Extreme smoke events: climate change and human health in western Montana

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EXTREME SMOKE EVENTS: CLIMATE CHANGE AND HUMAN HEALTH

IN WESTERN MONTANA

By

SARAH MORGAN LUTH

Undergraduate Professional Paper
presented in partial fulfillment of the requirements
for the University Scholar distinction

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ABSTRACT

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Community Health and Prevention Sciences

Extreme Smoke Events: Climate Change and Human Health in the Western United States

Faculty Mentor: Nicky Phear

Projections of climate change show that western Montana will experience hotter and drier summers that may extend already drastic fire seasons. Extended fire seasons can lead to extreme smoke events, which are known to have harmful impacts on human health. However, there is not extensive research on these human health effects or on adaptation strategies for smoke exposure. Research in this project was conducted through literature reviews as well as personal interviews. A final report draws on available research to synthesize the relationship between climate change, wildfire smoke, and human health impacts, as well as explore possible adaptation strategies and identify areas for further research. The interviews in this study supplement the literary research with personal experience, and ensure that research is grounded with community insight. This report can act as a resource for individuals living in areas affected by fire. It is incredibly important for community and public health workers, citizens, organizations, and policymakers to understand how climate change can influence smoke emergencies, what the actual and perceived health impacts are of these events, and the options for adapting to smoke and preventing negative health outcomes.
Section I: Global Climate Change

Weather vs. Climate
Weather and climate have separate meanings. Weather is a short term, highly variable phenomena. Local weather systems form and dissipate within hours to days, while continent-wide weather patterns develop over days to at most several weeks (Mathez, 2009). In contrast, Climate refers to long-term weather patterns or averages within a specific location (e.g. earth, Northwest US, the Redwood forest). Understanding the differences in these terms is useful for communicating about global warming and climate change. Many people tend to blame specific weather incidents on global warming. However, it is nearly impossible to link a single weather event to the gradually changing climate. Long-term trends are examined as having a causal relationship with warming, while singular events are understood as potentially correlated.

Earth’s Climate
Many factors of earth’s dynamic system interact with each other and with the sun to create the climate. The atmosphere, hydrosphere, cryosphere, biosphere, and lithosphere are the variables of interaction, playing key roles in climatic changes. Small changes in any one component will affect others. Heat and chemical exchanges drive these interactions and result in measurable outcomes (Mathez, 2009).

Earth’s climate has fluctuated throughout history. Orbital patterns, often referred to as Milankovitch cycles, along with atmospheric gas levels are the biggest determinants of temperature and climate change. Ice core samples provide evidence of these chemical and temperature changes dating back millions of years. While earth’s orbital tilt, wobble, and path create predictable patterns in temperature due to the varied solar radiation over 20, 40, and 100 thousand year movements, gaseous changes in the atmosphere have been noted to cause much more rapid climate change (Mathez, 2009).

Image 1. shows atmospheric carbon dioxide levels over the last 400,000 years. Current levels of 400 ppm exceed historical levels by over 100 ppm.

Image taken from the NASA Global Climate Change website
**The Greenhouse Effect**
Certain gases in the atmosphere absorb radiation emitted by the earth’s surface and reflect it back into our lower atmosphere. This process essentially creates a blanket that traps heat coming in from the sun around the earth. The more of these greenhouse gases there are, the less heat can escape, and the warmer the earth gets (Climate Change: Evidence from the geological record, 2010; Mathez, 2009). Not all gases have this chemical capability. Water can achieve this, as well as several carbon compounds such as methane and carbon dioxide (Climate Change: How Do We Know?, 2018).

**Climate Change**
The occurrence of global warming and climate change is a scientifically accepted fact. Rising global temperatures are directly correlated with increasing CO$_2$ levels in the atmosphere, due to the burning of fossil fuels (Climate Change: How Do We Know?, 2018; Mathez, 2009).
Rising temperatures are only one of many consequences resulting from increasing atmospheric CO2 and the greenhouse effect. Sea level rise, ocean acidification, changes to ocean circulation patterns, precipitation and extreme weather events are all tied to temperature and atmospheric make up.

Temperatures influence the formation and melting of glacial ice sheets, which cause sea levels to rise and fall. Sea level rise is further influenced by the expansion of water molecules in warmer conditions. Carbon dioxide from the atmosphere is absorbed into the ocean as a part of the carbon cycle, where it chemically reacts and causes changes in the pH of the water, causing acidification and damage to marine ecosystems. Precipitation patterns shift in response to changes in ocean current and wind circulation patterns, which are influenced by temperature (Mathez, 2009). With all of these factors in play, local climates may rapidly shift to be more suitable for different flora, fauna, and marine life, forcing movement or extinction.

