



## Review

# A systematic review of the physical health impacts from non-occupational exposure to wildfire smoke



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## ABSTRACT

**Background:** Climate change is likely to increase the threat of wildfires, and little is known about how wildfires affect health in exposed communities. A better understanding of the impacts of the resulting air pollution has important public health implications for the present day and the future.

**Method:** We performed a systematic search to identify peer-reviewed scientific studies published since 1986 regarding impacts of wildfire smoke on health in exposed communities. We reviewed and synthesized the state of science of this issue including methods to estimate exposure, and identified limitations in current research.

**Results:** We identified 61 epidemiological studies linking wildfire and human health in communities. The U.S. and Australia were the most frequently studied countries (18 studies on the U.S., 15 on Australia). Geographic scales ranged from a single small city (population about 55,000) to the entire globe. Most studies focused on areas close to fire events. Exposure was most commonly assessed with stationary air pollutant monitors (35 of 61 studies). Other methods included using satellite remote sensing and measurements from air samples collected during fires. Most studies compared risk of health outcomes between 1) periods with no fire events and periods during or after fire events, or 2) regions affected by wildfire smoke and unaffected regions. Daily pollution levels during or after wildfire in most studies exceeded U.S. EPA regulations. Levels of PM<sub>10</sub>, the most frequently studied pollutant, were 1.2 to 10 times higher due to wildfire smoke compared to non-fire periods and/or locations. Respiratory disease was the most frequently studied health condition, and had the most consistent results. Over 90% of these 45 studies reported that wildfire smoke was significantly associated with risk of respiratory morbidity.

**Conclusion:** Exposure measurement is a key challenge in current literature on wildfire and human health. A limitation is the difficulty of estimating pollution specific to wildfires. New methods are needed to separate air pollution levels of wildfires from those from ambient sources, such as transportation. The majority of studies found that wildfire smoke was associated with increased risk of respiratory and cardiovascular diseases. Children, the elderly and those with underlying chronic diseases appear to be susceptible. More studies on mortality and cardiovascular morbidity are needed. Further exploration with new methods could help ascertain the public health impacts of wildfires under climate change and guide mitigation policies.

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## 1. Introduction

Much remains unknown regarding the public health impacts of forest fire smoke, but interest in the topic is growing as forest fire incidence rises in many parts of the world (Dimopoulou and Giannikos, 2004). There is broad consensus that climate change is increasing the threat of forest fires (Albertson et al., 2010; Balling

et al., 1992; Flannigan and Vanwagner 1991; Keeton et al., 2007; Malevsky-Malevich et al., 2008; Spracklen et al., 2009), with fires that burn more intensely, occur more frequently, and can spread faster (Fried et al., 2004, 2008; Parry et al., 2007; Westerling and Bryant, 2008). The U.S. Forest Service noted that forest fires have already become more intense and that the forest fire season has expanded (U.S. Forest Service, 2009). While an increasing frequency of forest fires has often been attributed to many factors including changes in land use, higher spring and summer temperatures may be more relevant (Westerling et al., 2006). The Intergovernmental Panel on Climate Change (IPCC) anticipates that climate change will lengthen the window of high summertime

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forest fire risk in North America by 10–30%, and result in increased frequency of forest fires in many other parts of the world (Parry et al., 2007). As a result, exposure to air pollution from forest fires is anticipated to increase in coming decades (Interagency Working Group on Climate Change and Health, 2010).

The U.S. Forest Service recognizes forest fire smoke as a hazard to human health and identifies airborne particulate matter (PM) as the component of greatest concern for the public (U.S. Forest Service 2010). Numerous studies have demonstrated links between airborne particles and health outcomes including mortality and hospital admissions (Lepeule et al., 2012; Medina-Ramon et al., 2006; Peng et al., 2008; Pope and Dockery, 2006). However, not all particles appear to be equally toxic as research indicates that the size and chemical composition of airborne particles affect its impact on health (Ebisu and Bell, 2012; Franck et al., 2011; Zanobetti et al., 2009). In general, effects are stronger for smaller particles, which can deposit deeper in the respiratory tract (Valavanidis et al., 2008). The specific mechanistic pathways to adverse health outcomes remain unclear, but chemical composition, particle size, number, and shape have been identified as of putative importance. As the chemical composition of forest fire smoke is likely to differ from those of other sources (e.g., vehicles) (Mao et al., 2011; Pio et al., 2008; Robinson et al., 2011), the observed health associations for more commonly studied air pollutants and sources, such as particulate matter in urban settings, may not be generalizable to pollution from forest fires. Thus, scientific evidence is needed on the health burden from forest fire smoke specifically.

