fire

MDPI

Article

Air Quality Impacts during the 2015 Rough Fire in Areas Surrounding the Sierra Nevada, California

Ricardo Cisneros [1,*], Donald Schweizer [2], Hamed Gharibi [3], Pooya Tavallali [3], David Veloz [1] and Kathleen Navarro [2]

1 Department of Public Health, University of California, Los Angeles, CA 90095, USA; dveloz@ucmerced.edu
2 USDA Forest Service, Pacific Southwest Region, 1600 Tollhouse Road, Clovis, CA 93611, USA; dschweizer@ucmerced.edu (D.S.); kathleen_navarro@firenet.gov (K.N.)
3 Health Sciences Research Institute, University of California, Los Angeles, CA 90095, USA; hgharibi@ucmerced.edu (H.G.); ptavallali@ucmerced.edu (P.T.)
* Correspondence: rcisneros@ucmerced.edu

Abstract: The Rough Fire started on 31 July 2015 from a lightning strike, spread to over 61,000 ha and burned parts of the Sierra and Sequoia National Forests and the Sequoia & Kings Canyon National Parks, in California. Health advisories for smoke were issued in rural areas around the fire and in urban areas of the Central Valley. PM2.5 concentrations in rural and urban areas were used to assess the air quality impacts from the fire. Before the Rough Fire, 24-h PM2.5 concentrations for all sites ranged from 1 µg m^{-3}o 50 μgm^{-3}. During the wildfire, the 24-h PM2.5 concentrations ranged from 2 μgm^{-3} to 545 μgm^{-3}, reaching hazardous levels of the federal Air Quality Index (AQI). The results indicate that the largest PM2.5 smoke impacts occurred at locations closer to and downwind of the fire in mountain communities of the Sierra Nevada, while the smoke impacts were lower in the urban areas.

Keywords: Rough Fire; air quality; California; particulate matter; wildfire

Citation: Cisneros, R.; Schweizer, D.; Gharibi, H.; Tavallali, P.; Veloz, D.; Navarro, K. Air Quality Impacts during the 2015 Rough Fire in Areas Surrounding the Sierra Nevada, California. *Fire* **2021**, *4*, 31. https://doi.org/10.3390/fire4030031

Received: 9 June 2021
Accepted: 19 June 2021
Published: 22 June 2021

1. Introduction

Increased fuels from historic wildland fire suppression and climate change lengthening the fire season are creating a post-suppression era where large high-intensity wildland fires are becoming more common and leading to increased smoke exposure [1–12]. Wildland fires are an important natural process of disturbance, essential to the health of California's fire-prone ecosystems. The past suppression policy and climate change have led to an accumulation of unburned fuel that, when lighted, explodes and causes destructive forest fires [13]. The San Joaquin Valley, in California, is heavily impacted by air pollution from anthropogenic activities with negative consequences to human health [14–19]. In addition to the loss of property and life that can occur from large high-intensity wildland fires, the smoke from these fires, in an already anthropogenically polluted environment, could have devastating impacts on human respiratory health. Previous studies have found associations between exposure to wildfire smoke and self-reported respiratory symptoms [20,21], increases in respiratory emergency department (ED) visits, respiratory physician visits, and respiratory hospitalizations [19,22,23]. Clearly, we need strategies to allow this natural process on protected wilderness areas while minimizing the impacts to human health from the inevitable release of smoke from a large high-intensity wildland fire when suppression fails.

The Rough Fire, an example of a large high-intensity fire that occurs when suppression fails, started on 31 July 2015 from a lightning strike and spread to over 61,000 ha. The Rough Fire burned in parts of the Sierra and Sequoia National Forests and the Sequoia & Kings Canyon National Parks. The fire was contained over 4 months later on approximately November 2nd, and officially declared extinct in December. The majority (90%) of the fire consumption activity was completed by October 2nd. During the fire, there were unstable conditions that, together with severe drought, led to extreme fire conditions that allowed the fire to grow, on occasion, to over 4047 ha per day. When the fire activity was at its maximum, there were over 3700 fire personnel assigned to the fire suppression efforts.

Previous studies [4,24–26] have concluded that the majority of the smoke impacts from southern Sierra Nevada fires occur downwind of the fire and away from the San Joaquin Valley. In the complex terrain of the Sierra Nevada, ground-level wind patterns are driven by the mountainous terrain. The predominant wind patterns in this area are towards the east and north-east, and the smoke transport from these previous studies have followed these patterns particularly at ground level. The Rough Fire burned at a lower elevation than the fires in these studies. When the smoke from these higher elevation fires moved toward the San Joaquin Valley, it typically did not reach the ground probably because the smoke was above the mixing height [4,24].

The Rough Fire burned at a lower elevation, with less timber (primarily oak-brush-chaparral), and closer to the San Joaquin Valley, well within the daytime mixing height. The location of the fire could mean a different smoke exposure pattern than in previously published case studies. Air quality health advisories created by the San Joaquin Valley Air Pollution Control District suggested that the air quality in urban locations of the central San Joaquin Valley was impacted by the Rough Fire. The different circumstance could mean a different outcome than previously reported in past studies in this area and, additionally, be more extreme because of the size and intensity of this fire. Thus, the hypothesis of the present case study is that the Rough Fire impacted the air quality in urban locations in the San Joaquin Valley. In this study, we are using PM2.5 as an indicator for smoke from the Rough Fire, as it has been shown to be an excellent indicator for the exposure to forest fire smoke [4]. The objective of this study is to examine the air quality impacts of PM2.5 from the Rough Fire on the San Joaquin Valley, rural communities throughout the Sierra Nevada, and urban areas surrounding the fire.

2. Materials and Methods

2.1. Study Location Time Frame

The study includes urban locations in the San Joaquin Valley, mountain communities located on the western slope of the Sierra Nevada, and communities in the Owens Valley east of the Sierra Nevada (Figure 1). The selected locations were near the Rough Fire and sites that reported smoke impacts during the fire. The case study period is from May 31st through October 2nd. The Rough Fire started on July 31st and was declared contained on November 2nd 2015. Most of the fire activity decreased by October 2nd.

Daily fire growth information data for the Rough Fire were obtained from the Sierra Wildland Fire Reporting System and National Forest Staff.

2.2. Air Quality Data

Meteorological (Relative Humidity and Temperature) and $PM_{2.5}$ data were compiled from sites in the San Joaquin Valley and in the Sierra Nevada during the Rough Fire. There were 22 site locations used in this assessment (Table 1). The available air quality data were obtained from the California Air Resource Board (CARB) network and from the USDA Forest Service (FS). FS data were obtained using federal equivalency method (FEM) beta-attenuation monitors like those used at the CARB sites. Additional FS data were obtained from temporary environmental beta-attenuation monitors using protocol that provides a sufficient level of agreement with the FEM monitors, to be used comparatively at 24 h (daily) averages [27]. The sites were selected based on air quality data availability and the likelihood of the site being impacted by the fire. Satellite imagery, fire dispersion models (e.g., HYSPLIT, BlueSky), and on-site personal observations of smoke were used to determine smoke impacts. The air quality data provided by federal and state agencies must pass several quality control tests before being released.