**Positive feedback loops**

Positive feedback loops within the environment are a major concern of global climate change. Certain systems, when altered, can set off a series of reactions that further the degree of change. The relationships between melting glaciers and global temperatures, permafrost melt and atmospheric carbon, and between forest fires and global temperatures are all examples of positive feedback loops. Ice and snow reflect the sun's radiation back out into the atmosphere. When glaciers melt, this reflective property is lost,
allowing the earth to absorb more radiation and increase temperatures. The result is a nearly unstoppable circular process where warming contributes to melting and melting contributes to further warming. Forest fires are another positive feedback loop. As temperatures rise and precipitation is decreased in certain areas, wildfire becomes more likely. When forests burn, carbon is released into the atmosphere, contributing to the greenhouse effect and hence more warming (Mathez, 2009).

Temperature, precipitation, sea levels, acidification, and positive feedback loops are just several of the major climate change concerns. There are countless impacts that vary for different communities and locations around the globe—it is essential to understand these different factors and consequences in order to adapt and ensure a livable future.

**Responses**
Climate change affects all life on earth, which is why concerned citizens, scientists, activists, and leaders around the world are addressing the issue in a multitude of ways. These avenues for pursuing action include local community and individual efforts, student advocacy and education, scientific research, private sector innovation, large-scale government efforts, and international law.

**Section II: Climate Change and Forest Fires**
Climate research shows that the western United States is one of many global regions that will experience hotter, dryer summers as the earth warms. These changes, paired with the dense forests of western North America, fires are expected to increase in frequency, intensity, and duration.

**Forest Fires:**
There are many factors that influence the advent of forest fire, as well as their length and intensity. Some of these factors include the amount and type of fuel load, fuel aridity, temperatures, and tree health. Hot temperatures, paired with dry fuel are the perfect conditions for large, intense fires. Weather patterns can create these conditions in several ways. When spring temperatures are warm, mountain snowpack melts early, which is correlated with the drying of soils (Abatzoglou, 2016). Hot, dry summers further contribute to the drying of forest soils and trees. Warmer spring and summer temperatures are also linked to increased spread of insects and disease such as the bark beetle, which has been killing forests throughout the western United States and Canada (Mathez, 2009; Whitlock et al., 2017).
Climate Trends in the Western United States:
In the western U.S, global warming is expected to cause increased temperatures and changes in precipitation (Running, 2006). Models predict that precipitation will continue to increase in winter months, but will drastically decrease in summer months (Whitlock et al., 2017). This means that wetter, warmer winters will promote forest growth, while early snowmelt, decreased precipitation, and hot weather will create especially dry summer conditions. It is important to note that plant and forest growth is tied to atmospheric CO2 levels. To an extent, increased CO2 levels promote higher rates of growth through photosynthesis (Mathez, 2009). This increased growth is great for sucking CO2 out of the atmosphere, but also carries implications for forest fire. With higher rates of growth, more fuel is created for fire to burn. This combination of increasing temperatures, decreased summer precipitation, and more fuel creates an ideal environment for wildfire.

Montana Climate Trends:
The 2017 Montana Climate Assessment analyzed statewide historical data and future climate models for a number of factors including temperature and precipitation. Data showed that average temperatures across the state have increased by 0.5 degrees Fahrenheit per decade since 1950, with the greatest warming during spring (Whitlock et al., 2017). The image below shows future mid-century and end-of-century predictions of temperature increases, with expected increases of 4.5° - 6° F, and 5.6° – 9.8° F respectively.

![Temperature Increase Maps]

Whitlock et al, 2017

Minimum and maximum temperatures are projected to increase by 3° – 8° Fahrenheit, while the number days over 90° F are expected to increase by 5 – 35 additional days by mid-century. Frost-free days are projected to increase by 24-44 days in western Montana. Precipitation is more variable, but is predicted to increase in winter and spring, while
decreasing in summer. Each of these variables contributes to the occurrence, severity, and size of wildfire (Whitlock et al., 2017). With earlier snowmelt, precipitation changes, and warmer temperatures, moisture deficits are created that visibly impact risk of fire. The graph below shows areas of moisture deficit in the western United States compared with location and acres burned during wildfires.

