



REVIEW

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Environmental health of wildland firefighters: a scoping review

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Abstract

Background Wildland firefighters are likely to experience heightened risks to safety, health, and overall well-being as changing climates increase the frequency and intensity of exposure to natural hazards. Working at the intersection of natural resource management and emergency response, wildland firefighters have multidimensional careers that often incorporate elements from disparate fields to accomplish the tasks of suppressing and preventing wildfires. Thus, they have distinctly different job duties than other firefighters (e.g., structural firefighters) and experience environmental health risks that are unique to their work. We conducted a systematic scoping review of scientific literature that addresses wildland firefighter environmental health. Our goal was to identify studies that specifically addressed wildland firefighters (as opposed to firefighters in a broader sense), geographic and demographic trends, sample sizes, patterns in analysis, and common categories of research.

Results Most studies have clustered in a few highly developed countries, and in the United States within California and Idaho. Many studies fail to consider the impact that demographic factors may have on their results. The number of studies published annually is increasing and themes are broadening to include social and psychological topics; however, most authors in the field have published an average of < 3 articles.

Conclusions We identify three areas that we believe are imminent priorities for researchers and policymakers, including a lack of diversity in study geography and demography, a need for more complex and interactive analyses of exposure, and prioritization of wildland firefighters in research funding and focus.

Keywords Occupational health, Mental health, Performance, Safety, Well-being, Medical, Demography, Geography

Resumen

Antecedentes Los combatientes de incendios probablemente experimentan elevados riesgos en la salud, la seguridad, y en el estado de bienestar general a medida que los climas cambiantes incrementan la frecuencia e intensidad de exposición a los peligros naturales. Trabajando en la intersección entre el manejo de los recursos naturales y la respuesta a la emergencia, los combatientes de incendios tienen carreras multidimensionales que frecuentemente incorporan elementos de distintos campos para lograr completar las tareas de suprimir y prevenir incendios de vegetación. De esa manera, ellos tienen tareas distintivamente diferentes que otros bomberos (p. ej. bomberos estructurales) y experimentan riesgos ambientales en su salud que son únicos en sus trabajos. Condujimos un trabajo de naturaleza sistémica de revisión bibliográfica que se enfocó en la salud ambiental de los brigadistas de incendios de vegetación. Nuestro objetivo fue identificar estudios que específicamente se enfoquen en brigadistas de incendios de

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vegetación (en contraposición con otros bomberos en un sentido amplio, las tendencias geográficas y demográficas, el tamaño de las muestras, patrones de análisis, y categorías comunes de investigación).

Resultados La mayoría de los estudios se han agrupado en pocos países muy desarrollados, y dentro de los EEUU en California y Idaho. Muchos estudios fallaron en considerar el impacto que los factores demográficos podrían tener en sus resultados. El número de estudios anualmente se está incrementando y los temas ampliándose, incluyendo tópicos sociales y psicológicos; de todas maneras, la mayoría de los autores en esa especialidad han publicado un promedio < 3 artículos.

Conclusiones Identificamos tres áreas que creemos son inminentes prioridades para investigadores y decisores políticos, incluyendo una falta de diversidad en estudiar geografía y demografía, la necesidad de realizar un análisis más completo e interactivo de la exposición, y la priorización de los brigadistas en cuanto a fondos para investigación y su enfoque.

Context and background

Broadly, environmental health considers existing and potential hazards, access and equity in provisioning care and resources, and exposure incurred in an environment (Huber et al. 2011). As our global environment shifts with changing climates, environmental health impacts will be inequitably distributed among professions and geographic locations. Wildland firefighters, due to the nature of their work, are likely to see significantly increased environmental health risks as both hazards and their exposure increase due to the increased frequency and intensity of wildfires (Podur & Wotton 2010). Thus, wildland firefighter environmental health scientists are faced with an imminent challenge. They must necessarily create interdisciplinary solutions, relying on concepts from medical, occupational, environmental, and sociological fields to infer the conditions and state of the wildland firefighting workforce; in tandem, they must also identify the contributing factors that may promote or detract from the overall health and well-being of said population to rapidly address these looming issues (Huby & Adams 2009; Huber et al. 2011; Brown 2013).

Wildland firefighting is often considered a subfield of a broadly- or diffusely defined field of “firefighting” due to the smoke, flame, and heat exposure sustained by workers. Firefighting is included even more broadly as part of emergency management and disaster response, since workers in these fields are generally trained in incident command systems and can conduct interagency work that may include performing tasks that are not exclusive to fire suppression (e.g., traffic control and mitigation, evacuation, establishment of safety zones and shelters, VanDevanter et al. 2010; Thompson et al. 2018). While wildland firefighters may work in emergency management periodically and some commonalities with structural firefighting do exist, many of the occupational and environmental exposures and hazards that wildland firefighters face are distinctly different from other classes of emergency responders and firefighters. Here, we defined

a wildland firefighter as per Ragland et al. (2023) as a person “who is tasked with preventing, actively suppressing, or supporting the active suppression of fires occurring in natural or naturalized vegetation” and included such job categories as operational wildland firefighters (e.g., engine crews, hand crews, hotshot crews, smokejumpers, rappellers), fire prevention, fuel management specialists, fire ecologists, fire planners, wildland fire dispatchers, fire cache managers, fire equipment operators, and fire aviation.