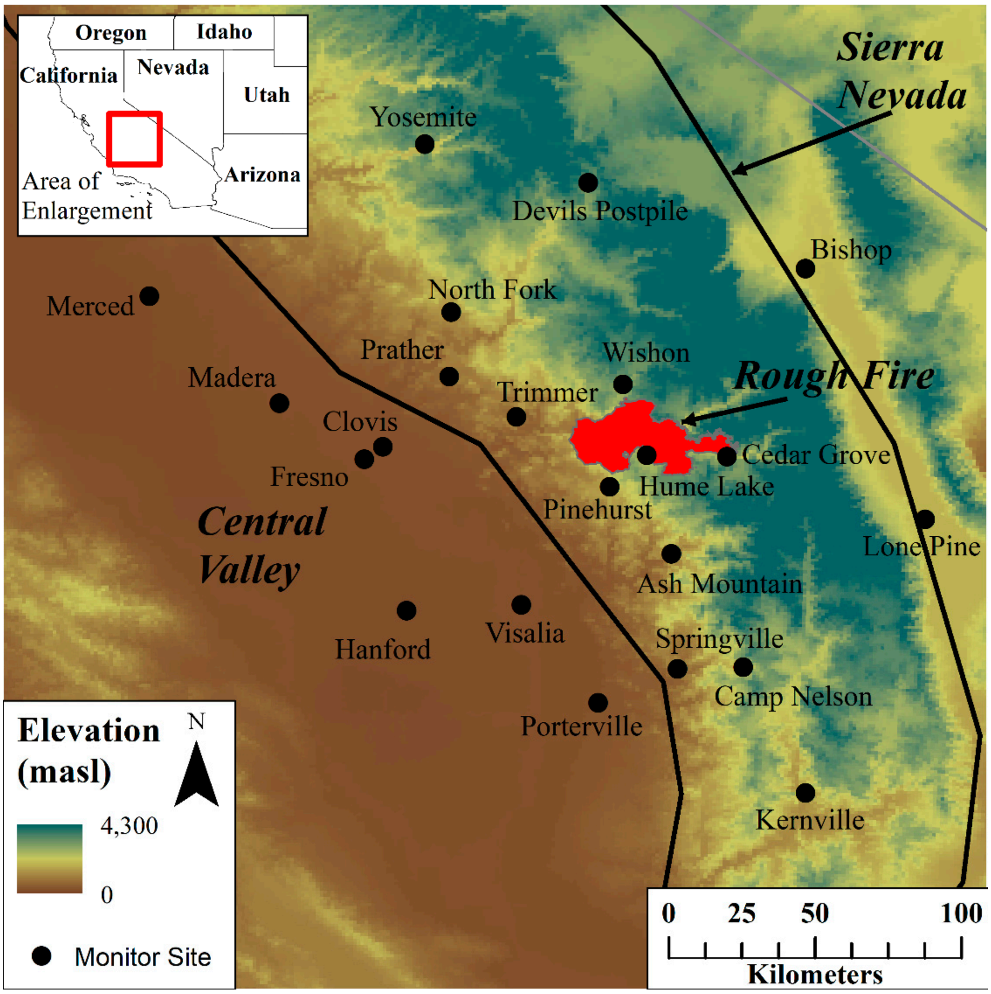

Figure 1. Location of study area and location of air quality monitors.

Table 1. Distribution of 24-hr average $PM_{2.5}$ concentrations before (1 June–30 July 2015) and during (31 July–2 October 2015) the Rough Fire, arranged by region and distance to fire. N is the number of 24-hr average measurements at the location.

Sampling Stations	Pre-Wildfire (1st June to 30th July)							During-Wildfire (31st July to 2nd October)						
	N	Mean (SD)	Min	Percentile 25	Percentile 50	Percentile 75	Max	N	Mean (SD)	Min	Percentile 25	Percentile 50	Percentile 75	Max
Sierra Nevada (North)														
North-Fork	41	**14 (12)**	6	8	11	12	50	64	**19 (14)**	5	8	12	24	55
Yosemite	60	**7 (3)**	3	5	7	9	16	64	**17 (27)**	2	7	9	12	165
Prather	2	11 (0.2)	11	11	11	11	11	64	18 (16)	4	9	11	22	99
Trimmer	0	NA	NA	NA	NA	NA	NA	52	24 (19)	4	11	15	33	89
Sierra Nevada (Central)														
Ash Mountain	58	**9 (3)**	3	6	8	11	16	51	**16 (12)**	3	8	12	19	62
Pinehurst	60	**8 (2)**	4	6	8	10	13	62	**21 (17)**	6	10	11	30	53
Wishon	0	NA	NA	NA	NA	NA	NA	28	70 (54)	9	18	67	114	204
Cedar Grove	0	NA	NA	NA	NA	NA	NA	47	99 (94)	10	19	53	175	381
Hume Lake	0	NA	NA	NA	NA	NA	NA	37	128 (138)	7	22	58	198	545
Sierra Nevada (South)														
Springville	0	NA	NA	NA	NA	NA	NA	20	9 (3)	6	8	9	10	18
Kernville	60	**10 (1)**	7	9	10	11	13	52	**14 (6)**	6	10	13	16	38
Camp Nelson	0	NA	NA	NA	NA	NA	NA	21	12 (5)	5	8	11	15	27

Table 1. *Cont.*

Sampling Stations	Pre-Wildfire (1st June to 30th July)							During-Wildfire (31st July to 2nd October)						
	N	Mean (SD)	Min	Percentile 25	50	75	Max	N	Mean (SD)	Min	Percentile 25	50	75	Max
Sierra Nevada (East)														
Bishop	60	**6 (3)**	1	3	6	8	20	64	**14 (17)**	2	5	9	17	97
Devils Postpile	42	**11 (9)**	4	7	8	11	55	62	**15 (12)**	3	8	12	20	70
Lone Pine	60	**7 (2)**	4	6	7	8	12	64	**9 (5)**	4	6	6	12	27
Central Valley (North)														
Clovis	60	13 (4)	6	10	12	16	21	64	15 (6)	4	11	14	19	34
Fresno	60	**8 (3)**	4	6	8	10	15	60	**11 (5)**	3	7	10	13	25
Madera	60	11 (2)	6	9	11	13	18	64	11 (5)	3	7	11	15	27
Merced	50	9 (3)	4	7	8	11	16	64	12 (6)	4	7	10	15	40
Central Valley (South)														
Hanford	60	**9 (3)**	4	6	8	11	20	64	**12 (6)**	4	7	12	15	32
Porterville	35	**8 (3)**	4	6	9	10	15	60	**13 (6)**	6	9	11	16	37
Visalia	51	**9 (3)**	4	7	8	10	17	60	**14 (10)**	3	8	11	15	58

NA: Not Available data. Bolded mean PM2.5 concentrations indicate statistically significant differences between pre-fire and during-fire concentrations at the 0.05 significance level using the Mann–Whitney Test.

