# Idaho Climate-Economy Impacts Assessment

# Smoke Report: Air Quality and Wildfire Smoke in Idaho

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## 1. Introduction

There are two main mechanisms that govern poor air quality in Idaho: (1) in cold months, air stagnation and inversions concentrate local air pollutants within valleys and close to the ground and pose significant health challenges to Idahoans and (2) in warm months, wildfires in Idaho and across the western U.S. emit huge quantities of pollutants that dwarf all other sources of pollutants (Idaho Department of Environmental Quality (IDEQ), 2020). Air quality has generally improved across Idaho over the past several decades, except for episodes of wildfire smoke that blanket large portions of the Gem State during warm temperature seasons. Wildfire smoke is a growing hazard for wildfire-prone regions like Idaho.

Studies estimate that across the U.S., the economic value of cases involving additional premature deaths and respiratory hospital admissions due to short-term exposure to smoke range between \$11 and \$20 billion (2010 USD) per year (Fann et al., 2018). Idaho is specifically vulnerable to adverse economic and health impacts of wildfire smoke. Wildfire activity has increased significantly across Idaho and the western U.S. in the past four decades, emitting smoke that covers large swaths of the region for days to weeks. Research projects that forests of the Northwest and Rocky Mountains will likely experience more than a 75% and 175% increase, respectively, in burned area by mid-century under a moderate greenhouse gas emissions increase scenario, doubling the carbonaceous aerosol emissions in the region by 2050 (Spracklen et al., 2009). Many regions in Idaho are projected to be among the highest risk areas of wildfire smoke in the U.S. by 2050, experiencing very poor air quality for several days during multiple events each year (Liu et al., 2016). While significant strides have been made to increase awareness and relay timely forecasts for Idahoans to mitigate the negative impacts of wildfire smoke, there currently are no comprehensive policies in place that address smoke impacts on the health and wellbeing of Gem State residents, specifically the most vulnerable populations (e.g., farm workers, elderly, children, people with preexisting conditions).

## 2. Background – Air Quality in Idaho

Air quality has consistently improved throughout the state since passage of the federal Clean Air Act and subsequent adoption of the National Ambient Air Quality Standards (NAAQS) (IDEQ, 2020). These measures limit man-made pollutants that are byproducts of anthropogenic activities. However, episodes of high-density wildfire smoke worsen air quality for days to weeks, often violating the NAAQS standards. The "Exceptional Event Rule" (Register, 2007; Engel, 2013) allows states to exclude air quality data impacted by exceptional events – such as wildfires – from NAAQS attainment reports (Hyde et al., 2017). Nevertheless, wildfire smoke poses significant health challenges to Idaho and the western U.S.

### a. Sources and seasonal/geographic distribution of pollutants in Idaho

Criteria pollutants that are commonly tracked by the IDEQ include carbon monoxide (CO); nitrogen dioxide ($NO_2$, and nitrogen oxides, NOx), ozone ($O_3$); coarse particulate matter with particle diameter less than 10 microns ($PM_{10}$); fine particulate matter with particle diameter less than 2.5 microns ($PM_{2.5}$); and sulfur dioxide ($SO_2$). Current NAAQS limits for these pollutants are listed here. Pollutant levels are also translated to an air quality index (AQI) that ranges from 0 to 500 over six categories:

(1) green: 0-50 – air pollution poses little or no risk
(2) yellow: 51-100 – air quality acceptable, but can pose risk to those unusually sensitive to air pollution
(3) orange: 101-150 – poses health risks for sensitive groups
(4) red: 151-200 – even some members of the general public may be at risk
(5) purple: 201-300 – risk is increased for everyone
(6) maroon: 301 and higher – emergency conditions

For each pollutant, an AQI value greater than or equal to 100 is considered unhealthy. See more here.

Periodic emissions inventories for these pollutants, volatile organic compounds (VOCs), and ammonia ($NH_3$) are developed by IDEQ and the U.S. Environmental Protection Agency (EPA) to document known significant sources (IDEQ, 2020). Four major sources are considered: (1) point, (2) non-point, (3) on-road, and (4) non-road sources. Table 1 summarizes pollutants that are emitted by each source and their impact on Idaho's air quality.

| Source | | Pollutant | | Additional Information |
|---|---|---|---|---|
| Category | Example | Major quantity | Minor quantity | |
| Point sources | Industrial facilities | CO, NO, $NO_2$, $SO_2$ | $PM_{10}$, $PM_{2.5}$, VOC, $NH_3$ | -Pollutants pass through stack or vent<br>-Except for $SO_2$, point sources are a minor contributor to air pollution in Idaho |
| Non-point sources | Area sources (e.g., residential wood combustion) | $PM_{2.5}$ | VOCs, $O_3$ (forming) | |
| | **Wildfires and prescribed burns** | **$CO_2$, CO, $PM_{10}$, $PM_{2.5}$, VOCs, NOx** | | **-Wildfire-induced $PM_{2.5}$, $PM_{10}$, $CO_2$, and CO can be transported long ranges downwind**<br>**-NOx compounds are usually short-lived and remain close to source**<br>**-VOCs and NOx are precursors of $O_3$** |
| | Agricultural residue burning | | | |
| | Biogenic sources (trees, plants, and soil) | VOCs, NO | $O_3$ (forming) | |
| On-road sources | Light- and heavy-duty vehicles | VOCs, $PM_{10}$, $PM_{2.5}$, CO, NOx, | $SO_2$, $NH_3$ | -Exhaust systems produce CO, NOx, VOCs, and $PM_{2.5}$<br>-Fugitive dust from road, tires, and brakes generates $PM_{10}$<br>-Typically influence air quality at the neighborhood to urban scale |
| Non-road sources | Vehicles and equipment that do not operate on the road (e.g., agricultural equipment, train, aircraft, etc.) | CO, NO, $NO_2$, $SO_2$, $PM_{2.5}$, and VOCs | | |

*Table 1. Sources of criteria pollutants in Idaho (IDEQ, 2020).*

As previously noted, there are two main mechanisms that govern poor air quality in Idaho: (1) in cold months, air stagnation and inversions concentrate local air pollutants within valleys and close to the ground and pose significant health challenges to Idahoans and (2) in warm months, wildfires in Idaho and across the western U.S. emit huge quantities of pollutants that dwarf all other sources (IDEQ, 2020). Among wildfire-induced air pollutants, $PM_{2.5}$ is long-lived, can be transported thousands of miles, and is a major health threat. Hence, $PM_{2.5}$ is focused on in this report.

In high wildfire activity years, wildfire-induced $PM_{2.5}$ dominates all other sources combined (see Figure 1). The highest concentrations of $PM_{2.5}$ (from all sources) are observed in highly populated counties of southwest, central, and northern Idaho. Figure 2 shows modeled background concentrations of maximum daily $PM_{2.5}$ averaged from 2014 to 2017 across Idaho.

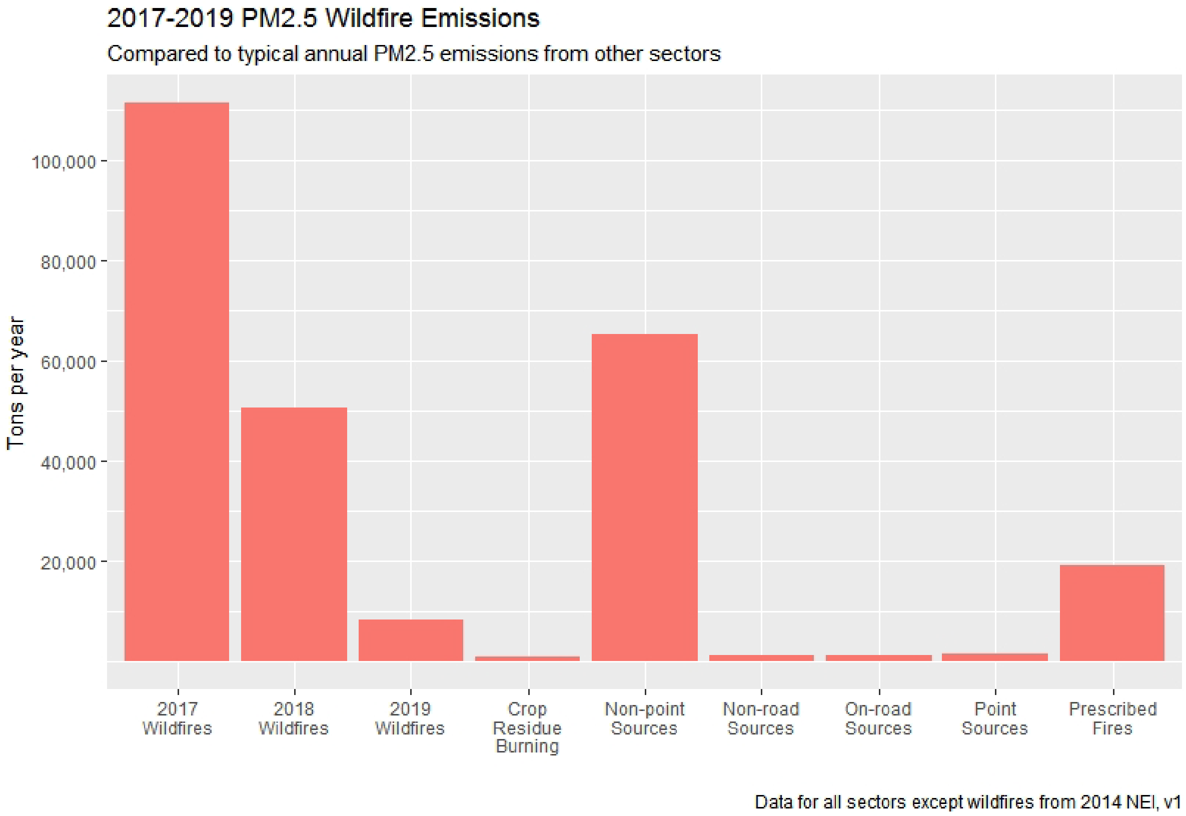


*Figure 1. Wildfire-induced $PM_{2.5}$ emissions as compared to other sources in Idaho during the period 2017-2019 (source: IDEQ, 2020).*