Between 1970 and 2003, most fires exceeding 10,000 ha of burned area occurred during years with greater moisture deficits (Running, 2006; Westerling et al., 2006).

**Wildfire Trends:**
In a study that analyzed 34 years of wildfire data in the western United States, researchers found that the frequency of large fires was nearly four times greater in the 14-year period from 1987 to 2003 than in the preceding 14 years. Total area burned was six times greater, and the length of fire seasons was longer by 78 days. In this study, fires were strongly correlated with spring and summer temperatures (Westerling et al., 2006).

Knowing that forest fires are impacted by land use management, natural climate variability, and human caused climate change, another study set out to calculate the approximate contribution to fire in the Western United States caused by anthropogenic climate change alone. Researchers found that anthropogenic climate change accounted for 55% of increases in fuel aridity in US forests from 1979-2015, and an additional 4.2 million hectares of forest fire burn area during that time. These numbers doubled what was expected in the absence of climate change factors. From 2000-2015, climate change contributed to 75% more fuel aridity (Abotzoglou, 2016).
Smoke
As forest fires in western Montana increase in size, frequency, and severity, wildfire smoke increases as well. Smoke in Western Montana can blow in from forest fires in Idaho, Canada, Washington, Oregon, and even California to affect air quality in populated mountain valleys such as Missoula and Seeley Lake. The topography of these areas allows for inversions, which trap cold air and smoke close to the ground. As wildfire seasons continue late into the summer, nights become longer and colder, strengthening these inversions that trap smoke in mountain valleys. Thick smoke prevents sunlight from reaching the ground level and breaking the inversion through warming (Coefield, 2017). The 2017 fire season is an example of severe smoke in western Montana from wildfires within and outside of the state.

![Seeley Lake, MT August 7th 2017](image1)
![Rice Ridge Fire near Seeley Lake, August 30th, 2017](image2)

Thick smoke covered the Seeley Lake valley for 50 consecutive days, from July 31st to September 18th, 2017. For 44 of these days, air quality was designated harmful to human health, and for 35 labeled hazardous (Coefield, 2017). The Environmental Protection Agency defines healthy air standards under 35 μg/m³ of particulate matter, and over 250 μg/m³ as hazardous. Monitors used in Montana to check particulate levels during smoke events register up to 1000 μg/m³, yet Seeley Lake smoke surpassed this maximum on 20 separate occasions (Coefield, 2018).

With the climate warming, and the likelihood of intense fire increasing, summers like 2017 will become more regular in Western Montana.

Section III: Health Impacts of Extreme Smoke Events

In order to prepare for increasing fire and smoke, and reduce impacts to population health and economy, communities first must understand the health effects of wildfire smoke.
Composition of Smoke
Wildfire smoke varies in its composition, depending on factors such as fuel type, moisture levels, fire temperature, and weather conditions. The compounds that typically make up smoke consist of a mixture of water vapor, particulate matter, carbon monoxide, hydrocarbons, nitrogen oxides, and other organic chemicals (Cascio, 2017; U.S EPA, 2016; Barn et al., 2016). Of these, the major pollutants of concern include fine particulate matter (PM2.5), carbon monoxide (CO), nitrous oxides (NOx), and volatile organic carbon (VOCs). Each of these microscopic chemicals negatively affects air quality and human health.

Particulate Matter
Particulate matter is a general term that describes particles suspended in air. Typically, particulate matter is made up of both solid particles and liquid droplets. Like smoke, the characteristics or particulate matter depend on variables such as its source and atmospheric conditions (Kampa, 2007). Because of it’s various forms, different types of particulate matter can cause varying health impacts. Particulate matter greater than 10 micrometers in diameter can irritate the eyes, nose, and throat, while particles smaller than 10 micrometers wide can reach deep into the lungs, causing more adverse affects (US EPA, 2016). Fine particulate matter is less than 2.5 µm (micrometers) in diameter and is more dangerous to health. For some perspective, a single strand of human hair has a width of about 60 µm. Most particulate matter found in smoke is within the PM2.5 category, with diameters of 0.4-0.7 micrometers (U.S. EPA, 2016). This means that most particulate matter from wildfire smoke can travel deep into the lungs and the cardiovascular system.

Physiological Effects of PM2.5:
While course particulate matter settles into the upper respiratory tract, fine PM2.5 deposits into the alveoli of the lungs (U.S EPA, 2016). The alveoli are sites where gas exchange takes place, transferring oxygen into the blood. Fine particulate matter triggers an inflammatory response within the lungs, physically impairing this gas exchange function while immune cells attempt to destroy the pollutants. Inhaled particulates also interact with neuron receptors that communicate with the autonomic nervous system. The resulting signals and chemical interactions can cause increases in blood pressure and changes to heart rhythm (Cascio, 2017).