Wildland firefighters’ work is unique in the physiological, psychological, performance, and safety demands it imposes on its workers (Ruby et al. 2023): (1) They work in natural environments and are exposed to natural elements for extended periods of time, sometimes multiple days; (2) They often are working in remote settings, which can mean crews are socially isolated for prolonged periods; (3) Wildland fires are often sustained events with unpredictable shifts in intensity occurring in rugged terrain, so the physicality of the work requires burst energy combined with extended periods of high endurance and high impact activity; (4) Many wildland firefighters wear significantly less PPE than structural firefighters (e.g., minimal or no respiratory or airway protection), though they may endure more sustained and prolonged smoke exposure [average of 7–11.5 h (Reinhardt & Ottmar 2004) in contrast to <11 min for 90% of structural fire incidents (Federal Emergency Management Agency 2006)]. This combination of exposure and physiological demands significantly alters the risk equation for injury, illness, and stress-related impacts on mental health and social interactions (Alfano et al. 2021).

Objectives and research questions

A study by the United States Bureau of Labor Statistics found that wildland firefighters account for 25% of all firefighter fatalities despite being only about 2% of the total firefighting workforce in the USA: This was attributed to an increased likelihood of multi-casualty events

because of a crew-based workforce (Clarke & Zak 1999). However, from 2007 to 2016, the top three causes of wildland firefighter death included heart attacks (24%), vehicle accidents (20%), and aircraft accidents (18%); entrapments were the fourth most common cause of death (PMS 841 2017). Despite this, wildland firefighter environmental health remains understudied relative to structural firefighting and other high-risk job fields (e.g., timber cutting, mining). Thus, this review is necessitated by a lack of scholarly consensus about potential occupational hazards to health, safety, and well-being of wildland firefighters. At present, we lack a comprehensive conceptual framework to address occupational hazards, and as a result, comparative research among studies is hampered.

Our research questions were as follows: (1) What is the scope of the wildland firefighter environmental health literature at present? (2) What categories do the existing literature fall into? and (3) What geographic locations and demographic groups are understudied in the field of wildland firefighter environmental health? We followed the review guidelines detailed in Peters et al. (2015) and

Munn et al. (2018) to conduct this review (see PRISMA, Fig. 1).

Inclusion criteria

We included all studies that directly or indirectly assessed wildland firefighter health, well-being, and/or safety. We also included studies that assessed other biotic or abiotic parameters of wildland fires with the stated goal of examining wildland firefighter health, well-being, and/or safety. We excluded survey studies where wildland firefighters were less than 5% of the total study population, non-scientific studies (i.e., personal narratives), literature reviews, non-peer-reviewed materials (except theses and dissertations), and materials that mentioned wildland firefighters as a motivator for the study but did not address a question directly related to wildland firefighters (i.e., Riley et al. 2022). This review also included studies that addressed environmental health topics related to wildland firefighters but did not experiment directly with wildland firefighters or human subjects when the primary motivation for the study was to assess wildland firefighters

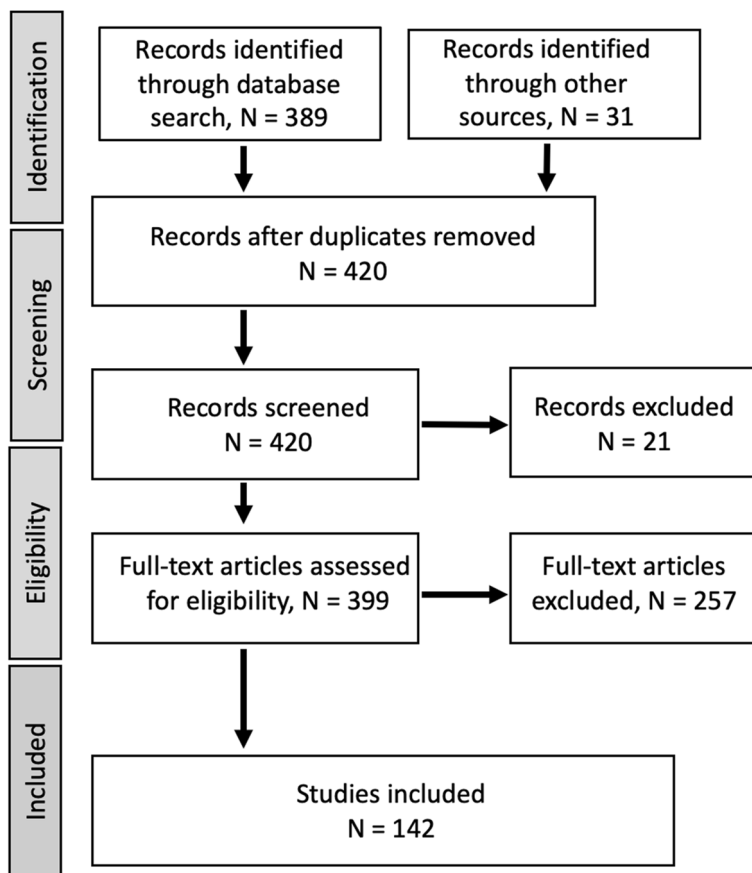


Fig. 1 Preferred reporting items for systematic reviews and meta-analyses (PRISMA) flow diagram for this scoping review

(i.e., studies of wood smoke on non-human tissue with the goal of understanding impacts on wildland firefighter health). Further, we excluded studies that focused on communities impacted by wildfire, even when wildland firefighters were mentioned within, as the primary focus was outside the realm of this review.

Search criteria

We assembled literature with an exhaustive Google Scholar, ORCID, OVID Medline, Web of Science, JSTOR, and SCOPUS search using the terms “wildland firefighter,” “wildland firefighter environmental health,” “wildland firefighter health,” “wildland firefighter occupational health,” and “wildland firefighter mental health.” We supplemented this search with known literature previously acquired through other means. We acquired all literature in which the title or abstract explicitly mentioned or referenced: wildland firefighters, firefighter health, safety, well-being, recruitment, and/or retention. Papers were acquired directly from search engine sources or using the Missouri University of Science and Technology Interlibrary Loan (ILLiad) Department when complete versions were unavailable elsewhere. Digital complete versions of all papers were compiled in a Google drive accessible to all authors.