2.3. Air Quality Index

The Air Quality Index (AQI) is a system created by the Environmental Protection Agency for reporting daily air quality. The AQI has 6 categories with thresholds depending on the air pollutant of interest. The 6 categories are good, moderate, unhealthy for sensitive groups, unhealthy, very unhealthy, and hazardous. These categories correspond to EPA breakpoints (0–12, 12.1–35.4, 35.5–55.4, 55.5–150.4, 150.5–250.4, 250.5–500 μgm^{-3}) when determining the AQI for the daily or 24 h $PM_{2.5}$ concentration.

3. Results

Smoke Impacts on $PM_{2.5}$ Concentrations

The air quality impacts during the Rough Fire were localized in the central Sierra Nevada and extended to the northern and eastern Sierra monitoring sites during the study period. Air monitors in the Central Valley were impacted on a few occasions but to a lesser degree (Table 1, Figures 2 and 3).

Table 1 and Figures 2–7 show $PM_{2.5}$ 24-h average concentrations before and during the fire. Without fire emissions, 24-h $PM_{2.5}$ concentrations for all sites ranged from 1 μgm^{-3} to 50 μgm^{-3}. During the wildfire, the 24-h $PM_{2.5}$ concentrations ranged from 2 μgm^{-3} to 545 μgm^{-3}.

The Central Valley (North) sites consisted of Fresno, Clovis, Madera, and Merced (Figure 2). Prior to the fire, Fresno experienced a mean PM2.5 concentration of 8 $\mu g/m^{-3}$ with a maximum of 15 μgm-3; Clovis a PM2.5 average of 13 μgm^{-3} and a maximum of 21 μgm^{-3}; Madera a PM2.5 average of 11μgm^{-3} and a maximum of 18 μgm^{-3}; and Merced a PM2.5 average of 9 μgm^{-3} and a maximum of 16 μgm^{-3}. During the fire, Fresno PM2.5 increased to 11 μgm^{-3} and the PM2.5 maximum to 25 μgm^{-3}; Clovis PM2.5 increased to 15 μgm^{-3} and the maximum to 34 μgm^{-3}; Madera PM2.5 stayed the same and the maximum increased to 27 μgm^{-3}; and Merced's mean PM2.5 concentration increased to 12 μgm^{-3} with a maximum of 40 μgm^{-3}. During the fire, PM2.5 concentrations reached an AQI of moderate and unhealthy for sensitive groups on one occasion in Merced. Fresno is the only location that experienced statistically significant differences between the pre-fire and the during-fire PM2.5 concentrations (Table 1).

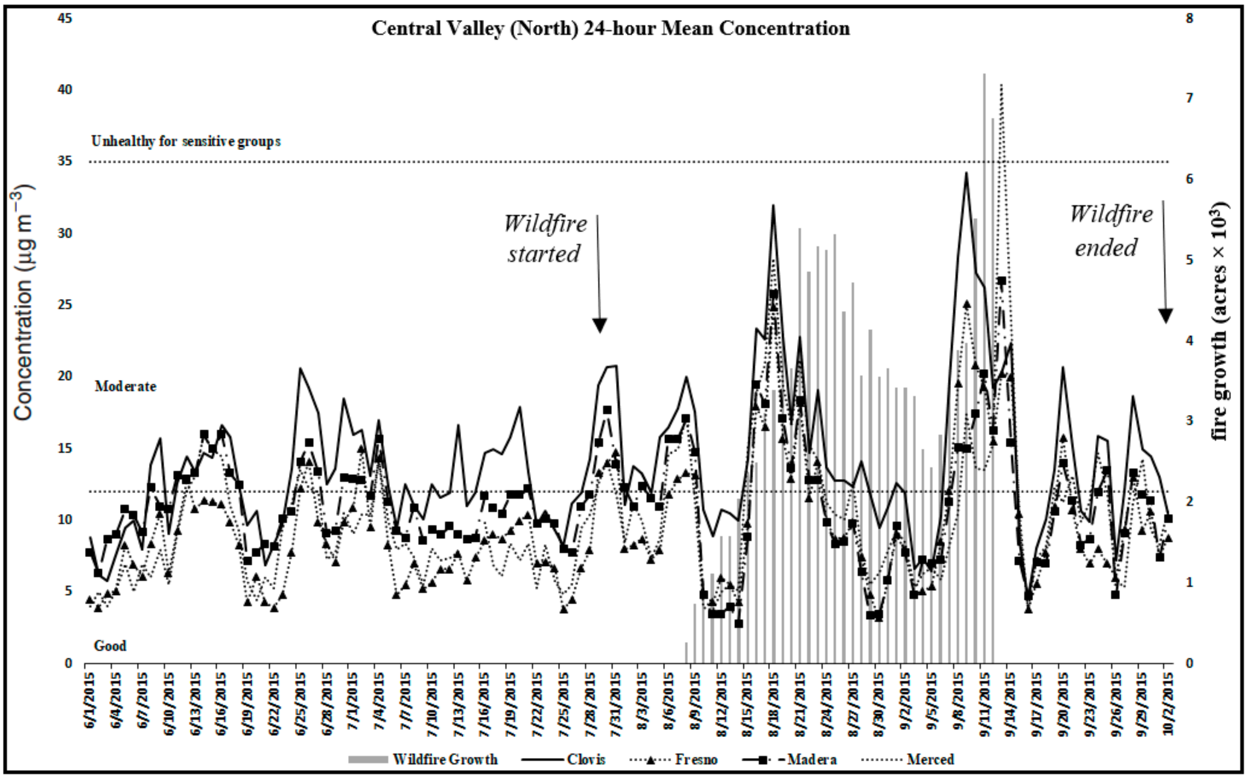

Figure 2. 24-Hour $PM_{2.5}$ concentrations with Air Quality Index (AQI) breakpoints for monitoring sites. Note: no daily fire growth data were available at the beginning of the fire.