In the case of wildfire smoke, individuals who are constantly breathing in particulate matter for multiple days or weeks can experience prolonged alveolar inflammation, as well as heart rhythm and blood pressure changes. Immune cells are overwhelmed by the constant influx of these pollutants. In people with lung lesions, lung diseases, or asthma, inflammation can worsen their condition or trigger an attack (Kampa, 2007). The chemical interactions that cause changes in blood pressure and heart rhythm also affect blood coagulation, potentially obstructing blood vessels, and leading to cardiovascular problems.
such as angina, chronic obstructive pulmonary disease (COPD), or myocardial infarction (Alman et al; Cascio 2017; Reid et al).

Ultrafine particulate matter (PM<0.1) can move across the alveolar membrane and cause endothelial damage that impacts the lungs ability to fight infection. This mechanism is one explanation for the observed increases in susceptibility to bronchitis, pneumonia, and other respiratory infections after severe smoke exposure (Cascio, 2017; Newby et al., 2015).

**Other pollutants** found in smoke, such as carbon monoxide and nitrous oxides also have damaging impacts to the respiratory and cardiovascular systems. Nitrous oxides have found to increase susceptibility to respiratory infection and virus-induced asthma in children (Chauhan, 2003). Carbon monoxide binds to hemoglobin in the blood and reduces the molecule's ability to carry oxygen to organs and tissues (Kampa, 2007). Typically, wildfires to do not pose significant carbon monoxide pollution threats, except for firefighters right on the front lines, or individuals particularly at risk, but more research on this topic is necessary as wildfire smoke events become more severe. Carcinogens are known to be found in wildfire smoke, but are found to have relatively small impacts on risk of cancer in comparison to most other carcinogens found in the average American's life (US EPA, 2016).

**Current Evidence**

Of the available studies completed on the health impacts of smoke from wildfire, most indicate a significant correlation with respiratory morbidity, cardiopulmonary illness such as COPD, and increased hospital visits in general, particularly for sensitive populations (Haikerwal et al., 2015; Cascio, 2017; Liu, 2014; Kampa, 2007). In 2008, during a large wildfire in North Carolina epidemiologists were able to calculate the adverse health impacts and costs attributable to smoke exposure. The fire lasted 202 days and burned over 40,000 acres (Rappold et al., 2011). Below is a table showing the reported health impacts attributable to smoke.

<table>
<thead>
<tr>
<th>Lower Respiratory Symptoms</th>
<th>Upper Respiratory Symptoms</th>
<th>Episodes of bronchitis</th>
<th>Non-fatal heart attacks</th>
<th>Asthma attacks</th>
<th>Premature deaths</th>
<th>Work days lost</th>
<th>Estimated health cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>530</td>
<td>769</td>
<td>41</td>
<td>31</td>
<td>810</td>
<td>4-5</td>
<td>3,700</td>
<td>$48.4 million</td>
</tr>
</tbody>
</table>

(Rappold et al., 2014)
Several systemic reviews of the health impacts of wildfire smoke have been conducted, showing similar results. Liu et al. identified 61 different peer reviewed studies around the globe that focused on smoke exposure and health outcomes. Of these, 45 focused specifically on respiratory disease, with 90% finding that wildfire smoke was significantly associated with respiratory morbidity (Liu et al., 2014). Another critical review of health outcomes associated with wildfire smoke examined 43 epidemiological studies determined to have low bias, and high standards of research. The reviewed studies analyzed mortality, respiratory morbidity, cardiovascular morbidity, birth outcomes, and mental health (Reid et al., 2016). The table below displays the common findings among the 43 studies:

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Direction of Association</th>
<th>Strength of Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mortality - All</td>
<td>Increased</td>
<td>Strong</td>
</tr>
<tr>
<td>Asthma</td>
<td>Increased</td>
<td>Very Strong</td>
</tr>
<tr>
<td>Respiratory Morbidity</td>
<td>Increase</td>
<td>Very Strong</td>
</tr>
<tr>
<td>Respiratory infection</td>
<td>Increase</td>
<td>Strong</td>
</tr>
<tr>
<td>COPD</td>
<td>Increase</td>
<td>Very Strong</td>
</tr>
<tr>
<td>Cardiovascular morbidity</td>
<td>Increase</td>
<td>Inconclusive</td>
</tr>
</tbody>
</table>

