Environmental Disasters and Health at Birth: Evidence from Wildfires in Spain.

Risto Conte Keivabu* & Maria Rubio-Cabañez†

Extended abstract prepared for "IPC 2025"

Abstract

Climate change is increasing fire-conducive weather conditions worldwide determining increased risks of wildfire exposure. Despite growing research on the impacts of wildfires on health outcomes, studies on birth outcomes, sociodemographic heterogeneities and for the European context are lacking. This study investigates the impact of wildfires on birth outcomes in Spain, a country suffering several public health threats due to climate change. We use Spanish administrative data comprising about 3.5 million live births from 2008 to 2021. We connect this data with precise measures of wildfire exposure based on data provided by the European Forest Fires Information System. We observe a decrease in birth weight and increase in low birth weight with exposure to a wildfire during gestation and the effect to be concentrated in the third trimester. Exploring heterogeneities, we do not observe major differences between sociodemographic groups. The results highlight the need for public health interventions and policies aimed at mitigating the health impacts of wildfires on vulnerable populations, particularly pregnant women.

Key Words: wildfires, Spain, birth outcomes, health, sociodemographic disparities.

* Max Planck Institute for Demographic Research. **Email:** contekeivabu@demogr.mpg.de
† Universidad Carlos III de Madrid. **Email:** marubioc@eco.uc3m.es

Introduction

Climate change is a growing threat for public health, due to the increase in weather conditions conducive to extreme weather events. In this context, wildfires are a growing environmental and public health concern globally (Gould et al., 2024; Jones et al., 2022), that could reverse recent health gains achieved through improvements in air quality (Burke et al., 2023). Wildfires have been shown to determine several negative health impacts on the exposed population (Gould et al., 2024; Reid et al., 2016a) such as mortality (Qiu et al., 2024), hospitalizations (Delfino et al., 2009; Malig et al., 2021), cardiovascular (Jones et al., 2020) and respiratory disease hospitalizations (Reid et al., 2016b) or on non-health outcomes such as test scores (Wen and Burke, 2022). Importantly, air pollution attributable to wildfires appears more detrimental for human health than from other sources (Aguilera et al., 2021). While the short-term effects of wildfires on mortality and morbidity at adult ages is well-documented, evidence on prenatal exposure to wildfire smoke and the implications for fetal development and birth outcomes is scarce and inconclusive (Reid, 2022; Xu et al., 2020).

Adverse birth outcomes such as preterm birth and low birth weight are critical public health concerns that can be affected by wildfires (Almond and Currie, 2011), potentially determining long-term health issues and increased healthcare costs (Foo et al., 2023). Three literature reviews described research on wildfires and birth outcomes denoting limited research on the topic, but an increase in studies in the recent years. In fact, the first review reported findings on 8 studies (Amjad et al., 2021), the second on 13 studies (Evans et al., 2022) and the latest on 31 (Foo et al., 2023). Several birth outcomes show to be negatively affected by wildfires and the mechanisms determining this link are two. On the one hand, increased maternal stress determined by a wildfire during gestation is likely to affect fetal development, as observed with other natural and human disasters (Cozzani, Triventi, and Bernardi, 2022; Torche, 2011). On the other hand, the impact of elevated levels of air pollution, most notably PM2.5 (Evans et al., 2022) is deemed to increase negative birth outcomes as observed in a large existing literature exploring the impacts of air pollution on health at birth (Fussell et al., 2024; Nyadanu et al., 2022).

Sociodemographic heterogeneity in the impact of natural disasters on health outcomes is expected due to disparities in exposure, sensitivity and access to support (Hajat and Kosatky,

2010). Considering wildfires, individuals could vary in their likelihood of being exposed to wildfires, as low socioeconomic status individuals could be more likely to live close to areas prone to be affected by wildfires (Leary et al., 2022; Modaresi Rad et al., 2023). Also, behavioral responses to wildfires could vary determining an SES gradient in the reduction in the exposure to air pollution related to wildfires as observed in a recent study (Burke et al., 2022). Equal exposure to a wildfire could still determine SES inequalities due to differences in the stress determined by the wildfire or in the negative impact of air pollution on mother's health due to existing health conditions. Access to health care and support especially if individuals are required to relocate due to the wildfire could become even more challenging for low SES mothers.