Extracting and charting results

All citations were entered in a .CSV file with basic information (authors, year, journal, volume, page numbers, category). We also recorded study location; study year; study length; total sample size; whether the study analyzed direct or indirect effects of fire on wildland firefighter health; whether the analysis considered age, gender, and ethnicity; and the summary findings of the study. We defined a direct effect as one that was directly attributable to a wildland fire or one that happened while on a wildland fire, whereas an indirect effect may have occurred secondary to or had a wildland fire as a contributing factor in its emergence but could not be causally linked to the fire itself.

We identified four primary conceptual categories, psychological/sociological, medical, occupational/safety, and performance, to which all studies were assigned. We assigned each included paper to a single category that best fits its theme. Categories were informed by a word cloud created from the titles of papers that met the criteria for study inclusion (Fig. 2). Within a category, we examined additional parameters as appropriate. Psychological and sociological studies were those that considered the impacts of wildland firefighting careers on mental health, mental well-being, community and peer-to-peer interactions, sleep, and behavioral stress responses. Medical studies were those that considered impacts of the career on physical health, physical

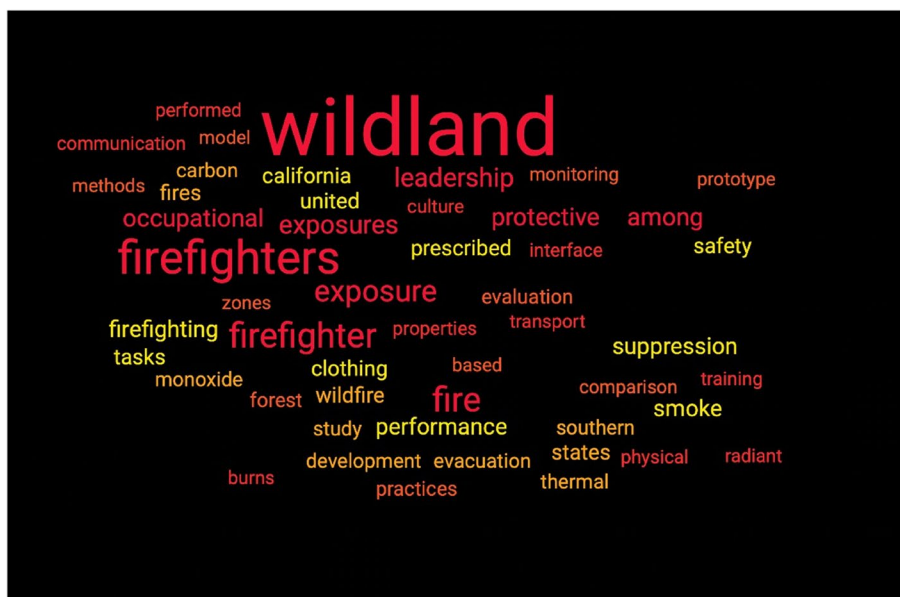


Fig. 2 Word cloud of publication titles that were analyzed for this study. Word size relates to frequency of occurrence. Themes related to traditional wildland fire values of performance, exposure, suppression, occupational health, and safety emerged as the most frequently used words. Culture, monitoring, comparison, training, methods, communication, and practices were much less frequently used in titles. Other important factors in environmental health such as well-being, mental health, co-worker interactions, demographic factors, and social support systems are absent

well-being, physiology, anatomy, and/or longevity. We considered performance studies to be those that measured how physical, chemical, mental, or other environmental parameters changed wildland firefighters' ability to complete tasks, tests, or other job metrics. Occupational and safety studies were defined as those that considered how worker safety, well-being, or health influenced work outcomes. Occupational and safety studies also included studies examining ways to increase worker safety and well-being, including improvements to PPE. Analyses were conducted from October 2022 to January 2023 and included literature published before January 2023.

Results

A total of 142 papers met requirements for inclusion in this review, within which we identified 376 total authors (Table 1). Individual authors published 1.51 papers on average (range 1–11). When we included only authors that had published more than one paper, the mean number of papers per author was 2.99. The median sample size across all studies was 35 individuals (quartile: 14.5–114.75). Studies were conducted primarily in highly developed countries and the western USA (Figs. 3 and 4) and focused on operational wildland firefighters ($N=141$). Overall, the annual number of publications on wildland firefighter environmental health has steadily increased since the 1990s (Fig. 5). In addition to narrow geographic scopes, most studies analyzed few

demographic variables (Fig. 6). Medical and occupational studies comprised a plurality of the articles we analyzed (41.4% and 39.3%, respectively).

Medical studies

We identified 59 studies that addressed medical topics in wildland firefighter environmental health. Of these, cardiovascular disease, and risk ($N=14$, 23.7%), smoke and pulmonary and respiratory impacts ($N=12$, 20.314%), and heat exposure ($N=10$, 16.9%) were the most examined subjects. Median study size was 36.5 participants (quartile 11.5–105.75), and most studies took place in North America ($N=42$) and Europe ($N=12$). The longest study followed participants for three fire seasons (approximately 3 years). Four (6.8%) studies included ethnicity in their analyses; 26 (44.1%) included age, and 19 (32.2%) included gender. Studies were most often conducted as direct assessments of wildland fire impacts on health ($N=42$, 71.2%). Overall, these studies attributed a suite of medical risks to wildland firefighter exposure to wood smoke, particulate matter, ash, soil, heat, and prolonged physiological stress. Short-term smoke inhalation effects were reported, but these effects appeared to dissipate rapidly (Dorman & Ritz 2014; Wu et al. 2021a, b); however, other studies found that 65% of career wildland firefighters complain of respiratory symptoms (Swiston et al. 2008), suggesting that long-term effects may exist, even if they are not readily apparent. While few COVID data exist for wildland firefighters, acute and chronic