(Reid et al., 2016; Cascio, 2017)

In Montana, data is currently being collected on wildfire smoke health outcomes in light of the 2017 fire season. Rachel Hinnenkamp is an epidemiologist with the state health department, and has been tracking the number of emergency room visits associated with respiratory related symptoms. For Missoula and Powell counties, the number of respiratory related visits to the ER more than doubled in 2017 compared to 2016, jumping from 163 to 378 (Saks, 2018). Hinnenkamp stated that most of these visits occurred about a month after heavy smoke first settled in the area. Kevin Eichhorn, an ER doctor at Saint Pats Hospital in Missoula observed this change. Eichhorn expressed concern about the increased number of people coming in with respiratory complaints, COPD, and general malaise. He explained that particularly with COPD, the ER was not only seeing more patients, but also having to readmit them within days. Typically, Eichhorn says, COPD patients are discharged with medication prescriptions and rarely readmitted (Eichhorn, 2018).

Despite the growing body of evidence that exposure to wildfire smoke results in adverse health outcomes, more research is necessary to understand these impacts completely. Larger populations should be studied, as well as specific demographics. More long-term studies are necessary as well, as the long-term health impacts of wildfire smoke exposure are not well understood. In research and policy creation, it is also critical to have a climate
change informed perspective, as wildfire smoke will not be a stagnant issue, but a growing one.

**Psychological Impacts**

Minimal peer-reviewed research has been published on the psychological impacts of wildfire smoke, but qualitative studies and interviews suggest that health effects may be significant. In Canada’s Northwest Territories during a bad 2014 fire season, one study conducted 30 qualitative interviews of individuals from four different smoke impacted communities. Interviewees reported feelings of fear, stress, and uncertainty as a result of isolation and evacuation experiences. Interviewees expressed that the prolonged smoke events negatively impacted their mental, emotional, and physical well-being (Dodd et al., 2018).

Interviews conducted with local Missoulians and residents of Seeley Lake show similar results. Suffocating smoke, coinciding with the experiences of fear and sorrow surrounding fire, land loss, and evacuation are undoubtedly associated with emotional stress. Outdoor exercise enthusiasts, who often use outdoor activity as a form of meditation or personal therapy, are pressured to stay indoors. Physical health impacts may cause emotional distress. Parents worrying about the health of their children during thick, long-lasting smoke may experience mental and emotional distress as well (Cilimburg, 2018; Coefield, 2018). A loss of direct sunlight and vitamin D due to a physical smoke screen may impact certain individuals, particularly those with seasonal depression and in areas of low winter sunlight. More research needs to be done in this area for any significant conclusions to be drawn, but so far qualitative studies depict psychological impacts of wildfire smoke as an issue of concern (Reid et al., 2016; Dodd et al., Eichhorn, 2018).

**Vulnerable populations**

Most healthy individuals will experience few health impacts and will recover quickly from smoke exposure due to a typical wildfire (US EPA, 2016). However, certain populations have heightened sensitivity to smoke, experiencing acute or chronic symptoms or disease. Several of the risk factors determining a person’s sensitivity include age, socioeconomic status, occupation, and health status as well as pre-existing conditions (Cascio, 2017; US EPA, 2016). Children are considered a sensitive group because their lungs are still developing. In development stages, pollutants are not as effectively removed from the lungs, and may cause loss of lung function. Children often spend more time outdoors, and participate in more vigorous activity than adults, which means their intake of pollution is higher. They inhale more air per pound of body weight than adults do and are therefore at greater risk.
Pregnant women are another population at greater risk of adverse health impacts from wildfire smoke. Increases in blood volume and respiratory rates during pregnancy also increase the amount of air pollution that enters the lungs and blood. There is little research on these effects of wildfire smoke on pregnant women and fetuses, however many studies have found that ambient air pollution, cigarette smoke, and other biomass burning are linked to negative prenatal health outcomes such as low birth weight or preterm birth (Holstius, 2012; US EPA, 2016).

Older adults are a group at higher risk of health impacts during short-term exposure to wildfire smoke, mainly due to increased prevalence in pre-existing lung and heart diseases. Further, immune responses decline with age, decreasing the body’s ability to remove toxic pollution (US EPA, 2016).