In this study, we explore the impact of wildfires on birth outcomes in Spain. Spain is expected to experience some of the most detrimental impacts of climate change on public health in the European area, mostly due to increased exposure to heatwaves (Forzieri et al., 2017). Considering wildfires, the frequency and total area burnt by wildfires has decreased in recent years (Turco et al., 2016), as observed in other areas of the world (Jones et al., 2022), but there is evidence of an increase in the intensity of each fire. Critically, policies implemented to contain wildfires have been effective in diminishing the total area burnt by wildfires, but the increase in fire-inducive weather conditions pose a challenge for future years (Brotons et al., 2013; Ruffault and Mouillot, 2015; Turco et al., 2016).

We contribute to the existing literature on the impact of wildfires on birth outcomes in three main ways. First, to the best of our knowledge, we provide first evidence on the impact of wildfires on birth outcomes in Europe and more precisely in Spain. Existing literature is mostly concentrated on the United States, Australia, Brazil (Amjad et al., 2021; Evans et al., 2022; Foo et al., 2023; Zheng, 2023), but a lack of studies appears for Europe and in particular the Mediterranean are that is expected to highly suffer from climate change impacts on public health (Forzieri et al., 2017; Hauer and Santos-Lozada, 2021). Secondly, we provide evidence on birth outcomes for which there is still scarce evidence (Evans et al., 2022). Thirdly, we explore sociodemographic disparities in the impact of wildfires on birth outcomes for which existing studies have shown contrasting results. For instance, a study for California observed an increase in low birth weight due to wildfire exposure on the second trimester only in low educated mothers, but an increase with exposure in the third trimester for highly educated mothers (Rauscher and Cao, 2024). Conversely, another study on California using a different

measure of exposure to wildfires and period of analysis did not observe disparities by race or income in the impact of air pollution related to wildfires (Heft-Neal et al., 2022).

Data and Methods

Birth Outcomes Data

In this study, we use data on birth outcomes provided by the Spanish Institute of Statistics (INE). This comprehensive dataset contains information on all births in Spain from 2008 to 2021, organized by month and municipality. Spain has 8,131 municipalities, but data on the municipality of residence of the mother is only available for mothers in municipalities with more than 10,000 inhabitants. Therefore, the dataset covers births from 768 municipalities, accounting for 85% of births during the study period. It contains information on the outcome variables used in this study: Birth weight and low birth weight, two widely used measures in neonatal health research (e.g. Almond and Currie, 2011; Conley and Bennett, 2000; Gluckman and Hanson, 2006) It also provides information on various characteristics of the newborns and their parents. In particular, we use information on the newborns' sex and the mothers' age, education, marital status, nationality, birth order and whether it was a singleton birth.

Mothers' education is categorized into three groups: low (up to first level of secondary education), medium (beyond first level of secondary education but less than a bachelor's degree) and high (at least a bachelor's degree). Marital status is either married (including civil partnership) or unmarried. Nationality is categorized as native or foreign. The birth order variable is coded as one for the mother's first delivery and zero otherwise. The variable for the number of newborns at this birth is one for singleton births and zero for multiple births.

Wildfire and Environmental Data

We measure exposure to wildfires leveraging data provided by the European Forest Fire Information System (EFFIS) (San-Miguel-Ayanz et al., 2012). The data is compiled using satellite observations of land area burnt during a wildfire. These satellite observations offer high-resolution and precise geolocation, enabling accurate mapping and wildfire-affected regions. Additionally, EFFIS data includes temporal information, the type of area burnt and the extent of wildfire

occurrences. In Spain, fires are classified in three main categories: 1) attempts, when burnt area is less than 1 hectare, 2) fire, when burnt area ranges between 1 and 500 hectares and 3) large forest fires when burnt an area is larger than 500 hectares. For our purposes, we focus our main analysis on exposure to large forest fires, but provide analysis with milder forms of fires in our robustness analysis. We connect exposure to large fires (from now on wildfires), based on the area burnt falling within a municipality. Consequently, our main variable of exposure is binary and coded as 1 when a municipality had a wildfire falling within the administrative boundaries.

In addition, we also control for weather conditions, which can influence both birth outcomes and the development of fires. The data on temperatures come from the E-OBS dataset, a daily, land-only, gridded observational dataset for Europe with a spatial resolution of about 10 kilometers (Cornes et al., 2018).