Table 1 Works included in the scoping analysis by category

Medical	Abreu et al. 2017, Adetona et al. 2011, Adetona et al. 2013a, b, Adetona et al. 2013a, Adetona 2016, Adetona et al. 2017a, 2017b, Betchley et al. 1997, Britton et al. 2013a, b, Broyles et al. 2017, Carballo-Leyenda et al. 2018, Cherry et al. 2022, Christison 2020, Christison et al. 2021a, b, Christison et al. 2021a, Collins 2018, Cuddy & Ruby 2011, Cuddy et al. 2015, Domitrovich 2011a, b, c, Dorman & Ritz 2014, Ferguson et al. 2016, Ferguson et al. 2017, Saint Martin et al. 2018, Garcia-Heras et al. 2022, Gaughan et al. 2008, Gaughan et al. 2014a, b, Gaughan et al. 2014a, Gurney et al. 2021a, b, Gurney et al. 2021a, Hunter et al. 2014, Jacquin et al. 2011, Jeklin et al. 2021, Main et al. 2020, Metz et al. 2022, Miranda et al. 2012, Moody et al. 2019, Navarro et al. 2019, Navarro et al. 2021a, b, Nelson et al. 2020, Niyatiwatchanchai et al. 2022, Oliveira et al. 2016, Oliveira et al. 2020, Pelletier et al. 2022, Peters et al. 2018, Pryor & Suyama 2015, Ramos & Minghelli 2022, Reinhardt & Ottmar 2004, Robertson et al. 2017, Rodríguez-Marroyo et al. 2022, Ruby et al. 2003a, b, Ruby et al. 2003a, Semmens et al. 2016, Slaughter et al. 2004, Smith et al. 2013, Sol et al. 2018, Swiston et al. 2008, Vincent et al. 2017, Watkins et al. 2012, Wolfe et al. 2012, Wu et al. 2020a, Wu et al. 2021a, b
Occupational Health & Safety	Adetona et al. 2012, Adetona et al. 2017a, Amster et al. 2013, Bayham et al. 2020, Bellingar 1994, Belval et al. 2018, Britton et al. 2013a, Broyles et al. 2019, Burbank 2016, Butler & Cohen 1998, Campbell et al. 2017a, b, Carballo-Leyenda et al. 2019, Carballo-Leyenda et al. 2021a, b, Carballo-Leyenda et al. 2022, Cardil et al. 2017, Collins 2018, Domitrovich 2011a, Fox et al. 2017, Fryer 2012, Fryer et al. 2013, Gabor 2015, Gordon & Lariviere 2014, Hummel et al. 2020, Laws et al. 2020, Leduc 2020, Lewis & Ebbeck 2014, Materna et al. 1992, Materna et al. 1993, McDonald & Shadow 2003, Mcquerry & Easter 2022, Miranda et al. 2010, Nagavalli et al. 2020, Navarro et al. 2017, Navarro et al. 2021a, Nelson et al. 2021, Page & Butler 2018, Page et al. 2019, Phillips et al. 2012, Phillips et al. 2015, Peña Cueto 2018, Reimer 2017, Reimer & Eriksen 2018, Reinhardt 2019, Riley et al. 2022, Roberts 2002, Robinson et al. 2008, Roise et al. 2022, Rose 2019, Semmens et al. 2021, Sol et al. 2021, Sun et al. 2000, Taylor et al. 2007, Waldron et al. 2015, Waldron & Ebbeck 2015, Wu et al. 2020a, b, Wu et al. 2021a, Yoo et al. 2000,
Performance	Campbell et al. 2017a, Carballo-Leyenda et al. 2017, Carballo-Leyenda et al. 2018, Carballo-Leyenda et al. 2021a, DenHartog et al. 2015, Domitrovich 2011b, Gaskill et al. 2020, Gumieniak et al. 2018, Leduc et al. 2022, Lui et al. 2014, Phillips et al. 2018, Ruby 1999, Ruby et al. 2002, Sharkey 1999, Strang et al. 2018, Sullivan 2020, Sullivan et al. 2020
Psychological & Sociological	Bode et al. 2022, Cherry et al. 2021, Collins 2018, Cvirn et al. 2017, Leykin et al. 2013, McGillis et al. 2017, Palmer et al. 2011, Palmer 2014, Theleritis et al. 2020, Vincent et al. 2015, Vincent et al. 2017, Williams-Bell et al. 2017, Wolklow et al. 2015