Many individuals, not just the elderly have pre-existing conditions that can worsen the impacts of wildfire smoke. More than 36 million people in the United States suffer from a chronic lung disease such as asthma or chronic obstructive pulmonary disease, including 6 million children (American Lung Association, 2008). These individuals experience frequent constriction of their airways and may suffer more severe responses to lung inflammation caused by smoke. A good portion of the population may also have airway hyper-responsiveness, a greater tendency of airways to constrict in response to respiratory irritants (US EPA, 2016). These individuals may experience asthma-like symptoms without actually having asthma.

Socio-economic status plays a role in the health effects of wildfire smoke as well. Epidemiological studies of short-term exposure to particulate matter that account for SES have shown that the lowest SES groups are at greater risk of health impacts and mortality (US EPA, 2016). There are several explanations for this, one being that lower socioeconomic status may contribute to the presence of fewer air conditioners, filters, or opportunities to avoid smoke through staying indoors or moving locations.

Another population at increased risk of negative health impacts are outdoor exercise enthusiasts. Particularly in Montana, many outdoor enthusiasts live and vacation near areas frequented by wildfire. Summers in western Montana are inhabited by avid trail runners, mountain bikers, hikers, ultimate frisbee players, and high school athletes. Exercise to these folks is not simply a fun activity, but a way of life, ingrained in a sense of self, and oftentimes a personal therapy or food for their competitive drive. Recommendations to stay indoors and reduce vigorous exercise are often ignored by these individuals. This may be due to a belief that they aren’t as susceptible, being young and fit, or that health impacts won’t be severe; it may be due to pressure from coaches, peers, competitors, or simply unwillingness to temporarily change lifestyle. Although young,
healthy adults are generally less likely to experience severe health impacts resulting from smoke, particles can more easily deposit deep into the lungs while respiratory rates are high. So, vigorous exercise places an individual at greater risk of adverse health impacts from wildfire smoke due to increased inhalation of pollutants (Coefield, 2018; U.S EPA, 2016).

Section IV: Adaptation Strategies

Forest Management
Forest management is commonly thought of as one of the ways to prepare for and prevent large wildfires. There is substantial research showing that prescribed spring burning and other fuel treatment strategies help reduce fires in those locations. However, there are many factors that play into the current state of forests, the practicality, and the effectiveness of modern forest management in terms of preventing wildfire.

A. History
For the last 100 years, fire suppression has been the common practice of forest management. Prescribed burns were uncommon, and outlawed in the National Parks Systems until 1967 (Johnson and Hale, 2002). Due to successful fire suppression, many ecosystems, particularly southern dry forests have experienced a gradual build up of fuels. The build up of these forests, mostly with non-native, fire intolerant species is correlated with the increase in severity of wildfires (Schoenagel, 2017). Generally, severity of fires and length of season have increased, but this is mostly contributed to climate warming. In recent years, fuel treatment strategies utilizing prescribed burning and mechanical removal have become more widespread with the hopes of preventing large, severe wildfire. However, controversy exists regarding the effectiveness of these fuel treatment plans, particularly in vast Western coniferous and sub alpine forests.

B. Benefits
Many northwest forests are historically fire dependent, relying on intermittent burns to clear invasive species, germinate seeds, increase sunlight to seedlings, prevent crowding, and return nutrients to the soil (Johnson and Hale, 2002). There is evidence to suggest that prescribed burning in combination with mechanical fuel treatments contribute to forest and wildlife health as well as temporarily reducing the severity of wildfire in those areas (Stein et al., 2013).
C. Costs
Although fuel treatment plans can be beneficial for forest health and can temporarily reduce fire severity, effectiveness is limited on a broad scale. Between 2001 and 2015, almost 7 million hectares of federal land were given fuel treatments (Schoenaggle, 2017). In comparison, total U.S. forests make up approximately 300 million hectares, 96,505,000 of which are federally owned (Forest Ownership, 2018). This means that forested area significantly exceeds areas treated for wildfire prevention. Regionally, treatments have had little relation to fire trends, with the main driver being patterns of drought and warming. These treatments last between 10-20 years, implying that treatments have little influence on fire regimes over time. Fuels management is also both challenging and costly. Between 2006 and 2015, US Forest service fuel treatments totaled 3.2 billion dollars (Schoenaggle, 2017).

For Montana, fuel treatments for the purpose of preventing large wildfires and smoke could be futile. Large forests both within the state and in neighboring Idaho, Washington, Oregon, and Canada surround western valleys such as Missoula. These forests together contain millions of hectares of fairly inaccessible land, making fuel treatments challenging, if not impossibly time consuming and expensive. When wildfires do occur in these areas, smoke can travel for miles, settling in valleys like Missoula. This means that despite local fuel treatments, smoke will still be a seasonal issue.