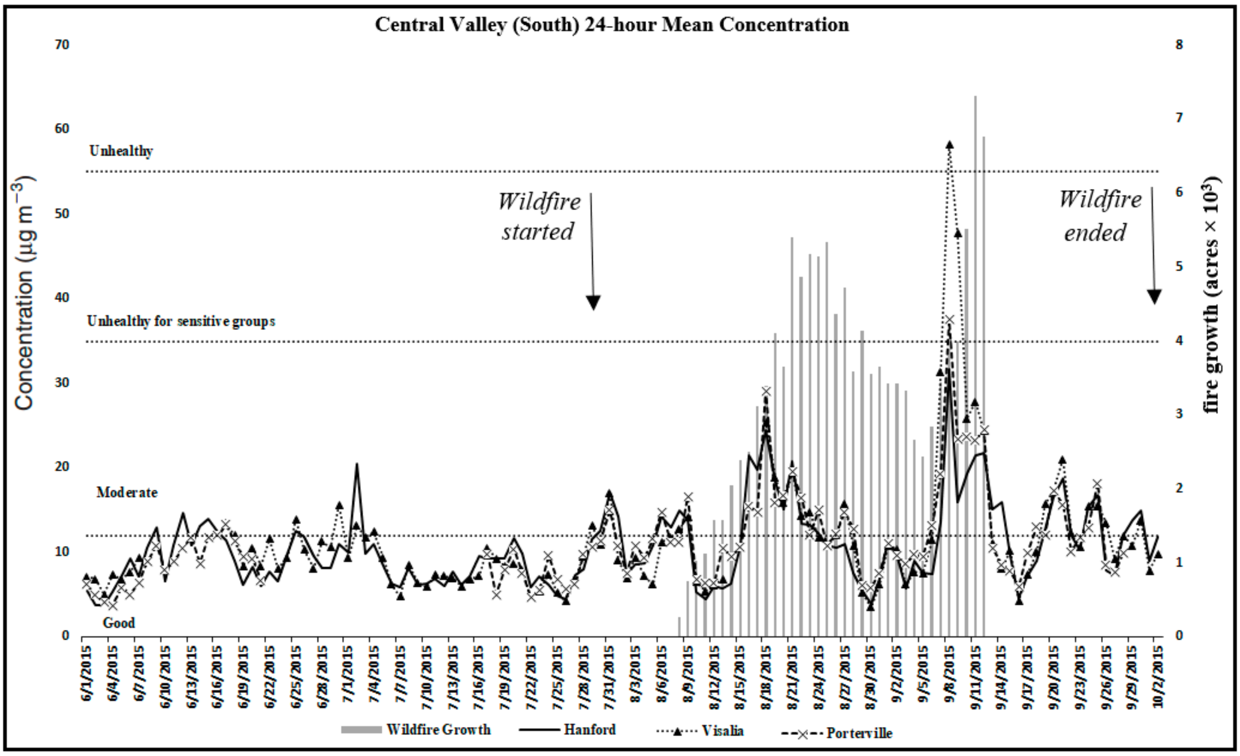

Figure 3. 24-Hour $PM_{2.5}$ concentrations with Air Quality Index (AQI) breakpoints for monitoring sites. Note: no daily fire growth data were available at the beginning of the fire.

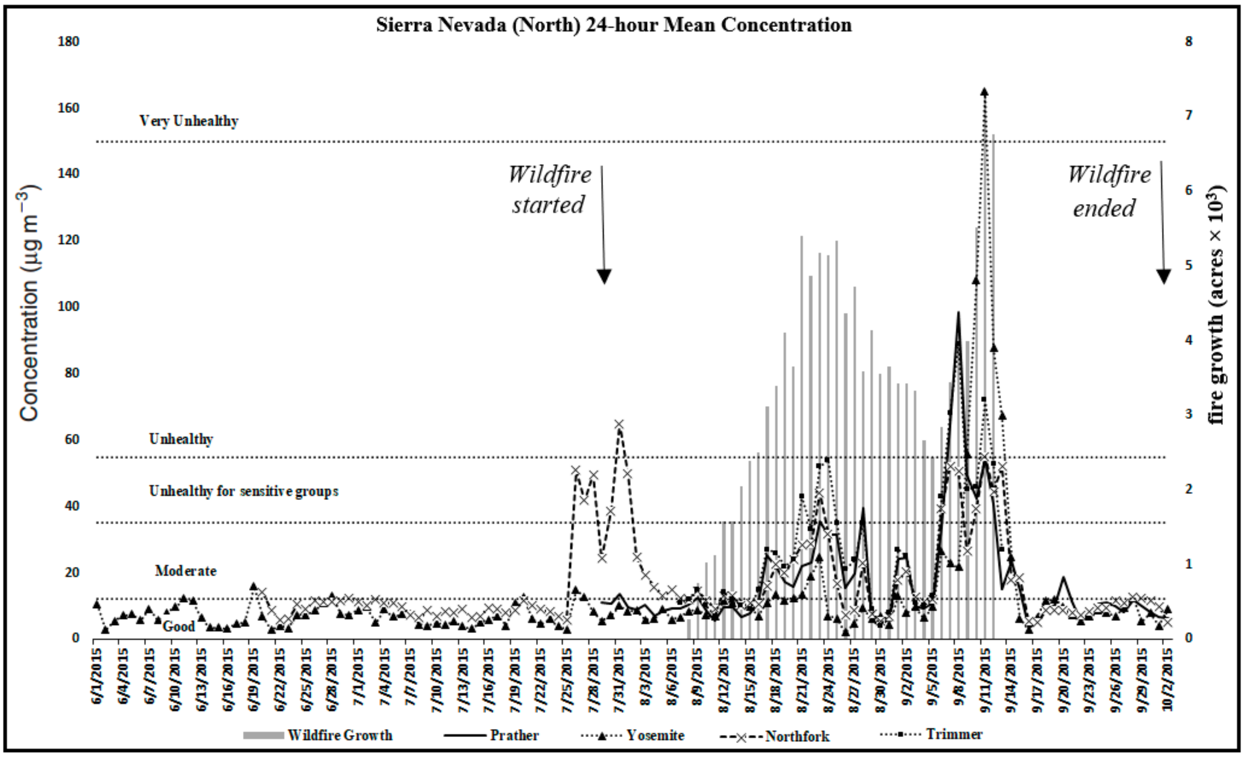

Figure 4. 24-Hour $PM_{2.5}$ concentrations with Air Quality Index (AQI) breakpoints for monitoring sites. Note: no daily fire growth data were available at the beginning of the fire.