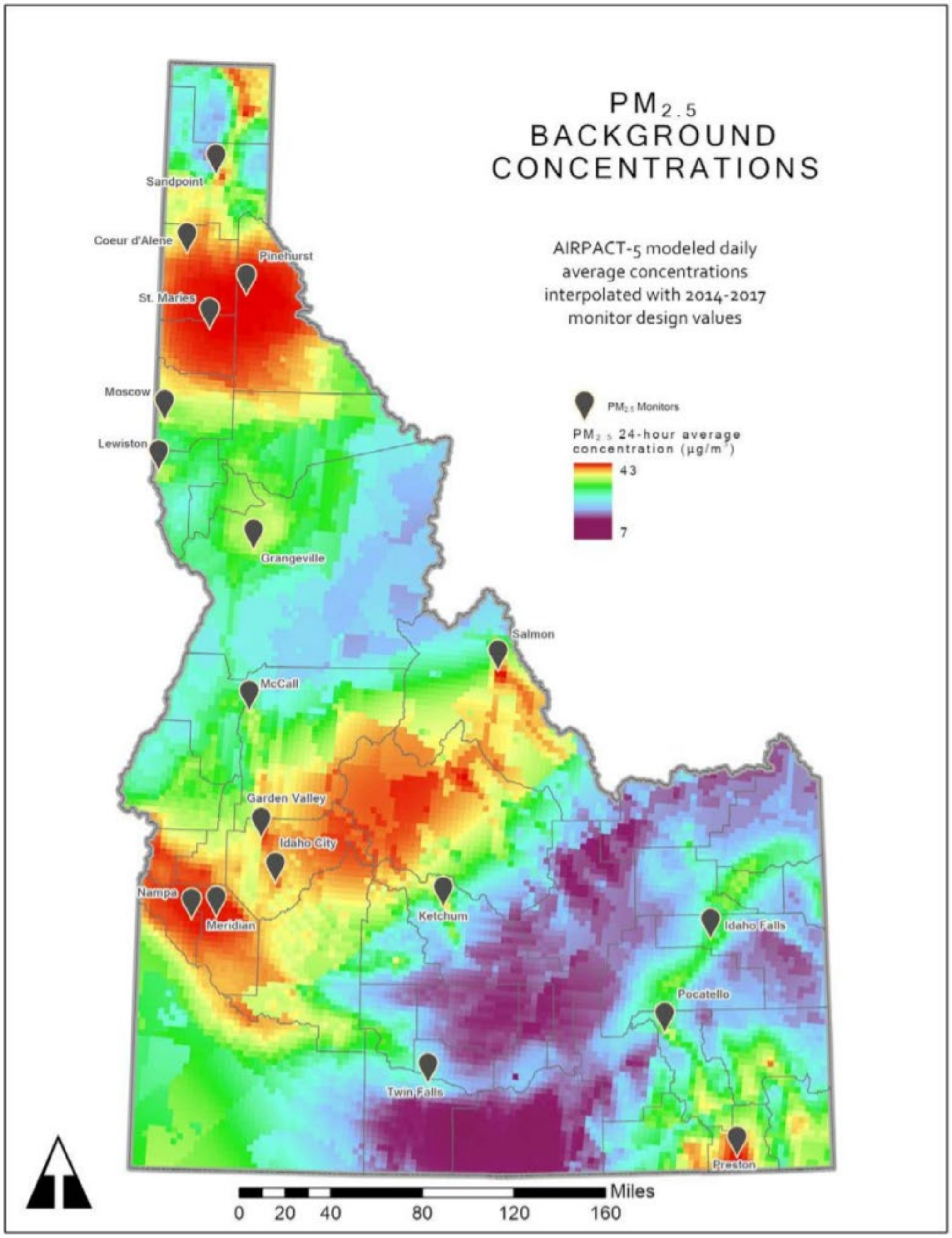


*Figure 2. $PM_{2.5}$ background concentrations in terms of maximum daily fine particulate matter concentrations averaged over 2014-2017 across Idaho (source: IDEQ, 2020).*

### b. Meteorological, climate, and topographic controls of air quality issues

Multiple variables can impact air quality in Idaho. **Topography** varies across the Gem State and has a complex influence on air quality. Inversions during cold months can trap pollutants near valley bottoms and worsen air quality, whereas diurnal winds due to differential cooling and heating of hillslopes and valleys can transport pollutants towards or away from populated areas, worsening or improving air quality. **Temperature** adversely impacts air quality at the two ends of the spectrum: during cold inversions and during dry, hot summers. Specifically, high temperatures facilitate formation of ozone from precursor elements in sunny days of summer months. **Precipitation** generally has a beneficial impact on air quality by absorbing and removing pollutants from the air and by diluting pollutants due to enhanced mixing during storm events. **Humidity** has a complex impact on air quality. Low humidity allows dust particles to become airborne. High humidity in summer inhibits formation of ozone through reducing solar radiation, whereas in winter, high humidity can facilitate coalescing and reacting between small chemical species, and forming secondary particles. Further, high humidity under very cold conditions can help form hoar frost, which is very effective in removing pollutants from the air (IDEQ, 2020). **Solar radiation** (sunshine) is generally troublesome in summer months by helping form ozone from NOx and VOCs that are plentiful in Idaho due to regional wildfires. **Forests and rangelands** provide a plentiful biomass source for wildfires that emit various pollutants as outlined in Table 1. For more information, see Section 3 of IDEQ, 2020.

### c. Background versus periodic air quality hazards in Idaho

A number of sources – including residential wood combustion, agricultural activities and burning, industrial boilers and operations, exhaust from on-road and non-road vehicles, dust from roads and storms, wildfires, and prescribed burns – release various air pollutants to Idaho airsheds (IDEQ, 2020; also see Table 1). Various regions in Idaho are vulnerable to violating the NAAQS for $PM_{10}$, $PM_{2.5}$, and ozone, mainly during large wildfire events (IDEQ, 2020). Ozone is very reactive and short-lived. Among PM fractions, fine particles ($PM_{2.5}$) are considered a greater health hazard. Hence, this report mainly focuses on $PM_{2.5}$.

Figure 3 shows sources of $PM_{2.5}$ emissions in Idaho from 1996 to 2018, based on the U.S. EPA's National Emissions Inventory (NEI) 2020 data (EPA National Emissions Inventory, 2020). Sources are categorized into three main groups: (1) all sources except wildfires, (2) wildfires, and (3) prescribed burns. *All sources except wildfires* have steadily reduced $PM_{2.5}$ emissions from ~350,000 tons/year across the Gem State in the late 1990s to ~60,000 tons/year in recent years, whereas wildfire-induced $PM_{2.5}$ emissions have steadily increased from ~5,000 tons/year in the early 2000s to ~140,000 tons/year in recent years. Emissions from prescribed burns remain rather flat, ranging between ~10,000 tons/year to ~25,000 tons/year during the period 2008-2018. Wildfire-induced $PM_{2.5}$ emissions have dwarfed all other sources in Idaho in recent years. While these numbers represent model estimates of Idaho emissions, pollutants can also be transported by atmospheric circulation for thousands of miles to and from Idaho (Goodrick et al., 2013), meaning that Idaho can be impacted by wildfire smoke from other regions and Idaho wildfires will impact air quality in other states and countries. It is hence of interest to analyze wildfire smoke at the regional and national levels.

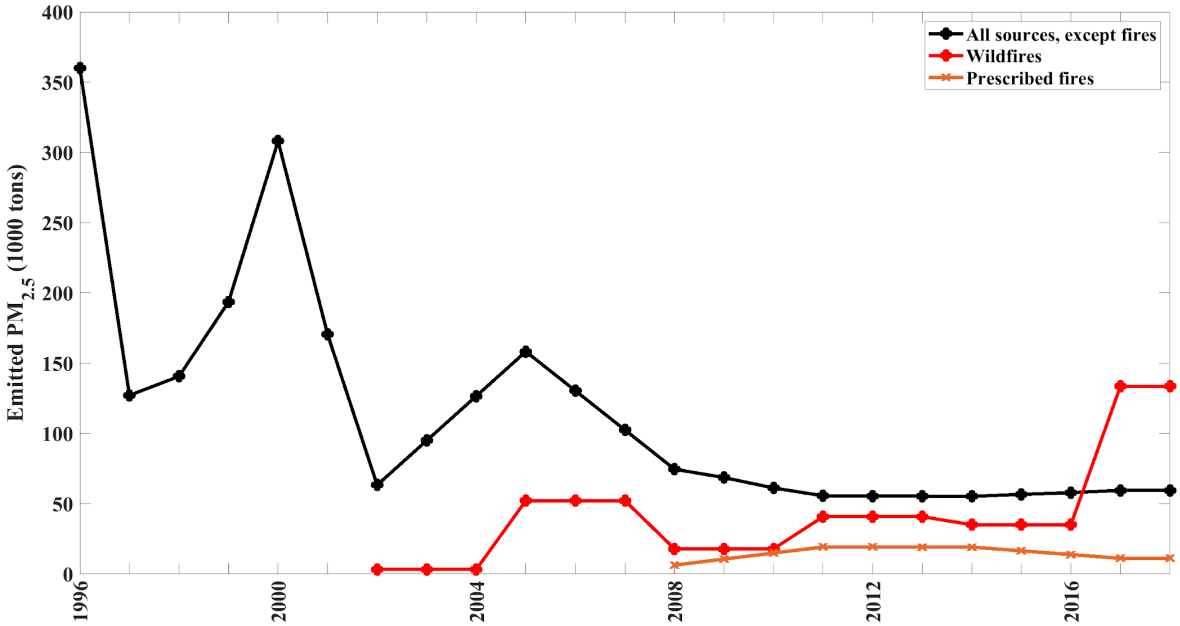


*Figure 3. Sources of* $PM_{2.5}$ *emissions in Idaho, categorized into (1) all sources except wildfires (black line), (2) wildfires (red line), and (3) prescribed burns (orange line). All sources include fuel combustion from all subcategories, including manufacturing, processing and all industries, storage and transport, waste disposal and recycling, highway vehicles and off-highway equipment, and miscellaneous (source: EPA National Emission Inventory, 2020).*