Empirical Strategy

We capture impact of wildfire exposure using a linear probability model (LPM) with fixed effects described in Equation 1:

$$Y_{ipt} = \beta Fire_{pt} + X_{ipt} + \delta_m + \gamma_p + \alpha_y + \epsilon_{ipt} \tag{1}$$

In the model, Y_{ipt} represents the birth outcome (birth weight/low birth weight) of individual i in municipality p at time t. $Fire$ is the key independent variable indicating wildfire exposure in municipality p at time t. The vector X includes individual level control variables and environmental factors. We add fixed effects for δ the month of birth m, γ municipality fixed effects and birth year fixed effects, α to control for seasonal variations and unobserved heterogeneity across locations. The standard errors are clustered at the municipality level to account for potential correlation in the error terms within each location. This approach enables us to isolate the effect of wildfire exposure from other confounding factors. We explore the heterogeneous impacts of wildfire on individuals by sociodemographic characteristics based on Equation 2 in which we add an interaction between our wildfire exposure and socioeconomic status variable:

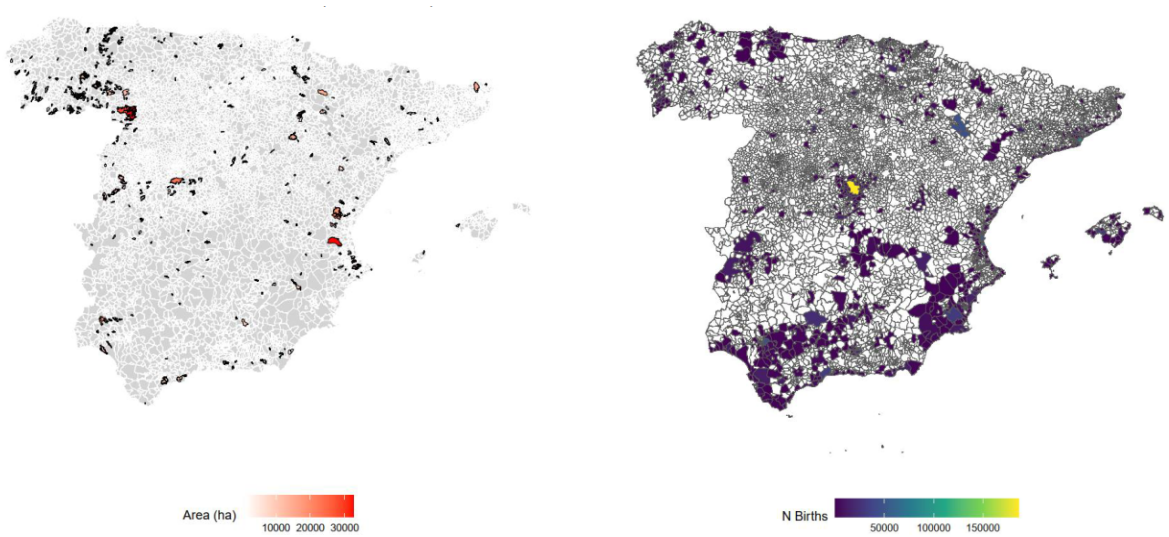
$$Y_{ipt} = \beta Fire_{pt} \times Socio_{ipt} + X_{ipt} + \delta_m + \gamma_p + \alpha_y + \epsilon_{ipt} \tag{2}$$

Results

Figure 1: Descriptive statistics

(a) Fires Above 500 ha

(b) Number of Births



In figure 1a panel (a), we describe the geographical distribution of fires burning more than 500ha in Spain between 2008 and 2021 . In panel (b) of figure 1a, we show the distribution of births in the municipalities included in the analysis in the Spanish territory from 2008 and 2021.