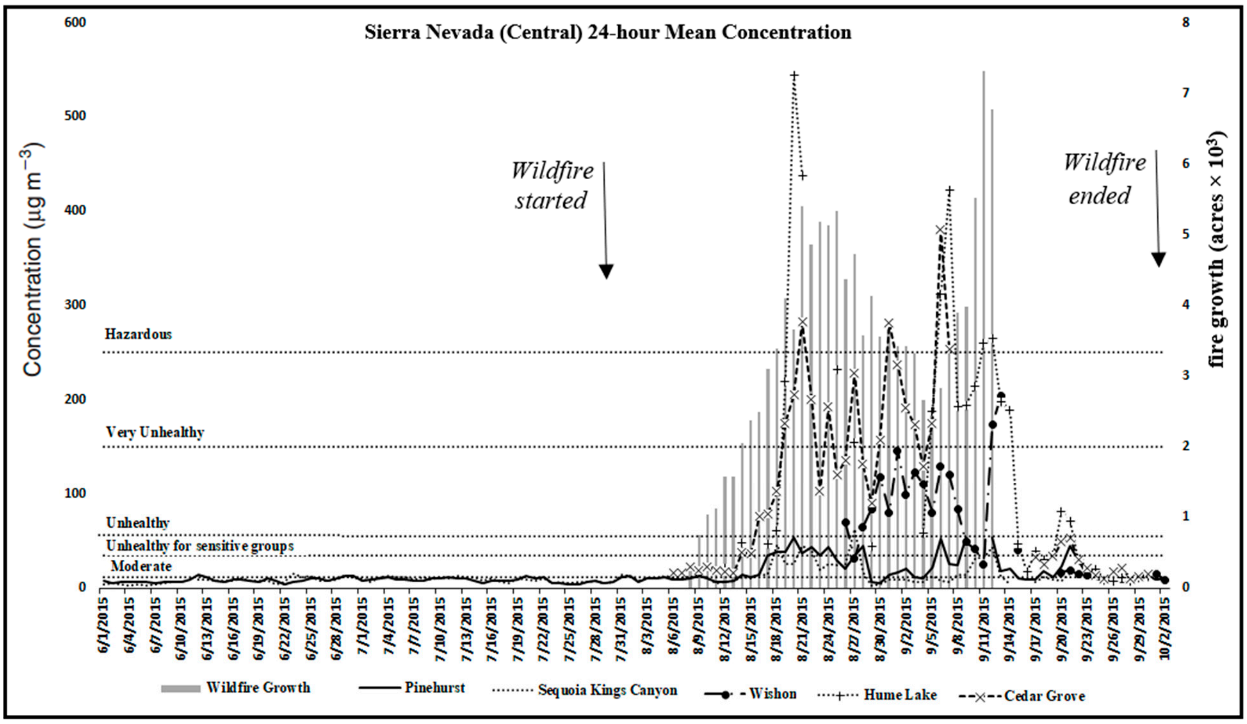

Figure 5. 24-Hour $PM_{2.5}$ concentrations with Air Quality Index (AQI) breakpoints for monitoring sites. Note: no daily fire growth data were available at the beginning of the fire.

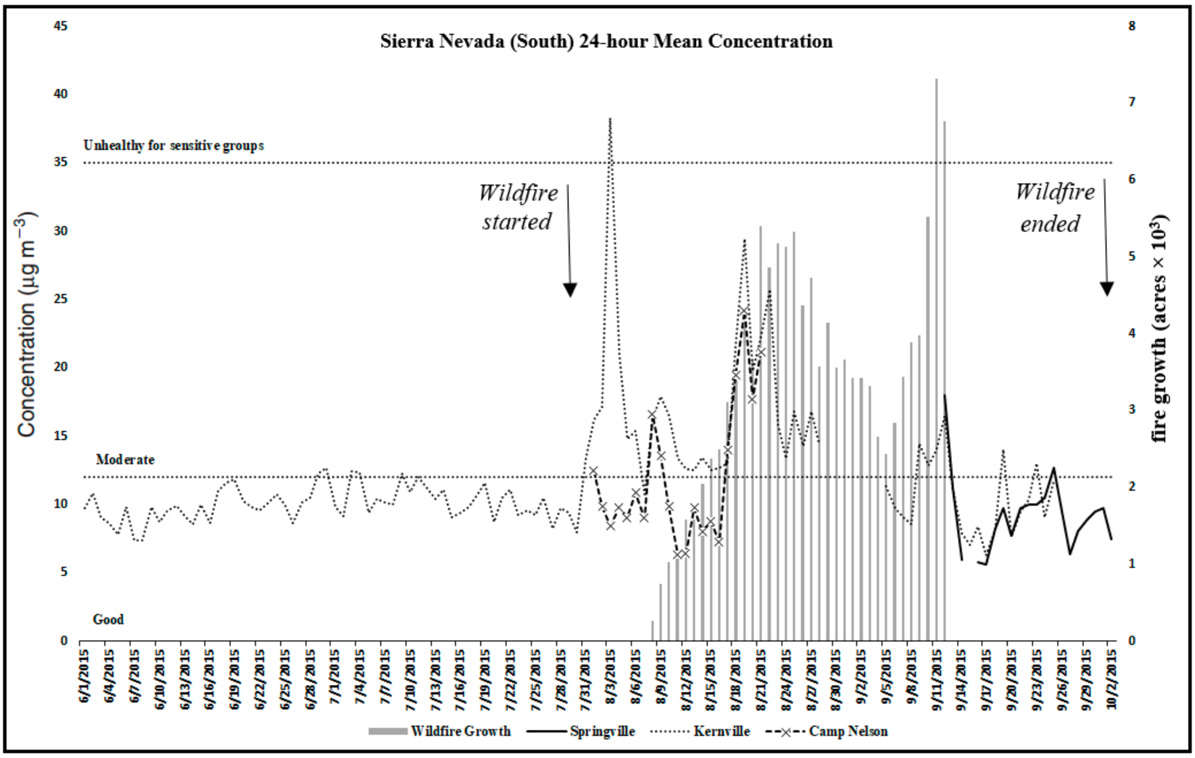

Figure 6. 24-Hour $PM_{2.5}$ concentrations with Air Quality Index (AQI) breakpoints for monitoring sites. Note: no daily fire growth data were available at the beginning of the fire.

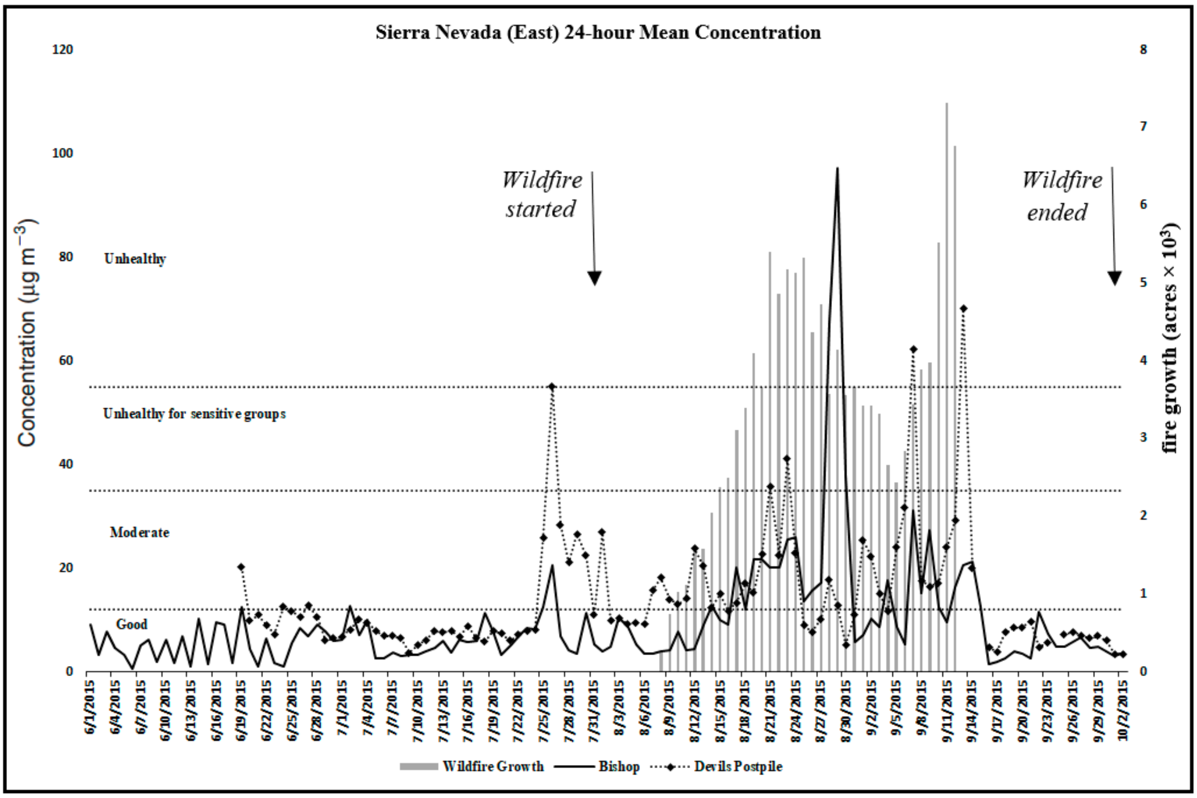

Figure 7. 24-Hour $PM_{2.5}$ concentrations with Air Quality Index (AQI) breakpoints for monitoring sites. Note: no daily fire growth data were available at the beginning of the fire.