Across the U.S., it is estimated that 25% of primary $PM_{2.5}$ is wildfire-emanated (EPA National Emissions Inventory, 2020; O'Dell et al., 2019). This fraction is much higher for the western and Northwestern U.S. (Burke et al., 2021). Figure 4 shows annual fractions of $PM_{2.5}$ across the west and Northwest between 2006 and 2018, estimated from a statistical model informed with ground and satellite imagery (Burke et al., 2021). Across the west, fraction of total $PM_{2.5}$ attributable to wildfire smoke has more than doubled in two decades, from less than 15% in late 2000s to greater than 30% in recent years (Figure 4). Wildfire smoke contribution to $PM_{2.5}$ is even more pronounced across the Northwest. Wildfires emitted more than 60% of $PM_{2.5}$ across the Northwest in 2018, which has tripled from the late 2000s (Burke et al., 2021). These trends are also confirmed with various mechanistic modeling efforts using Goddard Earth Observing System-Chem and Community Multiscale Air Quality models (Wilkins et al., 2018; O'Dell et al., 2019).

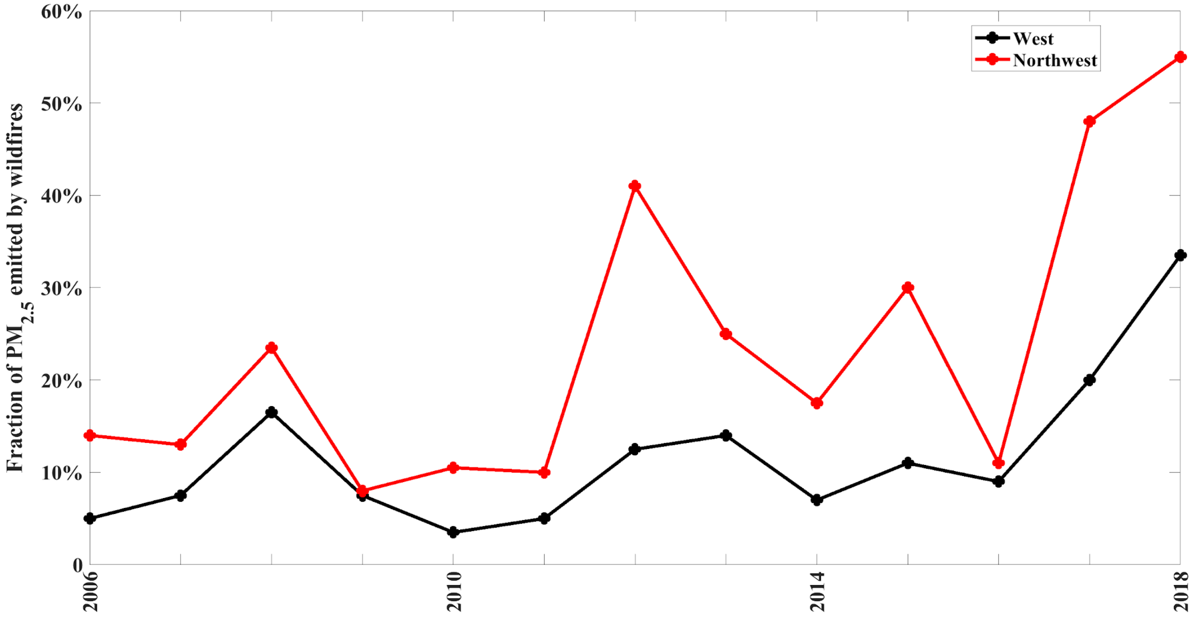


*Figure 4. Wildfire contribution to total annual $PM_{2.5}$ emissions across the west (black line) and Northwest (red line) in the U.S. (Recreated from Figure 1H of Burke et al., 2021.)*

Wildfires increased average annual $PM_{2.5}$ concentrations from less than 1 μg/m$^3$ (most Idaho counties) to approximately 4 μg/m$^3$ across some central Idaho counties between 2006 and 2008 (Figure 5; Burke et al., 2021). These values increased to an additional load of greater than 4 μg/m$^3$ for $PM_{2.5}$ for a majority of Idaho counties between 2016 and 2018 (Figure 5; Burke et al., 2021). This is significant since the majority of wildfire-related $PM_{2.5}$ load occurs during heavy smoke events, which are also the majority of days that Idaho air quality violates the NAAQS standards (IDEQ, 2020). Liu et al. (2016) showed that for days during which regulatory standards were violated between 2004 and 2009, more than 70% of $PM_{2.5}$ could be attributed to wildfires across the western U.S. This value is expected to have increased significantly in recent years due to the escalating wildfire activity across the region. Furthermore, Wilkins et al. (2018) showed that the number of grid cell-days that violate the 35 μg/m$^3$ daily NAAQS threshold for $PM_{2.5}$ across the U.S. due to wildfire emissions have increased by a factor of 4 between 2008 and 2012. In this study, the U.S. was divided to several thousand equal size grids (a rectangular shape area) and the number of days that air quality in each grid violated the regulatory standards was counted. This was subsequently aggregated across all grids, which is referred to as number of grid cell-days.

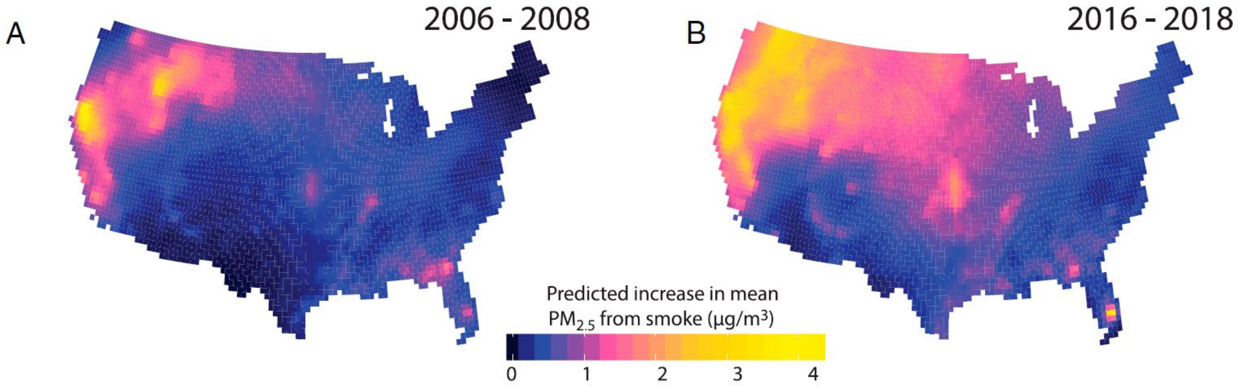


*Figure 5. Predicted increase in $PM_{2.5}$ attributable to wildfires (A) 2006-2008 and (B) 2016-2018, derived from a statistical model informed by satellite imagery and ground observations (source: Burke et al., 2021).*

### d. Trends and changes in air quality in Idaho

Anthropogenic air pollution emissions have decreased across the U.S. and Idaho since the Clean Air Act was implemented in 1970; thus, air quality has consistently improved over the past decades. This has been shown, for example, in terms of the 98th percentile of annual $PM_{2.5}$ concentrations (of regulatory importance by NAAQS) decreasing across the entire U.S. except for the Northwest (McClure & Jaffe, 2018). This anomalous trend in the Northwest is attributed to increasing wildfire activity. Idaho is located at the center of the geographic area that observed increasing trends of worsening air quality due to wildfire smoke (see Figure 5B). Figures 6-8, for example, demonstrate these trends for daily AQI values in Ada County between 1999 and 2020. The population of Ada County in 2020 was 456,849, the highest in the state (Idaho Demographics, 2021). Annual average AQI has decreased in Ada County (Figure 6 - solid line), while the annual maximum AQI levels have increased (Figure 6 - dashed line). Non-wildfire season (October-May) average AQI in Ada County also shows a statistically significant (95% confidence level) negative trend, highlighting improved air quality (Figure 7 - solid line). Finally, for the wildfire season (June-September), both average (Figure 8 - solid line) and maximum (Figure 8 - dashed line) AQI show increasing trends (trend in max AQI is statistically significant at the 95% confidence level), highlighting degrading air quality.