Table 1: Wildfire and birth outcomes

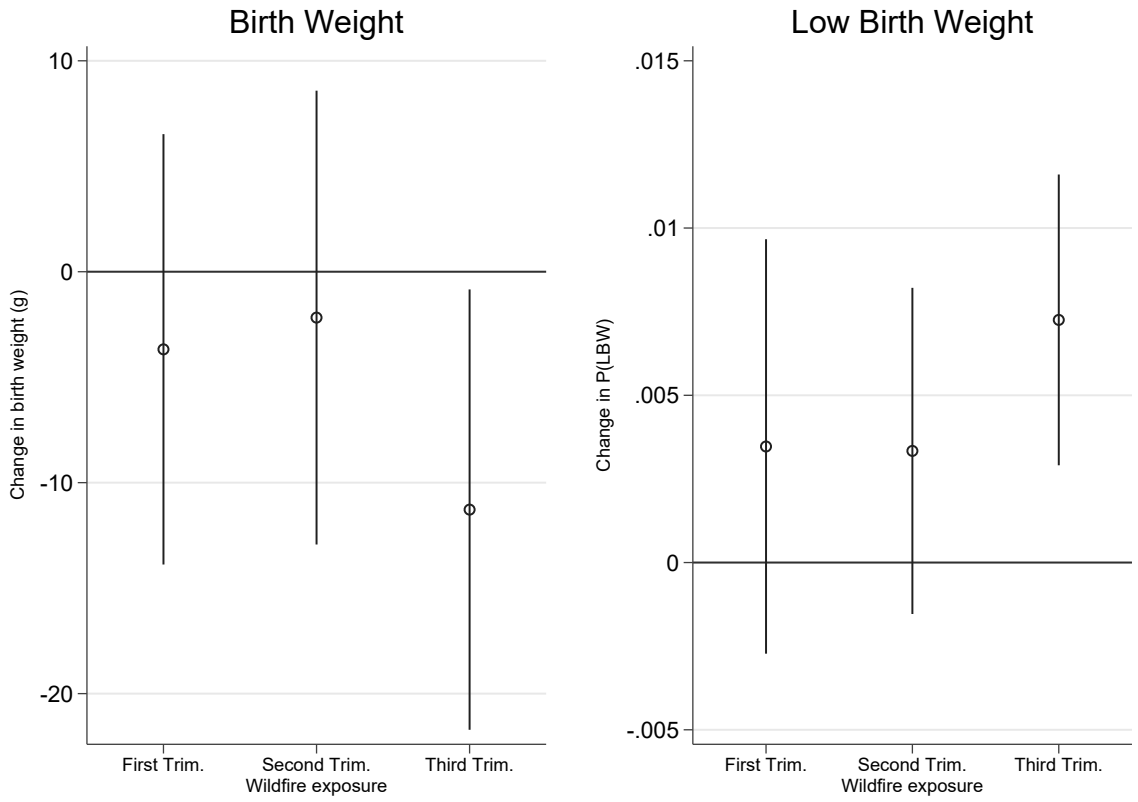
	Birth weight	Low birth weight
Wildfire (>500ha)	-4.749	0.004***
	(3.737)	(0.002)
FE	YES	YES
Controls	YES	YES
Observations	3,520,384	3,520,384

Note: Estimates are obtained by estimating Equation (1). Standard errors clustered at the province level and reported in parenthesis. * p<0.05

In table 1 we report the results of the analysis described in Equation 1. We observe a decrease in birth weight of 4.7 grams with exposure to a wildfire during gestation. However, such estimates are not statistically significant at the 95 % confidence level. Conversely, we observe a statistically significant increase in the probability of LBW with exposure to wildfire during gestation of 0.4 percentage points.

In Figure 2, we report the results of exposure to wildfires by trimester. Here, we observe a