The Central Valley (South) sites consisted of Hanford, Porterville and Visalia (Figure 3). Hanford experienced a mean PM2.5 of 9 μgm^{-3} and a PM2.5 maximum of 20 μgm^{-3} before the fire started. During the fire, Hanford's mean PM2.5 increased to 12 μgm^{-3} and the maximum to 32 μgm^{-3}. Before the fire, Porterville had a mean PM2.5 of 8 μgm^{-3} and a maximum of 15 μgm^{-3}; during the fire, the mean PM2.5 increased to 13 μgm^{-3} and the maximum increased to 37 μgm^{-3}. Before the fire, Visalia had a mean of 9 μgm^{-3} and a maximum of 17 μgm^{-3}. During the fire, the mean PM2.5 in Visalia increased to 14 μgm^{-3} and the maximum to 58 μgm^{-3}. The PM2.5 concentrations experienced at all these locations, before and during the fire, were statistically significant, indicating a PM2.5 impact from the Rough Fire. These locations spiked during August 12th–21st and September 7th–14th (Figures S1 and S2). During the latter time, the PM2.5 concentrations reached an AQI of very unhealthy at Visalia.

Prior to the fire, in the Sierra Nevada (North), the mean PM2.5 concentrations ranged between 3 and 50 μgm^{-3}. However, when the fire started, the PM2.5 concentration range increased to 2–165 μgm^{-3}. The majority of the sites experienced their first increase in PM2.5 from August 17th to August 31st (Figure 4). AQIs during this time were in the moderate and unhealthy to sensitive groups for PM2.5. The highest levels of PM2.5 occurred during a second spike, which happened from September 4th to September 14th. During this period, the levels reached AQIs of unhealthy and unhealthy for sensitive groups. The concentrations started to decrease after September 20th, and the AQI dropped to the good category after October 20th.

For the Sierra Nevada (Central) sites, the only locations that were monitoring the air quality prior to the fire were Pinehurst and Ash Mountain at Sequoia National Park (Figure 5). For the remaining central Sierra Nevada sites, temporary air quality monitoring equipment was installed upon the onset of the fire. Comparing the data available prior to the fire in the Central Sierra Nevada sites, the mean PM2.5 concentration was 8 μgm^{-3} in Pinehurst and 9 μgm^{-3} in Ash Mountain. During the fire, the mean PM2.5 increased to 21 μgm^{-3} in Pinehurst and to 16 μgm^{-3} at Ash Mountain. During the fire, the mean PM2.5 concentrations at all of the Sierra Nevada (Central) sites ranged from 16–128 μgm^{-3}, with 24 h maximums ranging from 53 μgm^{-3} to 545 μgm^{-3}. PM2.5 concentrations increased on August 6th and remained high until September 21st; during this period, the daily AQI was often in the unhealthy category and reached the very unhealthy and hazardous levels. The PM2.5 AQI at all sites decreased to the good category after October 15th.

Data before the fire started in the Sierra Nevada (South) sites were only available for Kernville (Figure 6). At Kernville, prior to the fire, the mean PM2.5 concentration was 10 μgm^{-3} and the mean of the 24 h maximum was 13 μgm^{-3}. During the fire, the mean PM2.5 concentration increased to 14 μgm^{-3}, with the mean 24-h maximum increasing to 38 μgm^{-3}. During the fire, at all sites, the mean PM2.5 concentrations ranged from 9–14 μgm^{-3}. The PM2.5 concentrations started to increase on August 3rd, with highs on August 20th. During the fire, the PM2.5 AQIs in these locations stayed in the good and moderate categories. These sites were the least impacted Sierra Nevada air monitoring sites during the Rough Fire.

Prior to the fire, the mean PM2.5 concentrations in the Sierra Nevada (East) sites ranged from 6 to 11 μgm^{-3} (Figure 7). During the fire, the mean PM2.5 concentrations range increased to 9–15 μgm^{-3}. Bishop experienced a mean PM2.5 of 6 μgm^{-3} and a maximum of 20 μgm^{-3} before the fire; and during the fire a mean of 14 μgm^{-3} and maximum of 97 μgm^{-3}. Devils Postpile had a mean PM2.5 of 12 μgm^{-3} and maximum of 55 μgm^{-3} before the fire started. During the fire, Devils Postpile's mean PM2.5 increased to 15 μgm^{-3} and the maximum increased to 70 μgm^{-3}. Lone Pine experienced a mean PM2.5 24-h concentration of 7 μgm^{-3} and a maximum of 12 μgm^{-3} before the fire began. During the fire, Lone Pine's PM2.5 concentration increased to 9 μgm^{-3} and the maximum increased to 27 μgm^{-3}. The PM2.5 concentrations at these sites reached an AQI of unhealthy on three occasions and unhealthy for sensitive groups on five occasions. The air quality improved to an AQI of good at these locations after September 20th.

4. Discussion

PM2.5 was seen to increase at many of the sites during the Rough Fire and in some areas reached hazardous air quality levels. The hypothesis of the present study was that the air quality of urban locations in the San Joaquin Valley was impacted by the Rough Fire because of the region's lower elevation, causing the fire to burn nearer to urban areas. The findings suggest that the smoke from the fire impacted PM2.5 at urban locations in the San Joaquin Valley. These smoke impacts occurred on two occasions and caused AQI to reach an unhealthy level only in Visalia. Previous studies of wildfires on federal lands higher up in the Sierra Nevada have not found significant impacts to PM2.5 in the San Joaquin Valley [24–26]. The Rough Fire was different from these other fires because it primarily burned at a lower elevation and nearer the San Joaquin Valley, and the increased smoke production from this high-intensity wildfire was likely the cause of the increased PM2.5 at the lower elevation sites [10,28].

Similarly to the findings of previous studies, the majority of the impacts occurred at the higher southern Sierra Nevada sites, downwind of dominant transport patterns and east of the San Joaquin Valley. The PM2.5 concentrations observed in the mountain locations were 10 times greater than the ones observed in the San Joaquin Valley, reaching AQIs of hazardous (Figures 2–7). The results of this study indicate that even for this high-intensity forest fire occurring at a lower elevation in the Sierra Nevada, the largest smoke impacts are observed at the more rural mountain communities closer to and downwind of the fire.