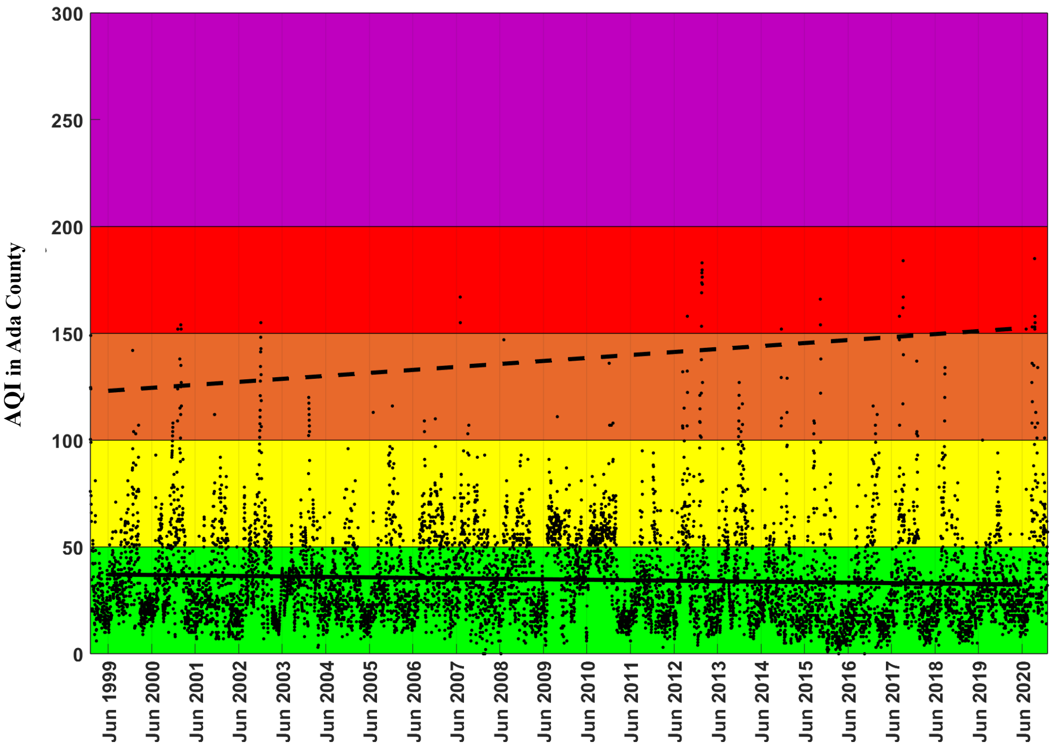


*Figure 6. Daily PM$_{2.5}$-based AQI values for Ada County between 1999 and 2020. Solid line presents the trend in average annual AQI values, whereas the dashed line presents the trend line of maximum annual AQI.*

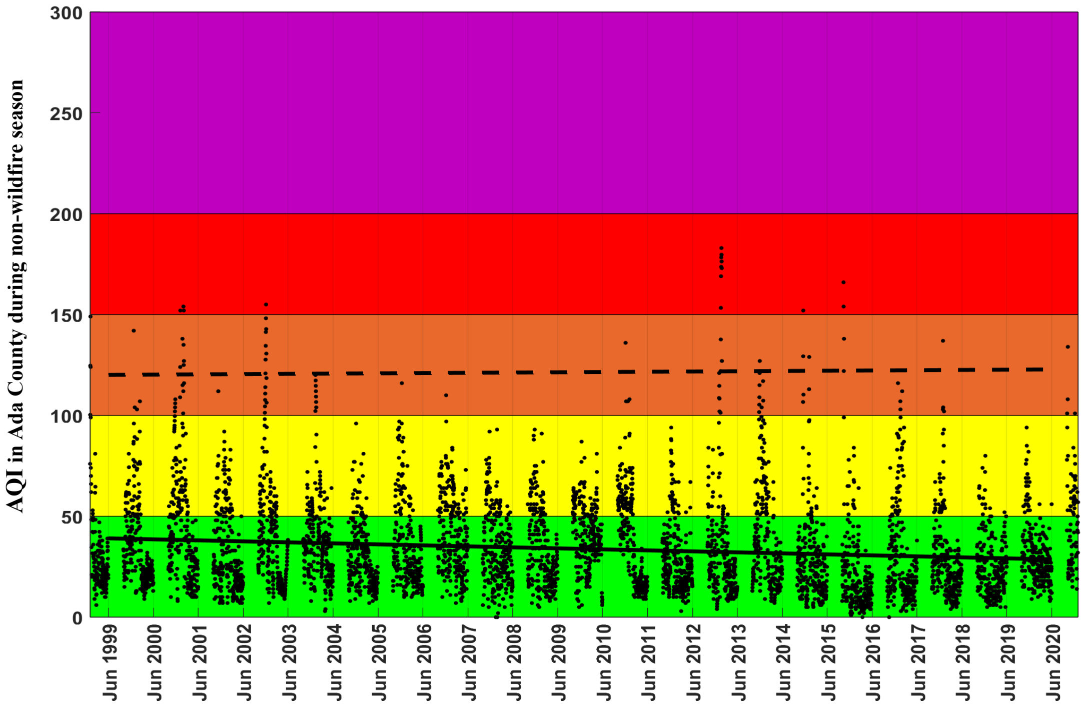


*Figure 7. Daily PM$_{2.5}$-based AQI values for Ada County in the non-wildfire season between 1999 to 2020. Non-wildfire season is defined as October to May. Solid line presents the trend line in average non-wildfire season AQI values, whereas the dashed line presents the trend line of maximum non-wildfire season AQI.*

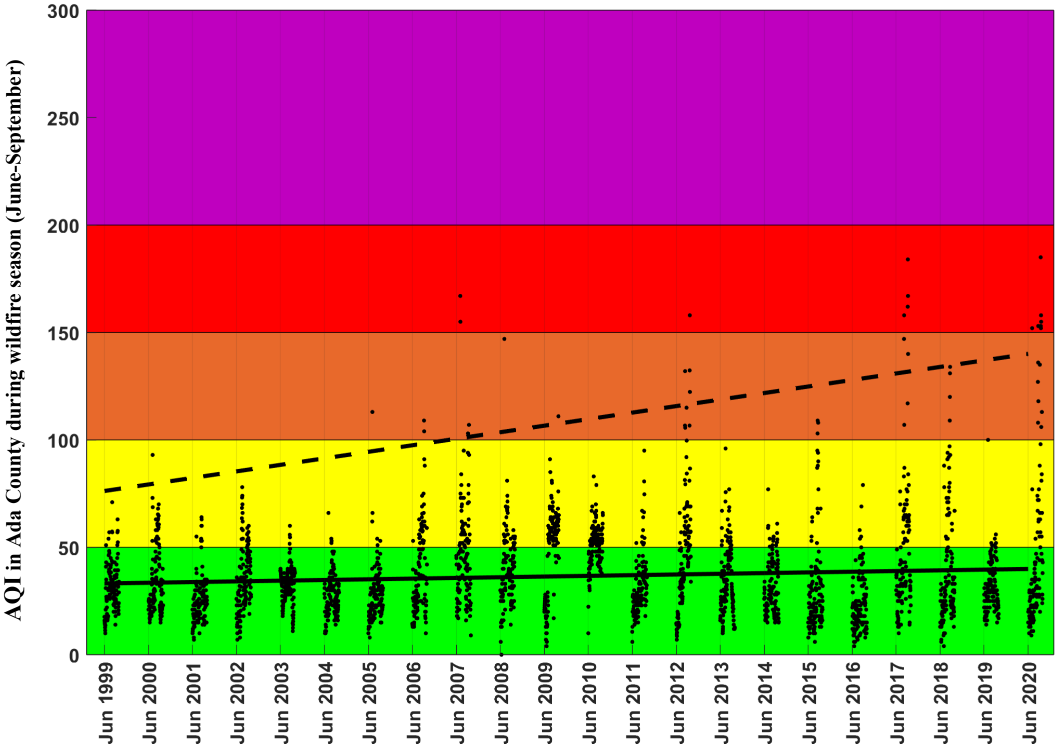
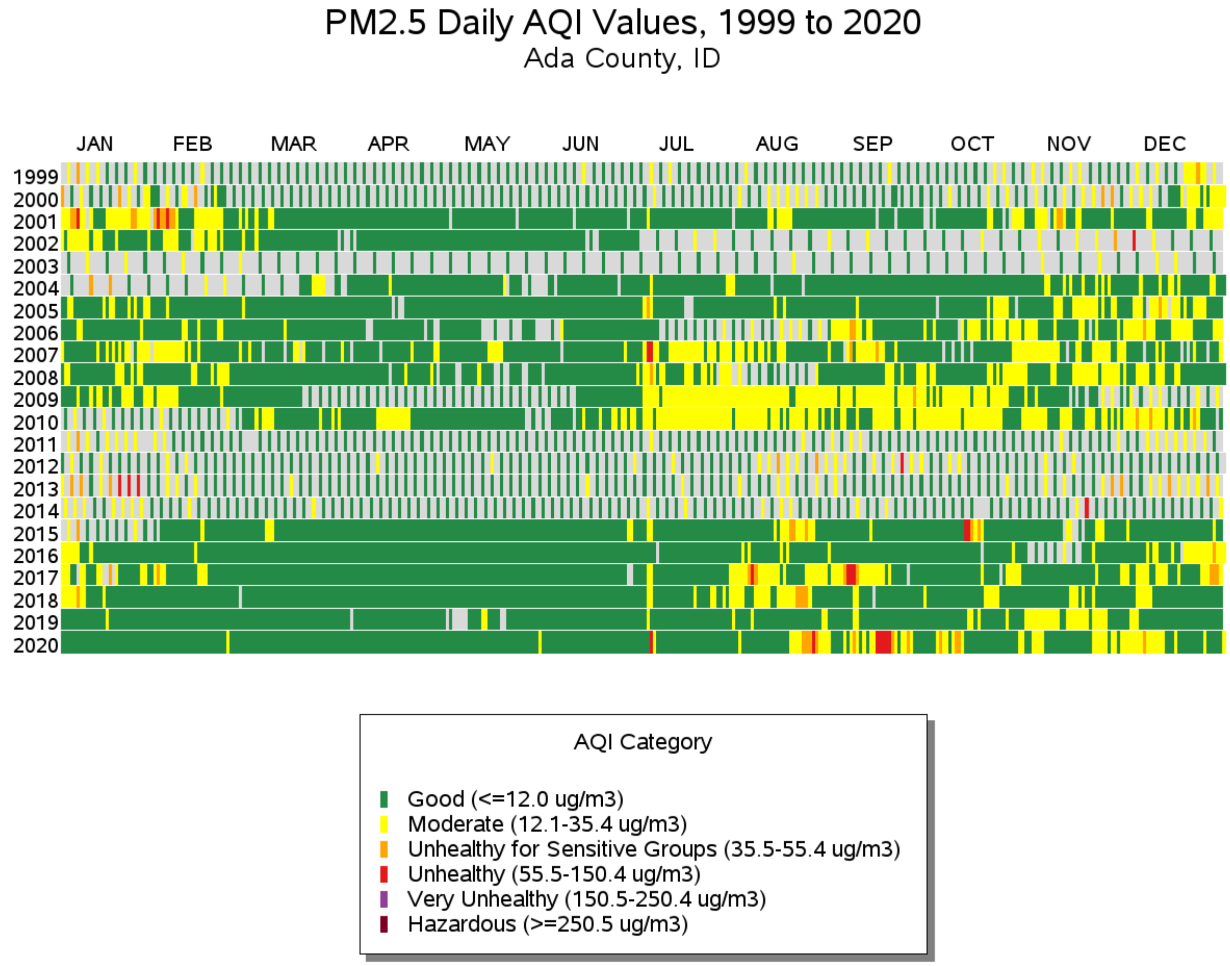