Figure 2: Wildfire exposure and birth outcomes by trimester



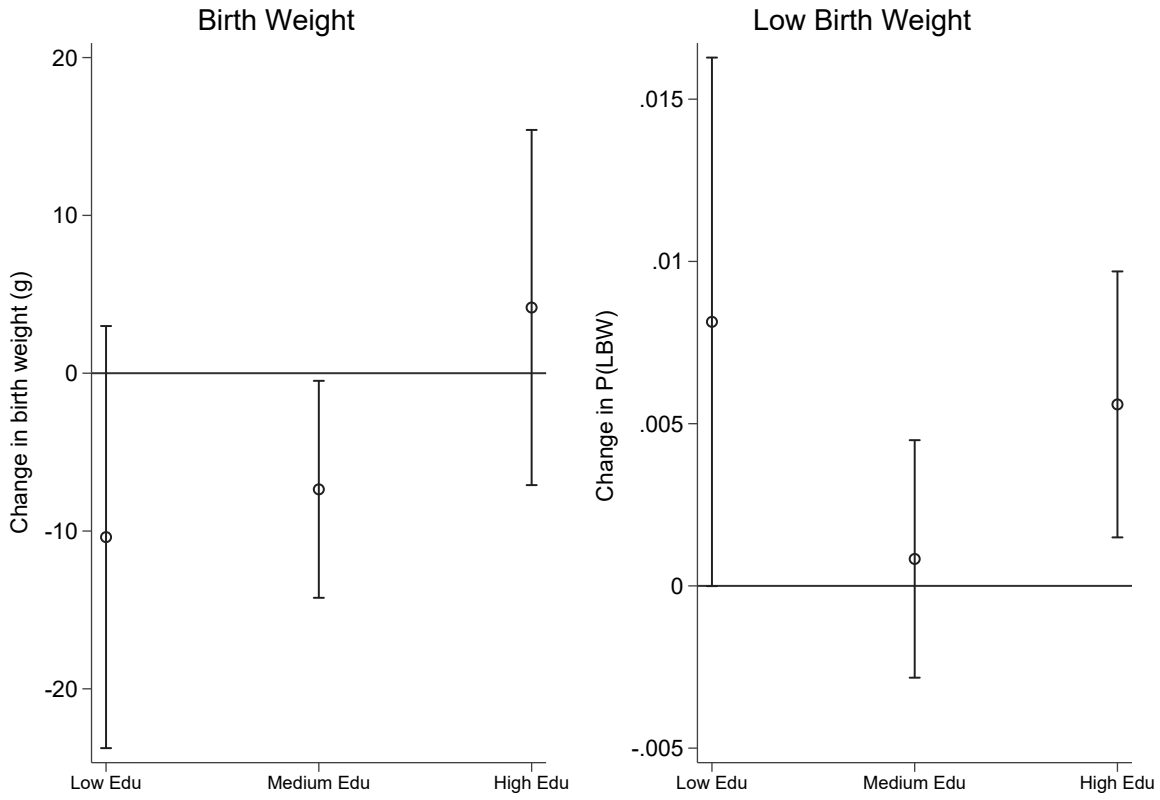
decline in birth weight of 11 grams with exposure in the third trimester. Similarly, we observe exposure in the third trimester to increase the probability of LBW by about 0.7 percentage points.

In Figure 3, we provide the results of the heterogeneity analysis described in Equation 2. Notably, we do not observe any major differences in the impact of wildfires by socioeconomic status. The effect size for birth weight is larger and negative for low and medium SES mothers, but the estimates are not statistically different from the High SES group. Differences between groups for LBW are even smaller than those observed for birth weight.

Future steps

In further analysis, we will test the robustness of our results and provide additional heterogeneity analysis. For instance, we will capture exposure to three alternative measures of wildfire exposure. First, we will test the impact of milder wildfires on birth outcomes classified on the

Figure 3: Wildfire exposure and birth outcomes by SES



area burnt ranging from 1 to 500ha. Additionally, we will test another administrative dataset of wildfire events provided by the Spanish Ministry for the Ecological Transition and the Demographic Challenge. This dataset differs from the EFFIS data as it provides point locations of wildfires as recorded by Spanish fire fighters. Also, we will analyze the direct impact of air pollution related to wildfires leveraging recently released daily data for all of Europe(Hänninen et al., 2022) and how such impact differs by SES. Finally, we will analyze how wildfires affect birth outcomes based on other measures of sociodemographic characteristics such as occupation, migration background, marital status and mother's age.

References

Aguilera, R., Corringham, T., Gershunov, A., and Benmarhnia, T. (2021). "Wildfire smoke impacts respiratory health more than fine particles from other sources: observational evidence from Southern California". *Nature communications* 12.1, p. 1493.

Almond, D. and Currie, J. (2011). "Killing me softly: The fetal origins hypothesis". *Journal of economic perspectives* 25.3, pp. 153–172.

Amjad, S., Chojecki, D., Osornio-Vargas, A., and Ospina, M. B. (2021). "Wildfire exposure during pregnancy and the risk of adverse birth outcomes: a systematic review". *Environment International* 156, p. 106644.

Brotons, L., Aquilué, N., De Cáceres, M., Fortin, M.-J., and Fall, A. (2013). "How fire history, fire suppression practices and climate change affect wildfire regimes in Mediterranean landscapes". *PLOS one* 8.5, e62392.

Burke, M., Childs, M. L., Cuesta, B. de la, Qiu, M., Li, J., Gould, C. F., Heft-Neal, S., and Wara, M. (2023). "The contribution of wildfire to PM2. 5 trends in the USA". *Nature* 622.7984, pp. 761–766.