Another significant cost of prescribed burning is the impact to air quality. As the purpose of this paper is to explore the health impacts of smoke due to wildfire, it is important to consider that any prescribed burning, despite potential wildfire reduction, could also contribute to harmful smoke-related impacts.

D. Future Research
The controversy over forest management strategies remains, making clear the need for more research on the effectiveness and practicality of treatments.

Clean Air
With the climate warming, and the impossibility of total wildfire prevention via management, smoky summers in western Montana are inevitable. So, from a public health standpoint, how can the negative health outcomes caused by summer smoke be reduced?

In the past, when air quality has deteriorated due to wildfire smoke, the Montana health department has recommended staying indoors or leaving the area until the smoke has cleared. However, these recommendations are less helpful, even useless when smoke sticks around for weeks on end. While taking several days off work to avoid smoke is feasible, most people cannot afford multiple weeks away. Further, few western Montana homes
have air conditioning, meaning the recommendation to stay indoors is helpful for only some, as most will not sacrifice open windows during hot weather in order to keep the smoke out. Additionally, without a filtration system smoke particles can seep into most homes even while all doors and windows are shut (Coefield, 2018).

A. Portable HEPA filters
Air filtration is one method of addressing health concerns, particularly for populations most at risk. Certain High Efficiency Particulate Air (HEPA) filters can catch particles as small as 0.3 micrometers. Most harmful particulates in smoke are between 0.1 and 2.5 micrometers, so these HEPA filters are effective in cleaning a majority of the particulate matter found in smoke out of indoor air (Prabjit, 2014). An analysis of air filtration interventions during the extreme wildfire season in 2003 in Southern California found that household portable HEPA filters by themselves reduced PM$_{2.5}$ by an average of 45% (Fisk and Chan, 2017). In combination with running HVAC systems, the study found an even higher 62% reduction in harmful particulates. The same California air filtration study also analyzed the correlation between air filtration, hospital admissions, and death rates, finding that within an all ages population air filtration reduced hospital admissions between 11% and 63% during periods of severe wildfire smoke. For the elderly population, this reduction was between 20% and 105% (Fisk and Chan, 2017). The large range of reductions in hospital admissions is contributed to varying usage. Within the populations studied, different filters were used. Some homes had lower grade HEPA filters, some had HEPA 0.3um filters, and others had high or low efficiency central heating and cooling systems that further filtered their air. Varying outdoor exposure and filter maintenance also contributes to the wide range of hospital reduction percentages. Another review of multiple studies on the benefits of portable air filters concluded that their effectiveness is significant and should become a fundamental piece of public health responses to wildfire smoke (Barn et al, 2016).

B. HVAC Systems
Heating, Ventilating, Air Conditioning systems all have an air filtration component. Systems have varying filtration capabilities, depending on the type of filter. HVAC systems with MERV ratings of 9-16 can filter out most to nearly all harmful smoke particles (US EPA, 2016). However, installing new HVAC systems can be both challenging and expensive, meaning owners of commercial and public buildings may choose to wait years until they are scheduled for an upgrade (Cilimburg, 2018; Coefield, 2018). Further, more research is needed to determine how effective each MERV rated system is in removing particles.

Several possibilities for HVAC systems as a key aspect of smoke adaptation are establishing clean air shelters, upgrading systems in schools and other public buildings, and even changing building codes to require high efficiency systems. Clean air shelters can be new or
existing public indoor spaces that have high efficiency HVAC systems, and are advertised to communities as safe places to go during extreme smoke events.

C. N95 Respirators
N95 respirators are a specific type of face mask capable of filtering PM2.5. Surgical masks, bandanas, and other one-strap paper or cloth masks do not prevent smoke particles from passing through into the airways (Coefield, 2018; U.S. E.P.A., 2016). N95 and N100 respirators, named for the amount of particulate matter they effectively filter (95% and 99.7% respectively) are worth considering as an adaptation strategy not only for their effectiveness but also their growing availability. Many can be found in hardware stores at low cost. However, N95 masks must be fitted to create a tight seal around the nose and mouth in order to provide protection. Without a proper training and a “fit test” while wearing the respirator, users might continue to breathe in particulates without knowing it. Further, the masks are not recommended for children or men with facial hair due to the inability to create a proper seal. In the E.P.A.’s 2016 Wildfire Smoke Guide for Public Health Officials, N95 respirators are recommended for use only after implementing other, more effective methods of protection such as HEPA filters, reducing activity, staying indoors, or relocating if possible.