*Figure 8. Daily $PM_{2.5}$-based AQI values for Ada County in the wildfire season between 1999 and 2020. Wildfire season is defined as June to September. Solid line presents the trend line of average wildfire season AQI values, whereas the dashed line presents the trend line of maximum wildfire season AQI.*

Figure 9 shows the tile plot of daily $PM_{2.5}$-based daily AQI reporting for Ada County. This supports that wildfire season, specifically in recent years, is associated not only with more poor air quality days – marked with orange ($101 \leq AQI \leq 150$) and red ($151 \leq AQI \leq 200$) – but also with extended periods of poor air quality. Years 2017 and 2020 stand out in this figure, showing week-long episodes of continuous orange-red air quality days (Figure 9). Extended smoke episodes are specifically challenging for those in charge of public health, as public responsiveness to health warnings sharply decline after 2-3 days of reduced-outside-activity orders (Fowler et al., 2019). $PM_{2.5}$-based daily AQI tile plots for the 1999-2020 period for Idaho counties are available here.



Source: U.S. EPA AirData <https://www.epa.gov/air-data>
Generated: January 20, 2021

*Figure 9. Daily AQI based on $PM_{2.5}$ for Ada County between 1999 and 2020 (source: EPA, 2021).*

Table 2 lists the frequency of NAAQS violations ($PM_{2.5}$-based AQI > 100) in 5-year periods between 2001 and 2020 for wildfire season (June-September), non-wildfire season (October-May), and the entire year for all counties across Idaho with available data from the U.S. EPA (EPA, 2021). For the non-wildfire season, the number of days with $PM_{2.5}$-based AQI exceeding 100 is generally decreasing across all counties. For example, Kootenai County, with a 2020 population of 157,322 people, observed 9 days with air quality violations in the non-wildfire season during 2001-2005, but observed one such day during 2016-2020. In the wildfire season, however, these numbers have increased from 1 day in 2001-2005 to 28 days in 2016-2020 for Kootenai County. Similar findings are observed for all counties in Idaho.

| County | 2001-2005 | | | 2006-2010 | | | 2011-2015 | | | 2016-2020 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | All year | Wildfire season | Non-wildfire season | All year | Wildfire season | Non-wildfire season | All year | Wildfire season | Non-wildfire season | All year | Wildfire season | Non-wildfire season |
| Ada | 20 | 1 | 19 | 12 | 8 | 4 | 23 | 6 | 17 | 37 | 26 | 11 |
| Bannock | 19 | 0 | 19 | 4 | 0 | 4 | 11 | 9 | 2 | 15 | 15 | 0 |
| Benewah | 7 | 1 | 6 | 14 | 1 | 13 | 38 | 12 | 26 | 71 | 31 | 40 |
| Blaine | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 16 | 16 | 0 |
| Boise | 39 | 2 | 37 | 20 | 14 | 6 | 31 | 12 | 19 | 62 | 41 | 21 |
| Bonner | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 8 | 3 | 38 | 34 | 4 |
| Bonneville | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 12 | 0 |
| Butte | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 0 | 5 | 5 | 0 |
| Canyon | 24 | 1 | 23 | 2 | 2 | 0 | 16 | 10 | 6 | 41 | 27 | 14 |
| Custer | 0 | 0 | 0 | 4 | 4 | 0 | 6 | 6 | 0 | 9 | 9 | 0 |
| Franklin | 22 | 0 | 22 | 11 | 0 | 11 | 52 | 8 | 44 | 30 | 8 | 22 |
| Idaho | 2 | 2 | 0 | 9 | 9 | 0 | 17 | 17 | 0 | 28 | 28 | 0 |
| Jerome | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 11 | 0 |
| **Kootenai** | **10** | **1** | **9** | **4** | **1** | **3** | **6** | **6** | **0** | **29** | **28** | **1** |
| Latah | 0 | 0 | 0 | 6 | 6 | 0 | 14 | 14 | 0 | 24 | 24 | 0 |
| Lemhi | 8 | 4 | 4 | 36 | 15 | 21 | 114 | 59 | 55 | 78 | 25 | 53 |
| Nez Perce | 0 | 0 | 0 | 6 | 6 | 0 | 20 | 20 | 0 | 33 | 27 | 6 |
| Shoshone | 35 | 0 | 35 | 74 | 0 | 74 | 80 | 13 | 67 | 53 | 27 | 26 |
| Twin Falls | 2 | 0 | 2 | 2 | 1 | 1 | 6 | 6 | 0 | 18 | 17 | 1 |
| Valley | 3 | 2 | 1 | 15 | 15 | 0 | 5 | 5 | 0 | 21 | 20 | 1 |

*Table 2. Number of days violating regulatory requirements during each 5-year period between 2001 and 2020 (PM$_{2.5}$-based AQI exceeding 100) for all counties with reported air quality data (source: EPA, 2021). Note: Daily data were not consistently reported by all counties between 2001 and 2020.*

### e. Direct and indirect impacts of wildfire smoke to economies

Various studies have attempted to quantify the economic costs of wildfire smoke at regional and national levels in the past decade. These studies use two general methods to monetize wildfire smoke impacts: cost of illness (COI) and willingness to pay (WTP). COI is focused on medical and other costs (e.g., labor loss), resulting from a specific disease or condition (U.S. Centers for Disease Control and Prevention

(CDC), 2021). WTP is a more comprehensive economic metric compared to COI (Kochi et al., 2010), taking into account various elements of "*medical expenditures, lost wages, investments of time or money in taking preventative actions to decrease exposure, and the disutility associated with symptoms or lost leisure*" (Richardson et al., 2012). Through the life satisfaction approach, recent studies further expanded this definition of WTP to include non-health aspects considering the general disutility of wildfire smoke (Jones, 2017).

Using a chemical transport model (namely the Community Multiscale Air Quality Modeling System (CMAQ)) that can separate wildfire smoke from background air quality, Fann et al. (2018) found that northern California, Oregon, and Idaho were most impacted by wildfire smoke. Using common health-response functions, they estimated that across the U.S., between 5,200 and 8,500 respiratory hospital admissions per year during 2008-2012 were attributed to wildfire smoke. Similarly, they estimated the number of deaths attributable to short-term exposure to wildfire smoke across the U.S. ranged from 300 to 500 per year during 2008-2012. Using a COI approach to monetize these impacts and assuming a $10.1 million value of a statistical life (a statistical value that society is willing to pay to save an anonymous person's life) and $36,000 cost of hospital admission (medical cost and lost earnings), they estimated that the economic value of deaths and respiratory hospital admissions due to short-term exposure to smoke ranges between $11 billion and $20 billion per year (2010 USD). These values increase to $76-$130 billion when long-term health effects of exposure to $PM_{2.5}$ are considered. Note that the wildfire seasons during this period (2008-2012) were much less intense than that of 2020, as well as projected future wildfire activity (Hurteau et al., 2014).

Other studies argue that the COI approach underestimates the actual costs of wildfire smoke by not considering the defensive actions that people take to mitigate smoke impacts (e.g., buying air filtration devices or medication) (Richardson et al., 2012) and neglecting the negative impacts that wildfire smoke imposes on communities (Jones, 2017). Different WTP estimates with respect to wildfire smoke are offered in the literature, such as $84.12 to avoid a symptom day (Richardson et al., 2012), $36-$68 per day to avoid mild cough (Johnson et al., 1997), $110 per day to avoid shortness of breath (Johnson et al., 1997), and $91-$129 per day to avoid severe asthma (Johnson et al., 1997). While studies on human response, in terms of different symptoms, to wildfire smoke are rather sparse, in a recent Idaho-centric study (Fowler et al., 2019), more than 90% of survey participants in the Treasure Valley declared that at least one person in their household observed one or more wildfire smoke-related symptoms during the 2018 wildfire season (which was a rather mild wildfire and smoke year). Figure 10 shows frequency of reported symptoms for 614 participants in the study (Fowler et al., 2019). Given the widespread experience of wildfire smoke-related symptoms in Idaho, the WTP-calculated economic damage to Idaho can reach millions of dollars per year. Note that extended periods of wildfire smoke also include mental health impacts that are difficult to quantify and even more difficult to monetize.