Burke, M., Heft-Neal, S., Li, J., Driscoll, A., Baylis, P., Stigler, M., Weill, J. A., Burney, J. A., Wen, J., Childs, M. L., et al. (2022). "Exposures and behavioural responses to wildfire smoke". *Nature human behaviour* 6.10, pp. 1351–1361.

Conley, D. and Bennett, N. G. (2000). "Is biology destiny? Birth weight and life chances". *American Sociological Review*, pp. 458–467.

Cornes, R. C., Schrier, G. van der, Besselaar, E. J. van den, and Jones, P. D. (2018). "An ensemble version of the E-OBS temperature and precipitation data sets". *Journal of Geophysical Research: Atmospheres* 123.17, pp. 9391–9409.

Cozzani, M., Triventi, M., and Bernardi, F. (2022). "Maternal stress and pregnancy outcomes evidence from a natural experiment: the 2004 madrid train bombings". *European Sociological Review* 38.3, pp. 390–407.

Delfino, R. J., Brummel, S., Wu, J., Stern, H., Ostro, B., Lipsett, M., Winer, A., Street, D. H., Zhang, L., Tjoa, T., et al. (2009). "The relationship of respiratory and cardiovascular hospital admissions to the southern California wildfires of 2003". *Occupational and environmental medicine* 66.3, pp. 189–197.

Evans, J., Bansal, A., Schoenaker, D. A., Cherbuin, N., Peek, M. J., and Davis, D. L. (2022). "Birth outcomes, health, and health care needs of childbearing women following wildfire disasters: an integrative, state-of-the-science review". *Environmental Health Perspectives* 130.8, p. 086001.

Foo, D., Heo, S., Stewart, R., Dhamrait, G., Choi, H. M., Song, Y., and Bell, M. L. (2023). "Wildfire smoke exposure during pregnancy and perinatal, obstetric, and early childhood health outcomes: a systematic review and meta-analysis". *Environmental Research*, p. 117527.

Forzieri, G., Cescatti, A., Silva, F. B. e, and Feyen, L. (2017). "Increasing risk over time of weather-related hazards to the European population: a data-driven prognostic study". *The Lancet Planetary Health* 1.5, e200–e208.

Fussell, J. C., Jauniaux, E., Smith, R. B., and Burton, G. J. (2024). "Ambient air pollution and adverse birth outcomes: A review of underlying mechanisms". *BJOG: An International Journal of Obstetrics & Gynaecology* 131.5, pp. 538–550.

Gluckman, P. D. and Hanson, M. A. (2006). "The Developmental Origins of Health and Disease". In: *Early Life Origins of Health and Disease*. Ed. by E. M. Wintour and J. A. Owens. Boston, MA: Springer, pp. 1–7.

Gould, C. F., Heft-Neal, S., Johnson, M., Aguilera, J., Burke, M., and Nadeau, K. (2024). "Health effects of wildfire smoke exposure". *Annual Review of Medicine* 75, pp. 277–292.

Hajat, S. and Kosatky, T. (2010). "Heat-related mortality: a review and exploration of heterogeneity". *Journal of Epidemiology & Community Health* 64.9, pp. 753–760.

Hänninen, R, Sofiev, M, Uppstu, A, and Kouznetsov, R (2022). "Daily surface concentration of fire related PM2. 5 for 2003-2021, modelled by SILAM CTM when using the MODIS satellite data for the fire radiative power". *Finnish Meteorological Institute*.

Hauer, M. E. and Santos-Lozada, A. R. (2021). "Inaction on climate change projected to reduce European life expectancy". *Population research and policy review* 40, pp. 629–638.

Heft-Neal, S., Driscoll, A., Yang, W., Shaw, G., and Burke, M. (2022). "Associations between wildfire smoke exposure during pregnancy and risk of preterm birth in California". *Environmental Research* 203, p. 111872.

Jones, C. G., Rappold, A. G., Vargo, J., Cascio, W. E., Kharrazi, M., McNally, B., Hoshiko, S., and CARES Surveillance Group, with the (2020). "Out-of-hospital cardiac arrests and wildfire-related particulate matter during 2015–2017 California wildfires". *Journal of the American Heart Association* 9.8, e014125.

Jones, M. W., Abatzoglou, J. T., Veraverbeke, S., Andela, N., Lasslop, G., Forkel, M., Smith, A. J., Burton, C., Betts, R. A., Werf, G. R. van der, et al. (2022). "Global and regional trends and drivers of fire under climate change". *Reviews of Geophysics* 60.3, e2020RG000726.