4.1. Case-Crossover Analysis

The present study conducted an epidemiological analysis (case-crossover analysis) to understand if the exposure to PM2.5 concentrations before and during the fire would have an impact on the health (respiratory diseases) of residents in urban locations. This analysis was only conducted for the San Joaquin Valley residents. The association was only found for PM2.5 exposure and asthma ED visits before the fire started [OR: 1.195 (95% CI: 1.001, 1.427)]. During the fire there was a decrease in asthma ED visits (OR: 0.327 (95% CI: 0.177–0.604) for every 10 $\mu g/m^3$ increase in PM2.5. No other associations between PM2.5 and ED visits due to the other respiratory diseases were found for the during-wildfire and pre-wildfire periods. A possible explanation for the lack of association, even with the increase of PM2.5 during the fire, is the robust smoke communication at the local, state, and federal levels. News releases and media warnings for residents on the risk of smoke exposure were widespread, in addition to the smoke-educated public in this smoke-prone area. Smoke alerts and health advisories put out by air regulators and fire managers informed residents and potentially allowed them to limit their personal exposure to PM2.5 by spending more time indoors or avoiding outdoor activities during the highest hours of ambient PM2.5. The purpose of this paper is not to conduct a health assessment. A more focused study is needed to investigate and confirm these findings. Another limitation of this assessment was the fact that the mountain locations that experienced the highest impact to PM2.5 from smoke did not have enough cases to be included in the epidemiological analysis because of the combination of lower population densities in these areas and the relatively short duration of smoke exposure. Future studies using more fires with known impacts from smoke in these less densely populated rural areas are needed to understand if there are effects at these locations during periods of wildland fire smoke.

4.2. Smoke Management Implications

Wildland fire is inevitable in the fire prone ecosystems of California. Smoke managers should prioritize having smoke-educated and prepared communities, where individuals are encouraged to have air filters for use during a wildfire and can easily access timely predictive information on local smoke conditions during the incident.

Large high-intensity wildfires appear to be the new normal in California in these lower elevation areas nearer urban areas. The smoke from these fires is of great concern to the foothill communities. Additionally, foothill communities experience smoke from fires that are more typical of the historic normal and may become averse to all wildland fire smoke. Education and the communication of the need for some smoke exposure to limit large smoke events is essential for an effective smoke management in this area.

5. Conclusions

Smoke from the Rough Fire, a lower-elevation, large, and high-intensity wildfire, reached the San Joaquin Valley sites, impacting PM2.5 on two occasions. PM2.5 increased at many of the sites during the wildfire, especially when the fire was consuming large areas. The PM2.5 levels in the Sierra Nevada locations reached a hazardous AQI. Similarly to previous studies, the largest smoke impacts were observed at the more rural mountain communities closer to and downwind of the fire. These findings suggest smoke managers should expect large high-intensity wildland fires that occur when suppression fails, particularly those occurring at lower elevations, to have an increased potential of exposure for the higher concentrated populations in areas of the San Joaquin Valley. Smoke management policies should adjust their limited resources to focus on the communication to rural areas where the largest smoke impacts occur, along with educating the general public on the importance of routinely allowing fire within the historic size and intensity levels in this fire-prone ecosystem and the seemingly paradoxical benefits of reduced smoke exposure over time through this approach. More research is needed to see if there is an elevation threshold for smoke impacts to the urban areas from fires with a size and intensity that are more typical of the historic normal, particularly in the federally protected wilderness, that could help air and land managers to better assess the risk to air quality from smoke.

Furthermore, the increase in PM2.5 during the fire did not create a subsequent impact to ED visits for asthma and other respiratory diseases in the Central Valley. This needs to be further studied, to confirm the findings, and expanded, to include rural communities more heavily impacted by smoke. The role smoke alerts and health advisories played in informing residents and allowing them to avoid outdoor activities during the times of the highest smoke levels needs a more thorough assessment. These air quality advisories during an event, along with pre-fire season planning for residential air filter use during a smoke event, are potentially vital tools in protecting human health from wildland fire smoke, particularly during the large high-intensity fires.

Supplementary Materials: The followings are available online at https://www.mdpi.com/article/10.3390/fire4030031/s1.

Author Contributions: Conceptualization, writing—review & editing R.C. and D.S.; formal analysis, software, and data curation, H.G. and P.T.; review & editing, D.V. and K.N. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data is available upon request.

Acknowledgments: We would like to thank those who helped us in conducting this project.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Bae, M.S.; Skiles, M.J.; Lai, A.M.; Olson, M.R.; Foy, B.D.; Schauer, J.J. Assessment of forest fire impacts on carbonaceous aerosols using complementary molecular marker receptor models at two urban locations in California's San Joaquin Valley. *Environ. Pollut.* **2019**, *246*, 274–283. [CrossRef]
2. Burley, J.D.; Bytnerowicz, A.; Buhler, M.; Zielinska, B.; Schweizer, D.; Cisneros, R.; Schilling, S.; Varela, J.C.; McDaniel, M.; Horn, M.; et al. Air quality at devils postpile national monument, sierra nevada mountains, california, USA. *Aerosol Air Qual. Res.* **2016**, *16*, 2315–2332. [CrossRef]