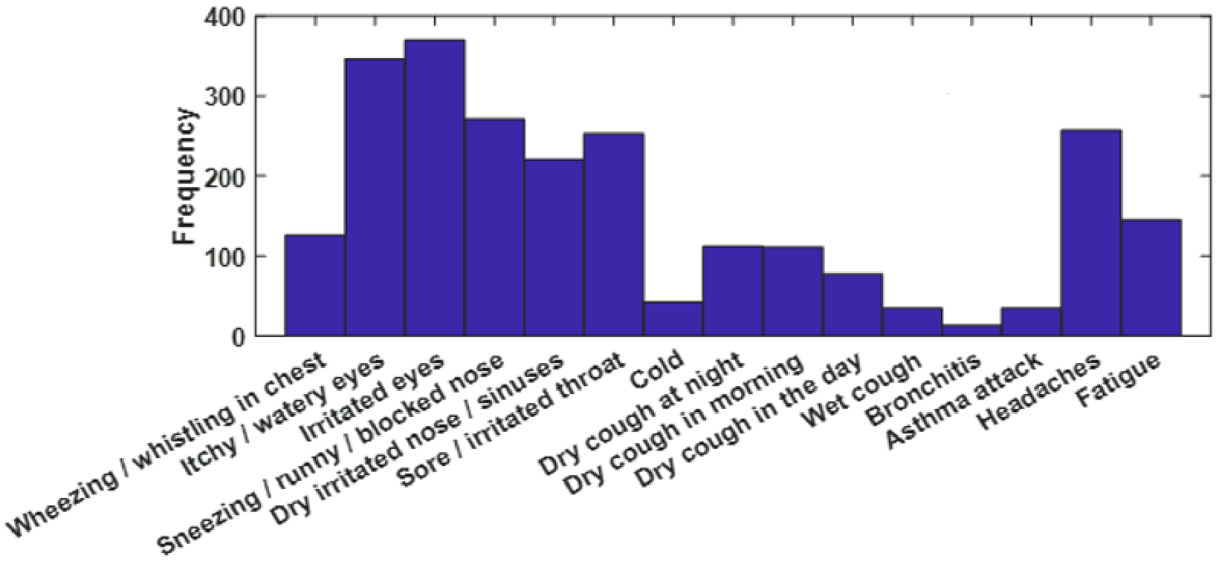


*Figure 10. Observed wildfire smoke-related symptoms reported by 614 participants during the 2018 wildfire season in the Treasure Valley, Idaho from Fowler et al. (2019). Participants reported symptoms when anyone in their household observed an impact. Participants could select more than one option. y-axis (frequency) shows number of participants that reported an observed symptom (x-axis) within their household.*

Finally, studies that also incorporated non-health related disutility of wildfire smoke estimated higher WTP rates. For example, Jones (2017) estimated that U.S. adults are willing to pay $373 to avoid one day of smoke in their county over a 6-month period. Recently, Borgschulte et al. (2018) showed that wildfire smoke leads to statistically significant economic losses in the labor market in the year that smoke occurred and the following year. Specifically, they estimated a 0.04% decline in the labor income for each smoke day across the two years of impact. While significant economic losses are recognized and quantified at the national and regional levels, Idaho could benefit from state-level studies.

## 3. Trends in wildfire activity across the U.S. and in Idaho

Wildfire hazards have increased across the western U.S. in the recent decades, increasing the burden placed on wildfire prevention and suppression efforts (Dennison et al., 2014). Changes in climate have increased fuel aridity, lengthened the wildfire season, and contributed to a significant increase in critical wildfire danger days across parts of the region (Abatzoglou & Williams, 2016; Westerling, 2016; Khorshidi et al., 2020). These changes have coincided with a legacy of wildfire suppression policies and subsequent historical wildfire deficits and elevated fuel loads in many regions, especially in forested lands (Parks et al., 2015). Figure 11 shows the total annual burned area across the U.S. (red bins) that is associated with an increasing trend of 170,000 acres/year (red line) between 1984 and 2019. This increase in area occurred while the number of reported wildfires decreased (black trend line in Figure 11), implying individual wildfires are burning increasingly larger areas. In Idaho, annual burned area has increased at a rate of 14,900 acres/year between 1984 and 2017 (Figure 12). This increase coincided with a lengthening of the wildfire season as shown by trend lines for the first and last large wildfire of the year (greater than 1,000 acres) (black dashed lines in Figure 12).

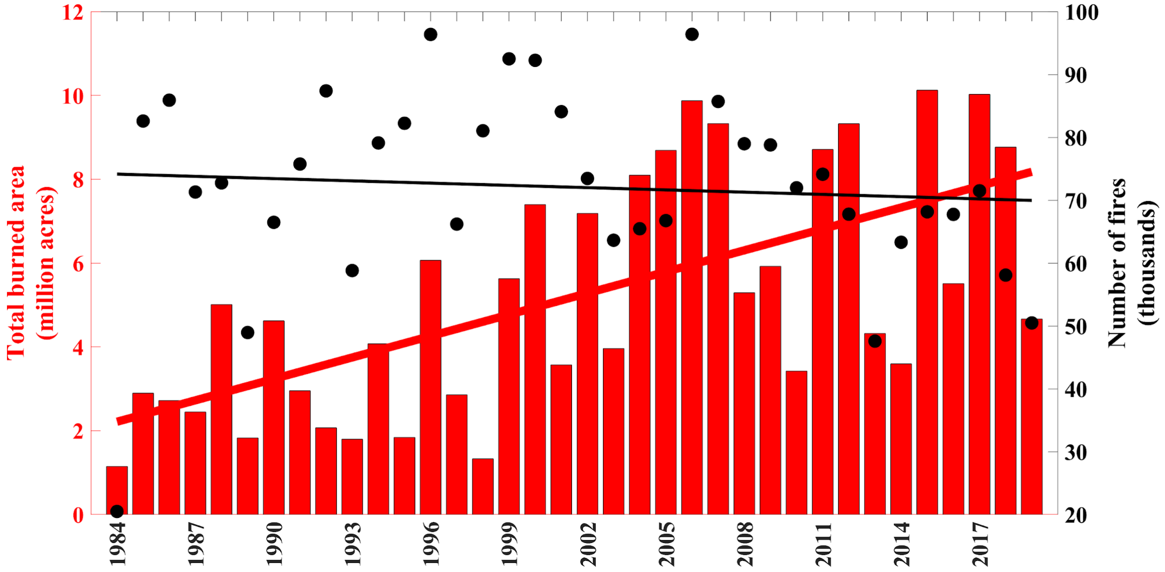


*Figure 11. Annual burned area across the U.S. (red bins) and total number of reported wildfires (black dots) across the U.S. Trends are shown with solid lines (data from National Interagency Fire Center, 2021).*

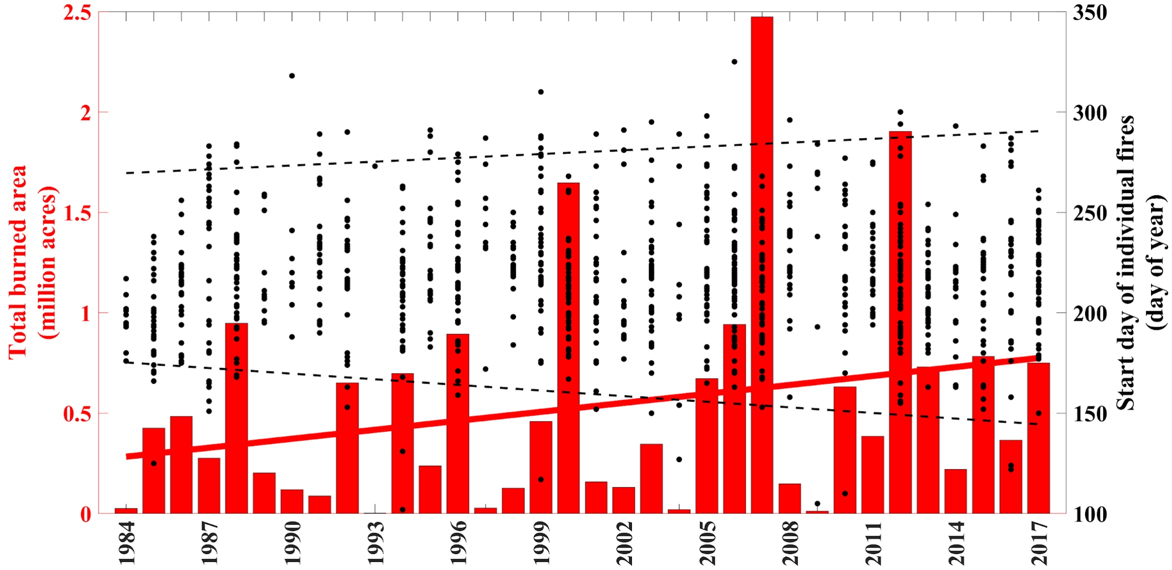


*Figure 12. Annual burned area in Idaho (red bins) and the start day of all large wildfires (greater than 1,000 acres) in each year (black dots). Trend in the annual burned area is shown with a red solid line, whereas trends in the start date of first and last wildfires in each year are shown with black dashed lines (data from National Interagency Fire Center, 2021).*

## 4. Case study of the 2020 smoke waves in Idaho

Wildfires caused severe damage across the western U.S. in 2020: California set a new record for total area burned in modern history (>4 million acres), Oregon observed one of its most destructive wildfire seasons, and Colorado set a record for wildfire size in June and then broke it twice later in the same wildfire season (Sadegh et al., 2020). A widespread drought across the western U.S. (Figure 13) and a very warm year that set several new heatwave records across the region procured abundant dry fuels, which when combined with the lightning storm of August 2020 in California, easterly windstorm on Labor Day in Oregon, and strong winds in Colorado during high-wildfire activity, facilitated one of the worst modern wildfire seasons in the western U.S.