Leary, C. S., Graham, J. M., Freeborn, P., and Semmens, E. O. (2022). "Nearby wildfire impacts, social vulnerability, and birthweight in a rural population". In: *ISEE Conference Abstracts*. Vol. 2022. 1.

Malig, B. J., Fairley, D., Pearson, D., Wu, X., Ebisu, K., and Basu, R. (2021). "Examining fine particulate matter and cause-specific morbidity during the 2017 North San Francisco Bay wildfires". *Science of the Total Environment* 787, p. 147507.

Modaresi Rad, A., Abatzoglou, J. T., Fleishman, E., Mockrin, M. H., Radeloff, V. C., Pourmohamad, Y., Cattau, M., Johnson, J. M., Higuera, P., Nauslar, N. J., et al. (2023). "Social vulnerability of the people exposed to wildfires in US West Coast states". *Science advances* 9.38, eadh4615.

Nyadanu, S. D., Dunne, J., Tessema, G. A., Mullins, B., Kumi-Boateng, B., Bell, M. L., Duko, B., and Pereira, G. (2022). "Prenatal exposure to ambient air pollution and adverse birth outcomes: an umbrella review of 36 systematic reviews and meta-analyses". *Environmental Pollution* 306, p. 119465.

Qiu, M., Li, J., Gould, C. F., Jing, R., Kelp, M., Childs, M., Kiang, M., Heft-Neal, S., Diffenbaugh, N., and Burke, M. (2024). *Mortality Burden From Wildfire Smoke Under Climate Change*. Tech. rep. National Bureau of Economic Research.

Rauscher, E. and Cao, X. (2024). "Unequal Effects of Wildfire Exposure on Infant Health by Maternal Education, 1995–2020". *RSF: The Russell Sage Foundation Journal of the Social Sciences* 10.1, pp. 255–274.

Reid, C. E. (2022). "Invited Perspective: What Do We Know about Fetal–Maternal Health and Health Care Needs after Wildfires? Not Nearly Enough". *Environmental Health Perspectives* 130.8, p. 081304.

Reid, C. E., Brauer, M., Johnston, F. H., Jerrett, M., Balmes, J. R., and Elliott, C. T. (2016a). "Critical review of health impacts of wildfire smoke exposure". *Environmental health perspectives* 124.9, pp. 1334–1343.

Reid, C. E., Jerrett, M., Tager, I. B., Petersen, M. L., Mann, J. K., and Balmes, J. R. (2016b). "Differential respiratory health effects from the 2008 northern California wildfires: A spatiotemporal approach". *Environmental research* 150, pp. 227–235.

Ruffault, J and Mouillot, F. (2015). "How a new fire-suppression policy can abruptly reshape the fire-weather relationship". *Ecosphere* 6.10, pp. 1–19.

San-Miguel-Ayanz, J., Schulte, E., Schmuck, G., Camia, A., Strobl, P., Liberta, G., Giovando, C., Boca, R., Sedano, F., Kempeneers, P., et al. (2012). "Comprehensive monitoring of wildfires in Europe: the European forest fire information system (EFFIS)". In: *Approaches to managing disaster-Assessing hazards, emergencies and disaster impacts*. IntechOpen.

Torche, F. (2011). "The effect of maternal stress on birth outcomes: exploiting a natural experiment". *Demography* 48.4, pp. 1473–1491.

Turco, M., Bedia, J., Di Liberto, F., Fiorucci, P., Hardenberg, J. von, Koutsias, N., Llasat, M.-C., Xystrakis, F., and Provenzale, A. (2016). "Decreasing fires in mediterranean Europe". *PLoS one* 11.3, e0150663.

Wen, J. and Burke, M. (2022). "Lower test scores from wildfire smoke exposure". *Nature Sustainability* 5.11, pp. 947–955.

Xu, R., Yu, P., Abramson, M. J., Johnston, F. H., Samet, J. M., Bell, M. L., Haines, A., Ebi, K. L., Li, S., and Guo, Y. (2020). "Wildfires, global climate change, and human health". *New England Journal of Medicine* 383.22, pp. 2173–2181.

Zheng, J. (2023). "Exposure to wildfires and health outcomes of vulnerable people: Evidence from US data". *Economics & Human Biology* 51, p. 101311.