3. Bytnerowicz, A.; Burley, J.D.; Cisneros, R.; Preisler, H.K.; Schilling, S.; Schweizer, D.; Ray, J.; Dulen, D.; Beck, C.; Auble, B. Surface ozone at the Devils Postpile National Monument receptor site during low and high wildland fire years. *Atmos. Environ.* **2013**, *65*, 129–141. [CrossRef]
4. Cisneros, R.; Schweizer, D. The efficacy of news releases, news reports, and public nuisance complaints for determining smoke impacts to air quality from wildland fire. *Air Qual. Atmos. Health* **2018**, *11*, 423–429. [CrossRef]
5. Cisneros, R.; Schweizer, D.; Tarnay, L.; Navarro, K.; Veloz, D.; Procter, C.T. Climate Change, Forest Fires, and Health in California. In *Climate Change and Air Pollution*; Akhtar, R., Palagiano, C., Eds.; Springer Climate: Cham, Switzerland, 2017.
6. Li, Y.; Tong, D.Q.; Ngan, F.; Cohen, M.D.; Stein, A.F.; Kondragunta, S.; Zhang, X.; Ichoku, C.; Hyer, E.J.; Kahn, R.A. Ensemble PM2. 5 Forecasting During the 2018 Camp Fire Event Using the HYSPLIT Transport and Dispersion Model. *J. Geophys. Res. Atmos. Atmos.* **2020**, *125*. [CrossRef]
7. Navarro, K.M.; Cisneros, R.; Schweizer, D.; Chowdhary, P.; Noth, E.M.; Balmes, J.R.; Hammond, S.K. Incident command post exposure to polycyclic aromatic hydrocarbons and particulate matter during a wildfire. *J. Occup. Environ. Hyg.* **2019**, *16*, 735–744. [CrossRef] [PubMed]
8. Preisler, H.K.; Schweizer, D.; Cisneros, R.; Procter, T.; Ruminski, M.; Tarnay, L. A statistical model for determining impact of wildland fires on Particulate Matter (PM2. 5) in Central California aided by satellite imagery of smoke. *Environ. Pollut.* **2015**, *205*, 340–349. [CrossRef]
9. Rooney, B.; Wang, Y.; Jiang, J.H.; Zhao, B.; Zeng, Z.; Seinfeld, J.H. Air quality impact of the Northern California Camp Fire of November 2018. *Atmos. Chem. Phys.* **2020**, 14597–14616. [CrossRef]
10. Schweizer, D.; Cisneros, R.; Navarro, K. The effectiveness of adding fire for air quality benefits challenged: A case study of increased fine particulate matter from wilderness fire smoke with more active fire management. *For. Ecol. Manag.* **2020**, *458*, 117761. [CrossRef]
11. Schweizer, D.; Preisler, H.K.; Cisneros, R. Assessing relative differences in smoke exposure from prescribed, managed, and full suppression wildland fire. *Air Qual. Atmos. Health* **2019**, *12*, 87–95. [CrossRef]
12. Schweizer, D.; Cisneros, R.; Buhler, M. Coarse and fine particulate matter components of wildland fire smoke at Devils Postpile National Monument, California, USA. *Aerosol Air Qual. Res.* **2019**, *19*, 1463–1470. [CrossRef]
13. Schweizer, D.; Cisneros, R. Forest fire policy: Change conventional thinking of smoke management to prioritize long-term air quality and public health. *Air Qual. Atmos. Health* **2017**, *10*, 33. [CrossRef]
14. Cisneros, R.; Gharibi, H.; Entwistle, M.R.; Tavallali, P.; Singhal, M.; Schweizer, D. Nitrogen dioxide and asthma emergency department visits in California, USA during cold season (November to February) of 2005 to 2015: A time-stratified case-crossover analysis. *Sci. Total Environ.* **2021**, *754*, 142089. [CrossRef] [PubMed]
15. Entwistle, M.R.; Gharibi, H.; Tavallali, P.; Cisneros, R.; Schweizer, D.; Brown, P.; Ha, S. Ozone pollution and asthma emergency department visits in Fresno, CA, USA, during the warm season (June–September) of the years 2005 to 2015: A time-stratified case-crossover analysis. *Air Qual. Atmos. Health* **2019**, *12*, 661–672. [CrossRef]
16. Gharibi, H.; Entwistle, M.R.; Ha, S.; Gonzalez, M.; Brown, P.; Schweizer, D.; Cisneros, R. Ozone pollution and asthma emergency department visits in the Central Valley, California, USA, during June to September of 2015: A time stratified case-crossover analysis. *J. Asthma* **2018**, *9*, 1–12. [CrossRef] [PubMed]
17. Gharibi, H.; Entwistle, M.R.; Schweizer, D.; Tavallali, P.; Cisneros, R. The association between 1,3-dichloropropene and asthma emergency department visits in California, USA from 2005 to 2011: A bidirectional-symmetric case crossover study. *J. Asthma* **2019**, *2*, 1–9. [CrossRef] [PubMed]
18. Gharibi, H.; Entwistle, M.R.; Schweizer, D.; Tavallali, P.; Thao, C.; Cisneros, R. Methyl-Bromide and asthma emergency department visits in California, USA from 2005 to 2011. *J. Asthma* **2019**, *31*, 1–10. [CrossRef] [PubMed]
19. Lee, T.S.; Falter, K.; Meyer, P.; Mott, J.; Gwynn, C. Risk factors associated with clinic visits during the 1999 forest fires near the Hoopa Valley Indian Reservation, California, USA. *Int. J. Environ. Health Res.* **2009**, *19*, 315–327. [CrossRef]
20. Kunzli, N.; Avol, E.; Wu, J.; Gauderman, W.J.; Rappaport, E.; Millstein, J.; Bennion, J.; McConnell, R.; Gilliland, F.D.; Berhane, K.; et al. Health Effects of the 2003 Southern California Wildfires on Children. *Am. J. Respir. Crit. Care Med.* **2006**, *174*, 1221–1228. [CrossRef]
21. Mirabelli, M.C.; Kunli, N.; Avol, E.; Gilliland, F.D.; Gauderman, J.W.; McConnel, R.; Peters, J.M. Respiratory symptoms following wildfire smoke exposure: Airway size as a susceptibility factor. *Epidemiology* **2009**, *20*, 451–459. [CrossRef]
22. Delfino, R.J.; Brummel, S.; Wu, J.; Stern, H.; Ostro, B.; Lipsett, M.; Winer, A.; Street, D.H.; Zhang, L.; Tjoa, T.; et al. The relationship of respiratory and cardiovascular hospital admissions to the southern California wildfires of 2003. *J. Occup. Environ. Med.* **2009**, *66*, 189–197. [CrossRef] [PubMed]
23. Rappold, A.G.; Stone, S.L.; Cascio, W.E.; Neas, L.M.; Kilaru, V.J.; Carraway, M.S.; Szykman, J.J.; Isling, A.; Cleve, W.E.; Meredith, J.T.; et al. Peat bog wildfire smoke exposure in rural North Carolina is associated with cardiopulmonary emergency department visits assessed through syndromic surveillance. *Environ. Health Perspect.* **2011**, *119*, 1415–1420. [CrossRef] [PubMed]
24. Navarro, K.M.; Cisneros, R.; O'Neill, S.M.; Schweizer, D.; Larkin, N.K.; Balmes, J.R. Air-Quality Impacts and Intake Fraction of PM2.5 during the 2013 Rim Megafire. *Environ. Sci. Technol.* **2016**, *50*, 11965–11973. [CrossRef] [PubMed]

25. Schweizer, D.; Cisneros, R. Wildland fire management and air quality in the southern Sierra Nevada: Using the Lion Fire as a case study with a multi-year perspective on PM2.5 impacts and fire policy. *J. Environ. Manag.* **2014**, *144*, 265–278. [CrossRef] [PubMed]
26. Cisneros, R.; Schweizer, D.; Zhong, S.; Hammond, K.; Perez, M.A.; Guo, Q.; Traina, S.; Bytnerowicz, A.; Bennett, D. Analysing the effects of the 2002 McNally fire on air quality in the San Joaquin Valley and southern Sierra Nevada, California. *Int. J. Wildland Fire* **2012**, *21*, 1065–1075. [CrossRef]
27. Schweizer, D.; Cisneros, R.; Shaw, G. A comparative analysis of temporary and permanent beta attenuation monitors: The importance of understanding data and equipment limitations when creating PM2.5 air quality health advisories. *Atmos. Pollut. Res.* **2016**, *7*, 865–875. [CrossRef]
28. Schweizer, D.; Cisneros, R.; Traina, S.; Ghezzehei, T.A.; Shaw, G. Using National Ambient Air Quality Standards for fine particulate matter to assess regional wildland fire smoke and air quality management. *J. Environ. Manag.* **2017**, *201*, 345–356. [CrossRef]