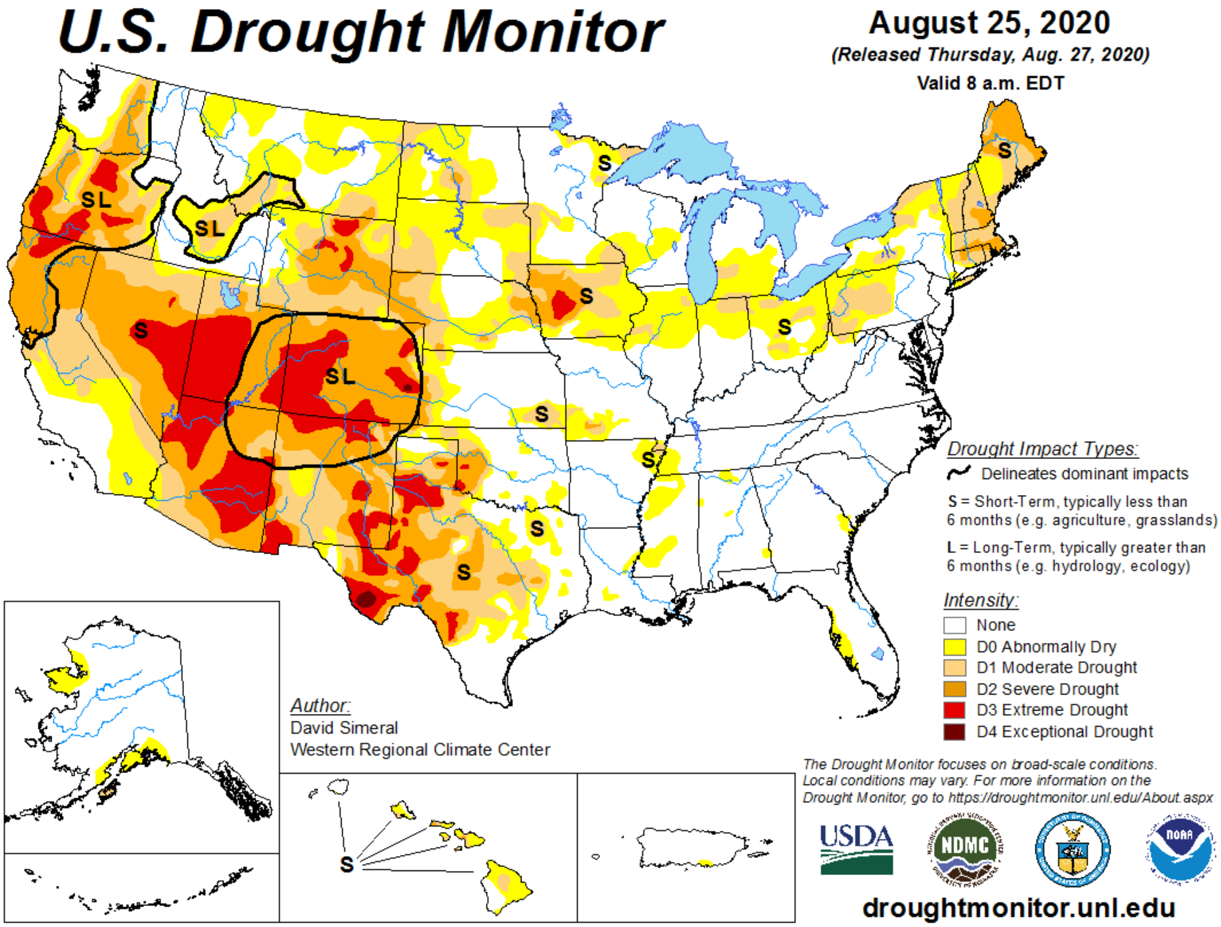


*Figure 13. Widespread severe to extreme drought covering much of the western U.S. on August 25, 2020 (prior to multiple devastating wildfires across the west). Similar conditions occurred through the summer and fall of 2020 (source: U.S. Drought Monitor, 2020).*

Although Idaho was not severely affected by large wildfires in the record-breaking wildfire activity in 2020, the entire state was blanketed under smoke from western U.S. wildfires for many weeks (Figure 14). As shown in Figure 15, several dozen days diverge from good air quality (AQI $\leq 50$) into moderate

($51 \leq \mathrm{AQI} \leq 100$) and poor (AQI $\geq$101) conditions across Idaho. Specifically, all six counties displayed in Figure 15 experienced orange ($101 \leq \mathrm{AQI} \leq 150$) and red ($151 \leq \mathrm{AQI} \leq 200$) conditions in August and September 2020 and Kootenai County experienced multiple days of purple ($201 \leq \mathrm{AQI} \leq 300$; very unhealthy - alert conditions) and maroon ($301 \leq \mathrm{AQI}$; hazardous - emergency conditions) air quality. These translate to more than 15.5 million person-days exposure to wildfire-driven poor air quality conditions (AQI >100), mostly due to California and Oregon wildfires in August and September 2020. Boise, Ada, and Canyon counties observed the highest number of days in violation of the NAAQS standards with 20, 17, and 15 days of AQI greater than 100 during the 2020 wildfire season (June-September), respectively. Ada and Canyon counties are home to a large portion of Idaho's population, accounting for more than 11 million person-days exposure to poor air quality of the total 15.5 million for the entire state. Detailed statistics for several Idaho counties are provided in Table 3.

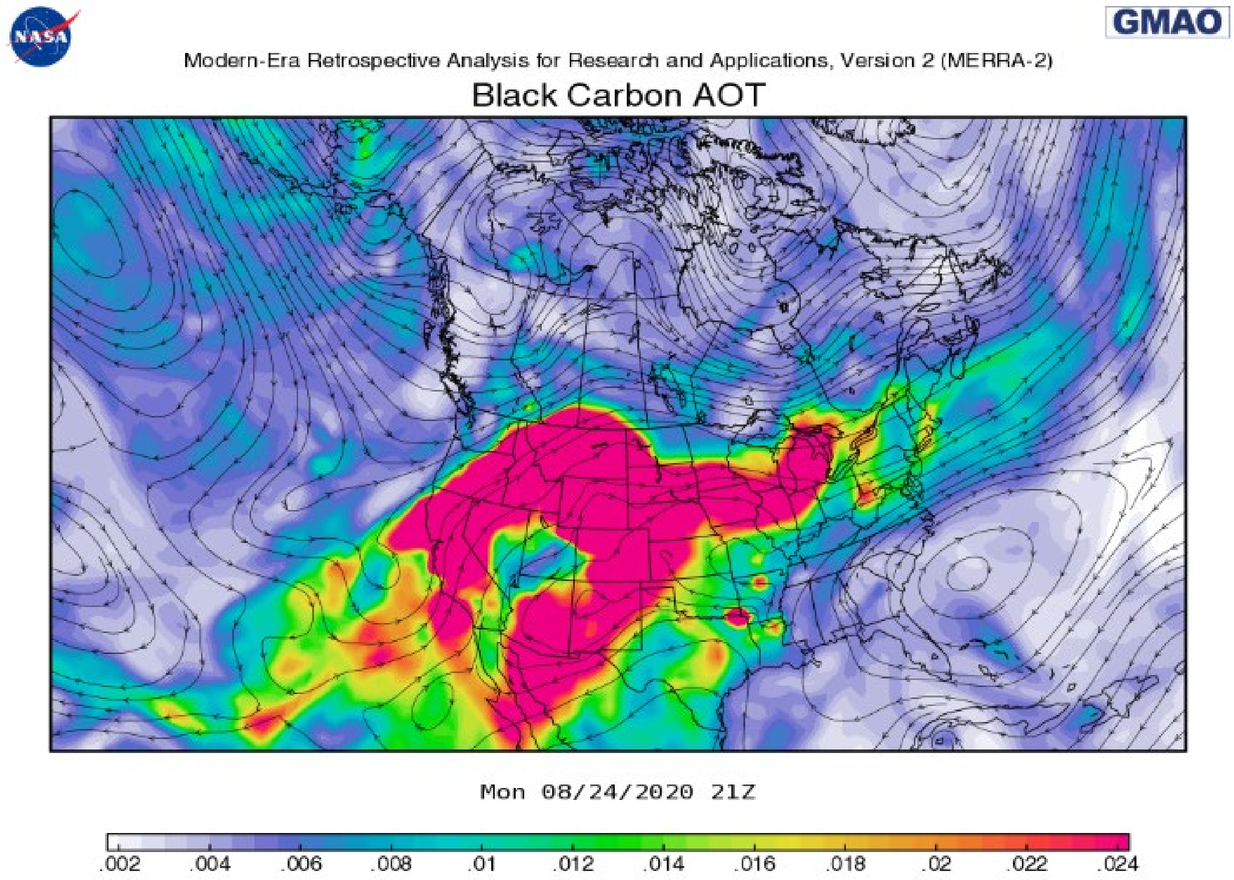


*Figure 14. Wildfire smoke covering much of the western U.S. and the entire state of Idaho. The figure shows wildfire-emitted black carbon aerosol optical thickness (a measure of clear/hazy sky) on August 24, 2020 and how smoke is transported to Idaho (source: MERRA-2 reanalysis by NASA).*