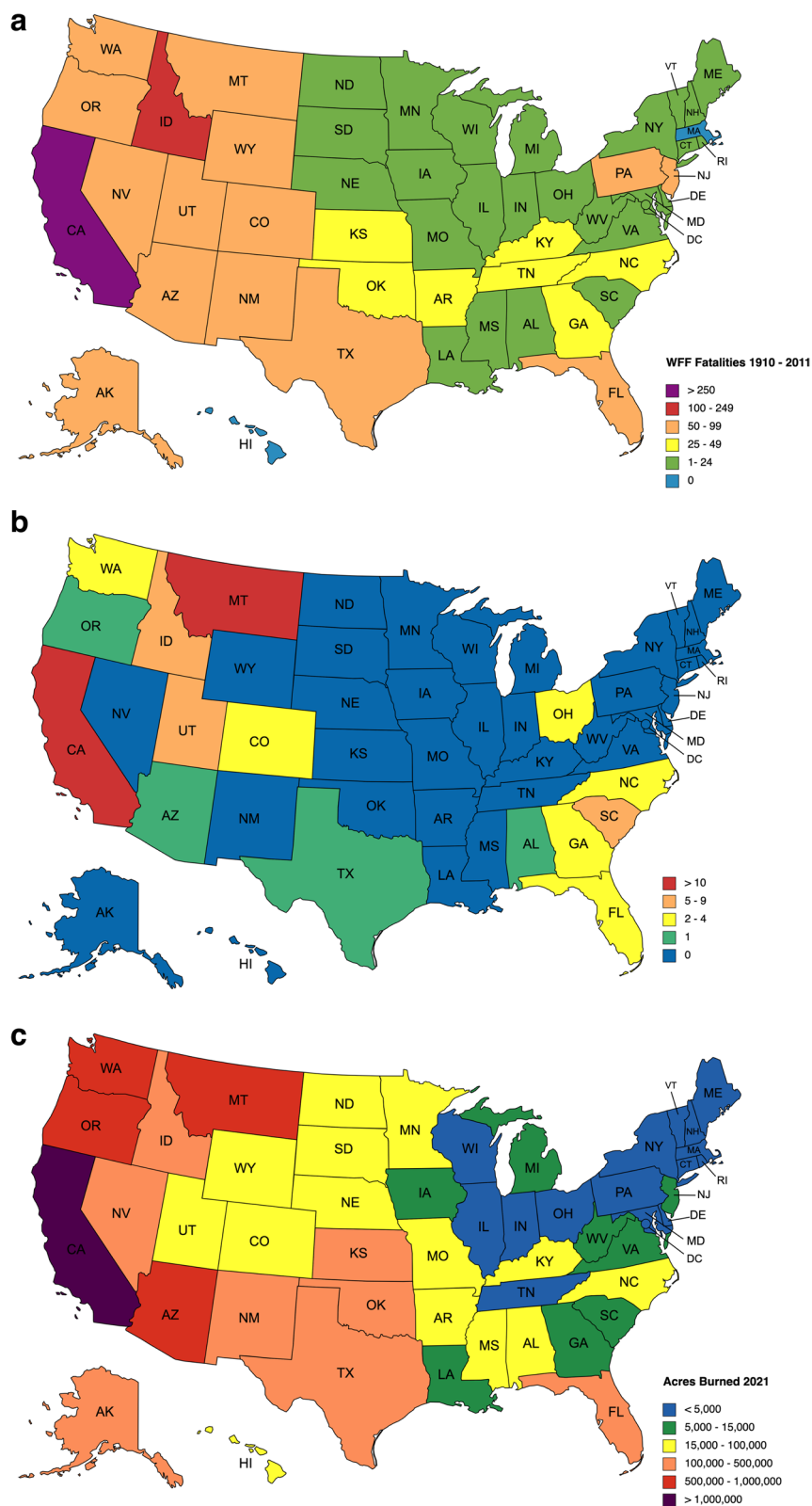


Fig. 3 The United States's distribution of wildland fire environmental health studies does not match the distribution of wildland fires or wildland fire fatalities, suggesting there is a need for a broader geographic distribution of study areas