Understanding how forest fire smoke affects public health has the potential to inform intervention-focused policies to protect public health in the present day, climate change mitigation policies, research on health impacts from a changing climate, and economic estimates of the health costs of forest fires. We reviewed and summarized the published literature regarding the public health impacts of forest fire smoke with the goals of synthesizing existing information and identifying gaps in scientific knowledge.

## 2. Methods

### 2.1. Eligibility criteria

We reviewed peer-reviewed journal articles on the topic of forest fire/wildfire smoke and health, published between 1 January 1986 and 30 May 2014. We included studies written in English or Portuguese (with English abstract), and excluded papers written in other languages. We considered all papers relevant to non-occupational exposure to wildfire smoke and physical health impact. We excluded experimental/chamber studies because it is not clear how relevant the exposure level/composition is to those experienced by the community. We excluded conference abstracts, unpublished studies, and non-research publications, such as commentaries. Natural fires were included and controlled prescribed burns were excluded. We did not exclude studies based on type or diversity of vegetation, such as trees peat bog or savannah. All fires are referred to as 'wildfire' hereon. We excluded studies of indoor and outdoor wood burning for heating or cooking purposes. Studies that investigated occupational exposures were excluded, as the focus of this review was impacts on communities or broader populations. Therefore, we excluded studies of fire fighters. Since mental health issues are not direct physical health consequences from exposure to wildfire smoke, we excluded studies that investigated only mental health outcomes. As this review focussed on wildfire smoke we also excluded studies that investigated only non-smoke related morbidities, such as burns and accidents. Thus,

we focused on wildfire smoke and its physical health impacts on the general population.

### 2.2. Information sources

We considered papers indexed in PubMed, a database of biomedical literature and life science journals, managed by the U.S. National Library of Medicine (NIH 2011) and Scopus, a comprehensive database of research literature (Elsevier 2013). References of the resulting papers were examined to better ensure a complete assessment of the literature.

### 2.3. Search terms

Detailed information on the search terms is provided in the supplemental material. Briefly, key words included "wildfire", "forest fire", or "bushfire" with any of the following: "health", "hospital\*", "respir\*", "pulmon\*", "asthma\*", "cardiac", "cardiovascular", or "mortality", where "\*" stands for any combination of letters (e.g., hospital\* can represent hospitalizations or hospital) (Appendix A).

### 2.4. Summary measures

We summarized the papers with respect to study setting, study design, exposure and outcome assessment, participant vulnerability, key findings, and estimates of association (e.g., odds ratios) when provided.

### 2.5. Study assessment

As exposure assessment is a critical challenge in the study of health impacts from wildfire smoke, we described the approaches used by identified studies to estimate exposures. We assessed the overall state of scientific evidence on associations between wildfire smoke and health outcomes for respiratory morbidity, cardiovascular morbidity, mortality, and other outcomes. The approaches to assess health outcomes are diverse, and we summarized the sources of health data for each study. We grouped the studies by health outcomes and summarized the results on health effects. We described factors that might have influenced the summary of evidence based on the studies reviewed. Finally, we highlighted the limitations of these studies and identified needs for future research.

## 3. Results

The database searches identified 926 papers. We then excluded 277 duplicates (i.e., papers identified by more than one search). We eliminated papers that did not meet the inclusion criteria, by first screening the titles and abstracts (526 papers excluded) and then by a review of the full articles (62 papers excluded). We also excluded studies for which wildfire smoke exposure was not a dominant component relative to other ambient sources (e.g. Sarnat et al., 2008). The final review included 61 studies of human health impacts of wildfires in community populations (Table 1).

### 3.1. Study setting

More studies were identified for more recent years, with 4 studies published before 2000 and 35 studies published in the last 5 years. Most studies focused on the Brazilian Amazon, Southeast Asia and the Pacific, the North American West, and the Mediterranean, where wildfires are common. The U.S. and Australia were the most frequently studied countries (18 U.S. studies,

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