Ada (population: 456,849)

Canyon (population: 217,633)

Kootenai (population: 157,322)

Bonneville (population: 114,392)

Bannock (population: 85,765)

Twin Falls (population: 84,869)

*Figure 15. The 2020 daily AQI tile plots for the six most populated counties in Idaho (source: EPA, 2021).*

| County | 2020 population | Number of days with AQI > 100 | Number of person-days exposure to AQI > 100 |
|---|---|---|---|
| Ada | 456,849 | 17 | 7,766,433 |
| Bannock | 85,765 | 6 | 514,590 |
| Benewah | 9,138 | 8 | 73,104 |
| Blaine | 22,373 | 8 | 178,984 |
| Boise | 7,378 | 20 | 147,560 |
| Bonner | 43,611 | 7 | 305,277 |
| Bonneville | 114,392 | 5 | 571,960 |
| Butte | 2,581 | Not reported* | Not reported* |
| Canyon | 217,633 | 15 | 3,264,495 |
| Custer | 4,169 | Not reported* | Not reported* |
| Franklin | 13,464 | 3 | 40,392 |
| Idaho | 16,411 | 9 | 147,699 |
| Jerome | 23,730 | Not reported* | Not reported* |
| Kootenai | 157,322 | 7 | 1,101,254 |
| Latah | 39,505 | 7 | 276,535 |
| Lemhi | 7,847 | 7 | 54,929 |
| Nez Perce | 40,217 | 8 | 321,736 |
| Shoshone | 12,609 | 7 | 88,263 |
| Twin Falls | 84,869 | 7 | 594,083 |
| Valley | 10,709 | 7 | 74,963 |
| **TOTAL** | **1,370,572** | **148** | **15,522,257** |

*Table 3. Number of days with NAAQS non-compliant air quality conditions (AQI > 100) during the 2020 wildfire season and number of exposed people in each county. Only counties that have U.S. EPA-provided AQI data are presented. *Not reported at the time of analysis in February 2021.*

## 5. Future smoke waves

The scientific literature projects increasing wildfire activity in the western U.S. in a warming climate (Krawchuk et al., 2009; Stavros et al., 2014; Littell et al., 2018; Alizadeh et al., 2021). Trends are more marked in the forests of Northwest and Rocky Mountains where fuel is abundant (greater than 75% and greater than 175% growth, respectively, by the mid-century in a moderate greenhouse gas emission scenario; Spracklen et al., 2009). Increasing wildfire activity is estimated to double carbon aerosol emissions across the western U.S. by mid-century (Spracklen et al., 2009; Hurteau et al., 2014). While a consistent decreases in other anthropogenic sources of $PM_{2.5}$ are expected to continue improving air quality across the U.S. during the non-wildfire season, wildfire-induced $PM_{2.5}$ is projected to offset the benefits of this improving air quality (Ford et al., 2018). For example, studies show that premature deaths attributed to wildfire-induced PM$_{2.5}$ could double by the end of the century (Ford et al., 2018), making smoke-related death rates comparable to those projected for heatwave-related mortality by 2100, although these estimations remain uncertain (Burke et al., 2021).

Liu et al. (2016) conducted a detailed analysis of future (2046-2051; under a medium greenhouse gas emissions scenario) smoke risk level at the county scale in the western U.S. as compared to the 2004-2009 period. Across the western U.S., average wildfire-emanated PM$_{2.5}$ levels are projected to increase by >150%, which translates to more than 82 million people experiencing greater than 50% and greater than 30% increases in the frequency and intensity of smoke waves, respectively (Liu et al., 2016). Smoke waves are defined as 2 or more consecutive days of high wildfire-emanated PM$_{2.5}$. Furthermore, an additional 7 million children and 5.7 million elderly are projected to experience smoke waves in the future period compared to the 2004-2009 period (Liu et al., 2016). This study can help to inform future smoke-related risks in Idaho (Figure 16). While a majority of Idaho counties are at high smoke risk in the present day, most of them will shift to very-high risk (Figure 16; Liu et al., 2016). Very-high smoke risk is defined as more than two smoke waves per year, each smoke wave lasting more than four days, or a combination thereof (refer to supplementary information of Liu et al. 2016 for more details).

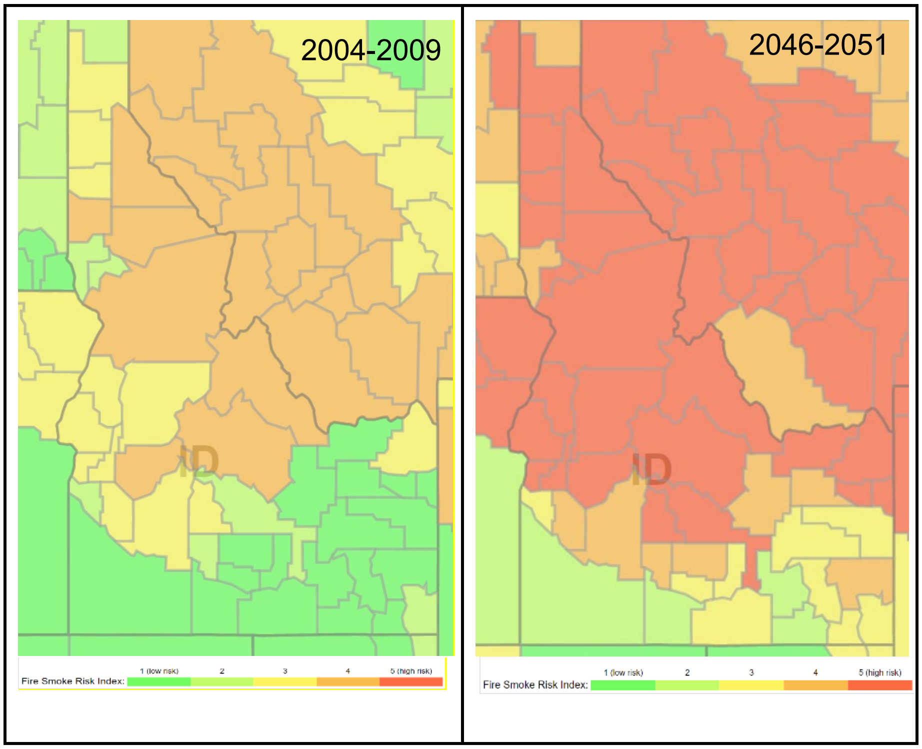


*Figure 16. Wildfire smoke risk index (FSRI) for Idaho counties in the 2004-2009 period and the 2046-2051 period, most comprehensive recent data comparing past and future smoke risk. FSRI is defined as a combination of smoke wave duration, intensity, and frequency (source: Liu et al. 2016; explore the mapping tool available here).*

## 6. Opportunities

There are two primary approaches to managing adverse health impacts of wildfire smoke: (1) suppress wildfires to reduce PM emissions and (2) temporarily remove/reduce susceptible population's exposure to wildfire smoke (Kochi et al., 2010). The first approach is highly disputed, as the legacy of fuel accumulation and unhealthy ecosystems may have worse implications for future years (e.g., larger wildfires and even more emissions; Schweizer & Cisneros, 2017). Eliminating exposure by moving vulnerable populations from the area of dense smoke is an effective approach, but may fail as the impacted population increases (Kochi et al., 2010). Personal preferences are also an important factor in effectiveness of this approach. Fowler et al. (2019), for example, showed that a majority of Idaho residents will not consider evacuating their homes to alleviate wildfire smoke risks. An alternative approach could be to use clean air shelters to provide relief to hard-hit, vulnerable populations; concerns about COVID-19 and other public health challenges complicate the efficacy of clean air shelters.

One opportunity to prepare for wildfire smoke is to stay informed on current smoke conditions.[1] The Idaho Wildfire Smoke Portal by IDEQ (available here) provides information about the current status and prediction of wildfire smoke in Idaho and the region. The U.S. EPA also provides smoke and air quality advisory notifications for the U.S. (available here). News coverage (TV, radio, and newspapers); social media; roadside dynamic signs; web posts; and other frameworks are also used to provide information to the public on wildfire smoke status, future prediction, and its impacts.

Wildfire management and air quality policies have been developed independently in the U.S. by different agencies (Hyde et al., 2017). As a warming climate and accumulated fuel due to historical wildfire exclusion continue to facilitate larger, more intense wildfires, a future decision will be whether a preferable alternative would be low intensity smoke from prescribed burns for the long-term benefit of healthy ecosystems and smaller, less intense future wildfires and smoke (Schweizer & Cisneros, 2017). The U.S. EPA's Exceptional Event Rule allows local/regional decision makers to exclude wildfire-induced poor air quality days when evaluating compliance with the NAAQS standards, but until 2019, did not allow for removal of smoke days from "controllable" prescribed burns. An approach to explore is holistic wildfire management, which incorporates all aspects of the wildfire, smoke, and post-wildfire processes (e.g., debris flow). Furthermore, other policies and strategies could be considered as wildfire smoke risks increase in the future, including forest management practices (e.g., understory fuel and debris removal); home improvements (e.g., high efficiency heating, ventilation, and air conditioning systems; air filtration devices with HEPA13 filters); workplace guidelines (e.g., provide air filtration in closed structures); and personal care (e.g., personal protective equipment). Idaho-centric studies of smoke impacts on human health also should be considered.

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[1] The CDC has provided tips to help protect people from breathing wildfire smoke, such as paying attention to local air quality reports. For more tips, visit here.

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