidence intervals $42–$1200).

Abbreviations: BenMAP-CE, environmental Benefits Mapping and Analysis Program—Community Edition; CMAQ, Community Multi-Scale Air Quality Model; U.S. EPA, United States Environmental Protection Agency; ICD, International Classification of Disease; NH_3, ammonia; NOx, nitrogen dioxide; O_3, ground-level ozone; $PM_{2.5}$, particulate matter, 2.5 μm or less in diameter; SO_2, sulfur dioxide; WHO, World Health Organization.

* Corresponding author.
E-mail address: Fann.Neal@epa.gov (N. Fann).

http://dx.doi.org/10.1016/j.scitotenv.2017.08.024
0048-9697/Published by Elsevier B.V.

Conclusion: The public health burden of wildland fires—in terms of the number and economic value of deaths and illnesses—is considerable.

Published by Elsevier B.V.

1. Introduction

The increasing frequency and intensity of large wildfires deteriorates air quality and adversely affects human health (Crimmins et al., 2016; Henderson et al., 2009; Liu et al., 2015, 2016; Westerling et al., 2006). These events in turn both promote, and are exacerbated by, long-term changes to the climate; current trends in these events are expected to continue (Crimmins et al., 2016; Stavros et al., 2014). While the level and type of pollutants emitted during wildfires vary according to region and fuel type, all fires release directly emitted particulate matter (PM) as well as precursors to fine particles ($PM_{2.5}$) and can contribute to downwind formation of ozone (Knorr et al., 2012).

While risks to human health from exposure to PM are especially well characterized in the epidemiological, toxicological and controlled human exposure literature (US EPA, 2009), health impacts from PM stemming from wildland fires have been less extensively studied, though epidemiological literature has consistently observed adverse human health impacts attributable to wildfire-related $PM_{2.5}$ (Liu et al., 2015). For example, Rappold et al. (2012, 2011) found that a peat fire episode in eastern North Carolina was associated with increasing numbers of Emergency Department visits for cardiopulmonary and respiratory outcomes. Similarly, Delfino et al. (2009) observed increasing rates of respiratory and cardiovascular hospital admissions resulting from a month-long wildland fire episode in southern California. Epidemiological studies conducted in other countries, including Australia, have observed similar affects (Johnston et al., 2007; Morgan et al., 2010). A systematic review of literature from the U.S., Australia and elsewhere by Liu et al. (2014) found that wildland fire-related coarse particles (PM_{10}) were most consistently associated with respiratory outcomes.

Despite the growing body of epidemiological studies, there are a relatively small number of air pollution risk assessments that attribute the number of premature deaths and illnesses and the economic value of health impacts to wildfire episodes. The risk assessments performed thus far have been limited in their temporal scope, using a single (2005) and projected (2016) year (Fann et al., 2013), or have been limited to examining one fire at a time (Jones et al., 2015; Kochi et al., 2012; Rappold et al., 2014; Rittmaster et al., 2006). This paper builds upon this literature to estimate the number and economic value of wildland fire $PM_{2.5}$-related premature deaths and illnesses in the contiguous United States using chemical transport model predictions of $PM_{2.5}$ from wildland fire episodes over a 5-year period beginning in 2008. Considering a national scope allows us to more fully capture the impact that wildland fires may have on human health.

2. Materials and methods

In this study we characterized the overall magnitude and distribution of adverse health impacts by age and race that were associated with exposure to fire-$PM_{2.5}$ during wildfire smoke episodes. We used health impact functions derived from epidemiological studies that assessed the relationship between fire-$PM_{2.5}$ and expected incidence of health outcomes. We also performed a systematic literature review and meta-analysis; however, using results from the meta-analysis in a health impact function would have introduced considerable uncertainty into the estimates, and thus were not used.

2.1. Health impact function

The risk assessment employs a health impact function to quantify the number of wildland fire-attributable premature deaths and illnesses in each of the five years we modeled. We estimated the number of $PM_{2.5}$-related deaths and hospital admissions (y_{ij}) during each year i ($i = 2008, 2009, 2010, 2011, 2012$) among individuals in each county j ($j = 1,\ldots,J$ where J is the total number of counties) as: $y_{ij} = \boldsymbol{\Sigma}_a\, y_{ija}$

$$y_{ija} = m0_{ija} \times \left(e^{\beta \cdot C}{}_{ij} - 1\right) \times P_{ija},$$

where, β is the risk coefficient, $m0_{ija}$ is the baseline death rate or hospital admission rate for the population in county j in year i among individuals for 5-year age strata a, C_{ij} is annual mean wildfire-attributable $PM_{2.5}$ concentration in county j in year i, and P_{ija} is the number of residents in county j in year i for five-year age strata a.

To perform a health impact risk assessment we used baseline incidence rates, population counts, and health impact functions included in the environmental Benefits Mapping and Analysis Program—Community Edition (BenMAP-CE, v1.1) (U.S. Environmental Protection Agency, 2014) to estimate counts of $PM_{2.5}$ attributable deaths and respiratory hospital admissions in each of five years from 2008 to 2012. These inputs have previously been used to estimate health and economic impacts in the national ambient air quality standards reviews, and the methods have been validated in previous publications (Berman et al., 2012; Fann et al., 2011; Office of Air Quality Planning and Standards, 2011). Below we describe how we specify inputs and use the BenMAP-CE tool with the appropriate input data.

2.2. Air quality modeling predictions

We simulated daily air quality from 2008 to 2012 using the Community Multiscale Air Quality version 5.1 (CMAQ v5.1) model with and without emissions from wildland fires in the contiguous United States. Wildland fires in our study included wildfires, prescribed fires, and other significant fires but it excluded agricultural fires. The difference between the two model runs represents the contribution of fire-$PM_{2.5}$ and $PM_{2.5}$ precursor emissions. Inputs to the model included gridded meteorological fields, emissions data, and boundary conditions. Gridded meteorological fields were provided by annual CONUS Weather Research and Forecasting (WRF) model simulation. Meteorological fields were defined on a 12×12 km horizontal grid with 35 vertical layers of variable thickness extending up to 50 hPa. The lowest model layer, which extended to approximately 20 m above ground was used to calculate the annual mean concentration of $PM_{2.5}$ (Δx) in the health impact function.

The CMAQ input emissions were based on a 12 km national U.S. domain with speciation for the Carbon-Bond 05 chemical mechanism (Yarwood et al., 2005). The emission inventory and ancillary files were based on the 2008 emissions modeling platform for 2008, 2009, and 2010 (EPA, 2012) and on the 2011 emission modeling platform for 2011 and 2012 (US EPA, 2016). Since the focus of this study is wildland fires, any additional information about the non-fire emission sources is noted in the references. The fire emissions were based on year specific daily fire estimates using the Hazard Mapping System fire detections and Sonoma Technology SMARTFIRE system version 2 (Sonoma Technology, 2007). Smartfire2 is a framework for producing fire activity data and allows for the merging of multiple data sources. Some of the fires included in the fire inventory come from satellite based remote sensing sources which cannot distinguish large prescribed or debris burning fires from wildfires with certainty. After multiple sources of fire information are reconciled to create fire activity estimates, the fire emissions are estimated using fuel moistures (via the USFS Wildland Fire Assessment System), consumption estimates