Moving forward: Recommendations, Strategies & Questions
Last summer, the Missoula county health department along with Climate Smart Missoula were forced to scramble together funding for additional HEPA air filters in light of extreme, long lasting wildfire smoke in the Seeley Lake Valley and Lolo areas. Funding for the desperately needed filters was hard to find, and the process of acquiring and delivering the filters was slow. In September, children sat in visibly hazy classrooms. In interviews with both Sarah Coefield, Air Quality Specialist at the health department and Amy Cilimburg, director of Climate Smart Missoula, each stressed the importance of building a cache of HEPA air filters for future summers. With a sizeable cache of filters, clean air can be provided to those most in need for the duration of a severe smoke event.

Other communities have utilized this strategy. Both the Hoopa Valley Tribe in California and the Confederated Tribes of the Colville Reservation in Washington created air filter distribution plans (Kim, 2017). In 1999, the Hoopa Valley experienced extended hazardous smoke levels from what was then the fifth largest wildfire in U.S history. During the following year, medical visits for respiratory illness increased by 52% (Mott et al., 2002). During the smoke event, the tribal government purchased 200 portable air filters that were then distributed to elders, children, and people with respiratory or cardiopulmonary illness. In later years, an additional 800 filters were purchased, two clean air shelters were opened, public buildings were updated with new HVAC systems, and 4,000 N95 respirators
were given to community members (Kim, 2017). The tribal government and health clinic set up a process for distribution, tracking, and filter maintenance (Mott et al., 2002).

During hazardous smoke levels on the Confederated Tribes of the Colville Reservation in 2015, forty portable HEPA air cleaners were purchased for distribution among tribal members. Unable to access more air filters due to their high demand that season and lack of funding, education and outreach efforts were implemented (Kim, 2017).

Several years before the horrific 2017 fire season in western Montana, the Missoula county health department and Climate Smart Missoula piloted an air filter program that included a 25 filter cache, and a plan to distribute to a select list of low income seniors with respiratory conditions. When air quality reached hazardous for weeks and months on end, the partners were forced to squeeze together funding for more filters, as 25 was not nearly enough, and the populations in need extended beyond homebound, low income seniors. By the time the smoke cleared, approximately 200 HEPA air filters had been distributed to individuals and schools (Cilimburg; Coefield, 2018). However, 200 clean air rooms were not enough as many low income, vulnerable individuals across the county still endured thick, month-long smoke.

These case studies that focus on the smoke responses of various communities help guide future preparation for extreme smoke in western Montana. For example, the Missoula County Health Department, partnered with Climate Smart Missoula, is now working to further build their cache of filters and prepare for future smoke. In order to prepare, there are many questions and needs regarding adaptation strategies that still need to be addressed:

- How many filters should be kept as a cache?
- Where will these filters be stored?
- Will they be returned, or kept by individuals?
- How will filters be distributed during emergencies?
- How will the distributing agency determine who is most in need – what is the hierarchy of populations at risk?
- How will at risk individuals access these services – is a medical referral system necessary or feasible?
- How will filters be properly maintained?
- What type of filters will be distributed and recommended?
- What information will outreach materials include, and how will this information reach critical populations?
• Assessments of HVAC systems in schools and public buildings are necessary in order to determine current filtration efficiency and upgrade needs.
• Is there a possibility for future city, county, or statewide infrastructure laws or building codes in order to ensure smoke-safe work places, homes, and public buildings?

Addressing these questions will guide a more thorough preparation for severe wildfire smoke in Montana and other communities. In interviews with Sarah Coefield and Amy Cilimburg, each expressed the importance of planning ahead, and working to answer these so far unanswered questions about emerging wildfire smoke practices.

**Conclusion**

Anthropogenic climate change is the cause of increasing temperatures and decreasing summer precipitation in the western United States. These climatic changes are significantly contributing to altered forest fire patterns by increasing incidence, length of season, and severity of fires. Wildfire smoke exposure is a growing issue for western communities as fire seasons worsen. More research is necessary to better understand the short and long term health effects of smoke, as well as to validate emerging practices. However, current research suggests that wildfire smoke is harmful for human health across many populations, and that utilizing clean air filters is an effective strategy for reducing community health impacts. Montana communities should begin developing specific action plans for the acquisition and distribution of air filters, for further research, and for community education.
Sources


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