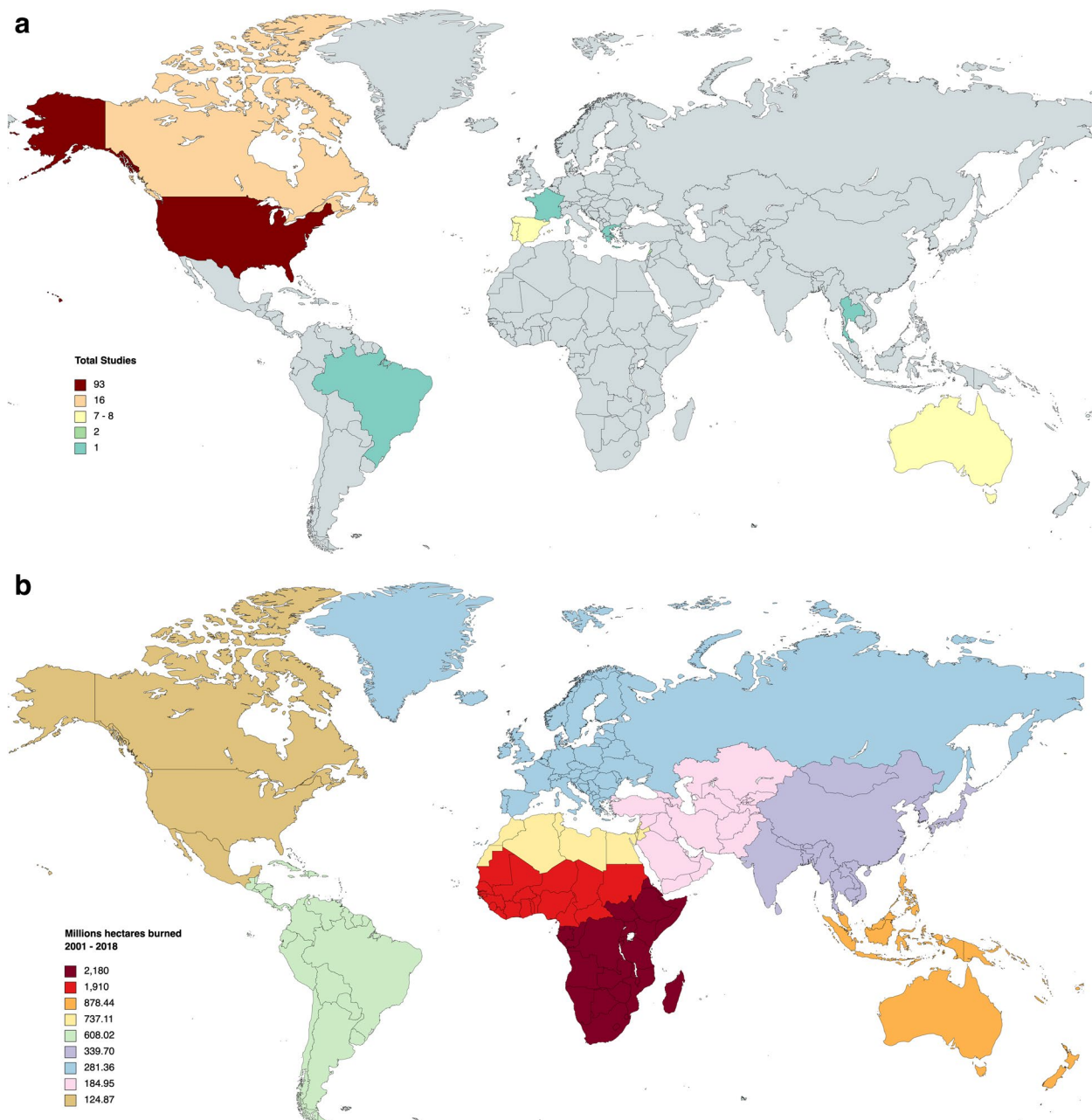


Fig. 4 Studies of wildland firefighter environmental health are geographically scattered and are not occurring in areas that receive the highest amount of wildfire. Countries in gray have zero studies conducted in their borders

smoke exposure and dense crew housing may increase risk and vulnerability to infection and may make symptom-based pulmonary diagnoses more difficult (Metz et al. 2022).

Physical injury rates on the job for wildland firefighters were reported at 20% (Christison et al. 2021a, b; Garcia-Heras et al. 2022), and heat-related stress and injury risk were reported to be exacerbated by the

personal protective equipment and packs (20.5 kg+) that wildland firefighters wear (Carballo-Leyenda et al. 2019). Common injury sites included the knees, low back, and shoulders, and 30% of all injuries were the result of a slip, trip, or fall (Moody et al. 2019). Fitness often was an important physiological indicator of muscle damage and short-term overuse, and higher levels

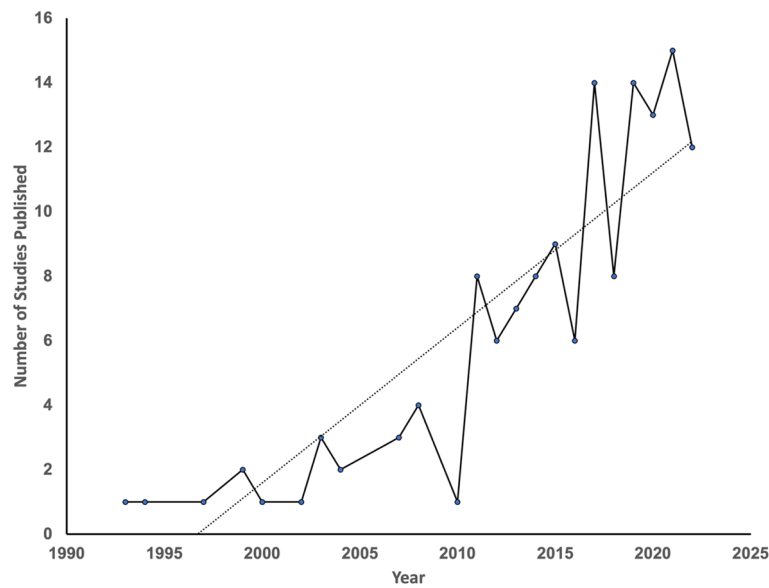


Fig. 5 The total number of studies published annual increased since the first studies on wildland firefighters were published. X=year. Y=number of studies published annually

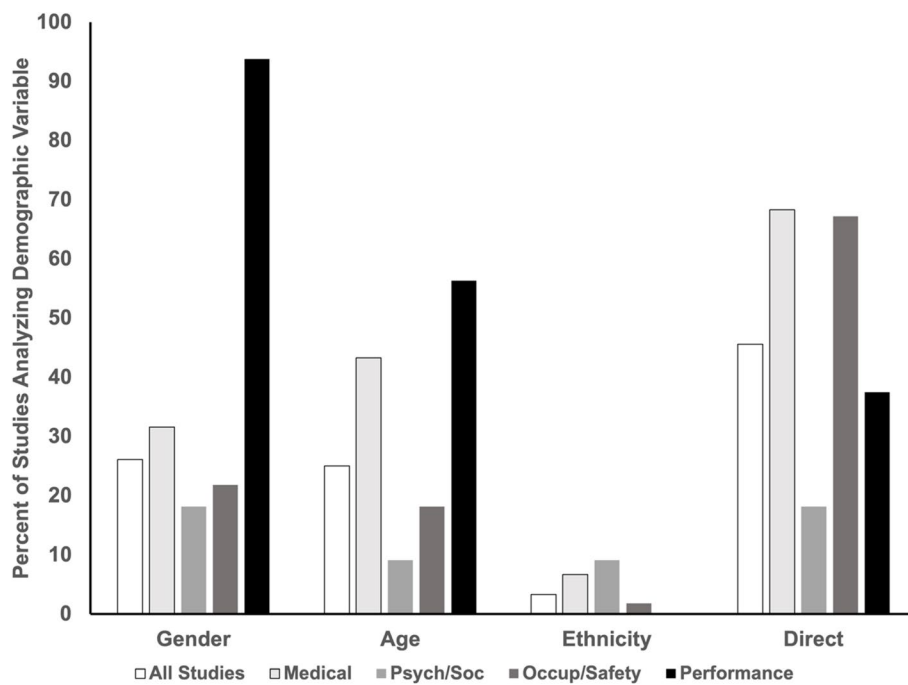


Fig. 6 Percentage of studies considering gender, ethnicity, or age directly in analyses by category. “All studies” is a category where the data are summated for all categories to allow visualization of trends in the entire set. Y axis=percentage of studies including a demographic variable of interest in their analysis. X axis=categorical variables. “Direct” indicates studies that assessed direct effects of wildland fires on wildland firefighter health, rather than studies that may have used correlative inference

of physical fitness were often an indicator of decreased risk for rhabdomyolysis (Christison et al. 2021a).

Medical incidents are the leading direct cause of wildland firefighter death in the USA (Butler et al. 2017),

but substantial gaps exist in our understanding of both long- and short-term medical impacts of the physiological strain, environmental exposure, and additional risk factors incurred during wildfires and other portions

of wildland firefighter careers. No studies consider the impacts of wildland firefighting on endocrine function, microbiomes, digestive function and nutrition, skin infection, vision and ocular systems, fertility, long-term neurological risks, cancer risk (except lung cancer, Navarro et al. 2019), or reproductive health or gestation. Further, studies of wildland firefighting-specific injury recovery and surgical outcomes are non-existent. These areas represent potential avenues of future exploration.

Psychological and sociological studies

We identified 11 studies of psychological and sociological factors in wildland firefighter environmental health. These studies were published between 2011 and 2022 and most addressed sleep ($N=5$) and post-traumatic stress disorder ($N=2$). Studies were conducted in North America ($N=6$), Australia ($N=3$), Europe ($N=1$), and Israel ($N=1$) and were generally single-survey, single-trial, or single-season events ($N=10$, 90.1%). The longest study was 30 months in duration (Cherry et al. 2021). The median sample size was 37 participants (quartile 11–102). Over half of the studies utilized surveys ($N=6$, 54.5%); other common techniques were interviews ($N=5$, 45.5%) and experimental trials ($N=3$, 27.3%). Nine (81.8%) studies considered indirect effects of wildland fire careers, whereas two (18.2%, both addressing sleep) directly examined fireline effects. A single study (9.1%) considered gender and age jointly (Theleritis et al. 2020), and a single study considered age and ethnicity jointly (Leykin et al. 2013). One study considered gender alone (Vincent et al. 2015).

Psychological studies primarily centered on maintaining cognitive performance and either mitigating, managing, or assessing environmental factors that may precipitate declines via stress (Palmer 2014), sleep deprivation (e.g., Bougard et al. 2016), lack of training and support (Cherry et al. 2021), or poor diet (Bode et al. 2022). Absent from many studies were considerations of mental health history which may impact wildland firefighters' experiences in the field (Ragland et al. 2023). Mental health and social support are emerging fields of interest in wildland firefighter environmental health research, and one survey found that 16% of respondents have had suicidal thoughts that were worsened by the stress of their jobs (Verble et al. 2022).

Performance studies

Performance studies combine medical and occupational elements to assess human biometrics that can be related to job-specific tasks. A total of 16 wildland firefighter environmental health performance studies were identified, conducted between 1999 and 2022. The most common topics addressed were performance on work tests

($N=4$) and rate of travel ($N=2$). Most studies were conducted in North America ($N=4$) and two were conducted in Europe ($N=2$, Spain). Common biometrics utilized were walking and running speed, skin and core temperature, and body mass. Sample sizes ranged from 8 to 320 participants with a median of 52.5 (quartile 17–80.5). Fifteen studies lasted for one fire season (approximately 6 months) or less. One study ran for 4 years (Gaskill et al. 2020). Of all categories, performance studies were the most likely to consider demographic factors. Fifteen studies (93.8%) considered some combination of age and gender, together or independently (4 both, 11 gender, 5 age); however, none considered ethnicity. Six studies performed direct fireline measures of performance (37.5%).

Occupational and safety studies

We identified 56 studies that covered topics relating to occupational health and safety of wildland firefighters. Studies were published between 1992 and 2022 in North America ($N=47$), Europe ($N=5$), Australia and Asia ($N=3$), and Latin America ($N=1$). One study (Carballo-Leyenda et al. 2022) occurred in both Europe and Latin America and is included in the count for both regions. Themes included job-based environmental exposure (smoke: $N=13$, 23.2%; heat: $N=3$, 5.4%; other: $N=1$, 1.8%), personal protective equipment ($N=7$, 12.5%), leadership and decision making ($N=6$, 10.7%), fatalities and injuries ($N=6$, 10.7%), evacuation and safety zones ($N=5$, 8.9%), communication ($N=4$, 7.1%), training ($N=4$, 7.1%), gender ($N=3$, 5.4%), and impacts of the job on task performance ($N=2$, 3.6%). A total of 38 (67.8%) studies included human participants, and the mean number of participants per study was 31 (quartile 15–245).

Study length varied widely by methodology. The longest study retrospectively analyzed 70 years of fatality data (Cardil et al. 2017) and the shortest observed wildland firefighters on an active wildfire for 4 six-hour shifts (Phillips et al. 2015). Most studies observed direct effects of fire ($N=38$, 67.8%). Few studies accounted for age ($N=10$, 17.9%), gender ($N=12$, 21.4%) or ethnicity ($N=1$, 1.8%) in their analyses. While many studies included human subjects, less than half included survey responses of participant experiences ($N=21$, 37.5%). All studies focused on operational wildland firefighters' working environments.

Occupational studies often cited a lack of sufficient training for and use of safety equipment (e.g., hearing protection, Broyles et al. 2019), high rates of job-related environmental exposure to pollutants (e.g., Adetona et al. 2017a, b), gender disparity (Reimer 2017), and a need for improved psycho-social support systems (e.g., Leduc 2020) as key priorities for improvements to the field. While safety is often considered in the context of

operations and protective gear (e.g., McQuerry & Easter 2022), less work has been done to assess cultural and social aspects of safety and well-being in occupational settings, and this is also an important line of future research.

Critical gaps in knowledge

Our review identifies three emergent themes—(1) a lack of geographic and demographic diversity, (2) limited knowledge of the interaction between physiological factors and the natural environment, and (3) a broad need for prioritization of wildland firefighter health, safety, and well-being in future research. Addressing these themes will represent improvements toward enhancing the comprehensivity, inclusivity, applicability, and relevance of future research and help advance the state of the field.

Multiscale geographic diversity is essential to fully encompass the heterogeneity of landscapes, ecosystems, and wildland firefighters that exist. To date, wildland firefighter environmental health has been unstudied in significant portions of the globe where fires are most widespread and deadly (Figs. 2 and 3). Fireline hazards, smoke composition, interpersonal interactions, and medical risk factors will vary among localities and populations: Neglecting to consider these differences leaves a substantial portion of the world's wildland firefighters without access to quality environmental health data and unable to make informed decisions to protect themselves from unnecessary exposures. For example, Wu et al. found that wildland firefighters in the midwestern USA who worked on prescribed burns have a higher incidence of urinary mutagenicity and systemic oxidative changes associated with smoke exposure than wildland firefighters in other areas of the country (2020), highlighting the importance of geographic diversity of studies.

Further, wildland firefighting strategies and wildland firefighter demographics vary significantly across geographic regions. Our review highlights the need for demographic diversity in studies of wildland firefighter environmental health. Environmental justice research has repeatedly demonstrated that the effects of environmental inequities are disproportionately born by minority groups (e.g., Bullard & Wright 1993; McGregor et al. 2020), and non-white wildland firefighters were more likely to experience injury or illness on the fireline than white wildland firefighters (Verble et al. 2022). Further, variables such as sexual orientation, veteran status, and mental health status may be important to the work experiences of wildland firefighters (Ragland et al. 2023). By neglecting to intersectionally consider important demographic and socioeconomic data about wildland firefighters, important patterns and contributing factors to environmental health risk are likely being obscured.

The current state of wildland firefighter environmental health literature almost exclusively considers operational wildland firefighters (except Palmer 2014). While operational wildland firefighters are the most conspicuous members of the enterprise, wildland firefighting consists of an interconnected web of actors, each contributing to the success of suppression efforts through their roles. Wildland firefighters include people working in wildland fire dispatch, logistics, radio operations, incident command, aviation, supply cache management, and fuels management, among others. Some of these firefighters may not experience heat or smoke exposure, but they experience many other high-stress and demanding elements of the wildland fire environment, including trauma, sleep deprivation, driving and transportation hazards, interpersonal interactions, and others. Further studies are needed to understand the impacts of the work environment on their health and well-being.

Finally, the field has a deficient understanding of the relationship between physiological and physical parameters of work and exposure. As wildland firefighters work harder in smokier conditions, their ventilation rate increases, which likely increases the amount of exposure to airborne particulate matter and smoke. Likewise, not all positions on a fireline experience the same amount of smoke, and this is largely governed by terrain and atmospheric conditions. Reinhardt and Ottar linked smoke exposure to fireline position, fire type (prescribed fires yielded more exposure), task, and weather (2004); however, they stopped short of incorporating physiological measurements such as heart rate and ventilation rate into their study. We could identify no studies that included the combination of physiology, local geography, and exposure; however, synthesizing these variables will further resolve our understanding of fireline risk and inform future fire management and decision making. Additionally, our study found that researchers often pursued topics long enough to publish 1–3 papers, suggesting that funding may be a significant limiter in their ability to sustain research in this arena. Thus, researcher attrition may be driving a lack of deep exploration in the field, leaving critical gaps in knowledge and unaddressed needs for this population. Increasing focused and dedicated research efforts requires the commitment of both researchers and government agencies.

Limitations

Considerable variation in sampling methods, populations, and definitions of disease and fitness exists among studies. Subjective questionnaires also present inherent and systemic bias, which make assessment of differences among results difficult. Further, restricting this review to peer-reviewed literature excluded numerous federal

technical reports that contain valuable and relevant topical data. Despite these limitations, this review allows an opportunity to summarize and discuss the overarching themes within each subtopic, and this contribution advances our current understanding of the environmental health of wildland firefighters and offers paths for future research.

Conclusions

In conclusion, the scope of the current wildland firefighter environmental health literature reveals a need for more research into the psychological, physical, occupational, and overall health, well-being, and safety of a workforce tasked with defending communities, protecting natural resources, and preventing future wildfires. Studies that consider multifactor and interactive factors and that integrate physiogeography, ecology, sociology, and physiology will produce the most robust and informative science. Future work should prioritize these interdisciplinary perspectives, as they represent the frontiers of the field.

Abbreviation

PPE Personal protective equipment

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Authors' contributions

RMV compiled literature, wrote the manuscript, and conducted analyses. RMG conceived the project and compiled the original literature. MRR compiled and organized literature, edited the manuscript, conducted analyses, and categorized data. OC, AP, and SWP categorized data and conducted analyses. SW conducted analyses, prepared figures, and categorized data. MBH wrote the manuscript and analyzed and categorized data.

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SWP and RMG are wildland firefighters. MBH and MRR are graduate researchers. OC, SW, and AP are undergraduate researchers.

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All articles used in this publication are available online through their respective publishers and also at www.wildlandfiresurvey.com.

Declarations

Ethics approval and consent to participate

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Competing interests

The authors declare that they have no competing interests.

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