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Environmental health hazards and wildland firefighting: a qualitative analysis

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Abstract

Background Despite growing attention to wildland firefighter safety, little is known about the full scope of environmental health hazards experienced occupationally. Previous research has documented exposures to carcinogens and combustion byproducts from smoke, dust, ash, engine exhaust, ignition devices, and location-specific chemical and radiological hazards. With growing attention to firefighters' health outcomes, more research is needed on the environmental health hazards that they experience routinely and non-routinely. Qualitative research is well suited for exploratory investigations of environmental hazards. This study draws on a long-term ethnographic research project with federal wildland firefighters in Oregon to identify the environmental health hazards that wildland firefighters experience. I took detailed fieldnotes during participant observation working as a wildland firefighter with federal engine and handcrews. I also shadowed an incident management team, attended relevant meetings and trainings, and conducted 22 semi-structured interviews. I analyzed all data in NVivo, a computer program for coding qualitative data.

Results Wildland firefighters were aware of commonly identified hazards of their work, including smoke exposure, heat, and "human factors" such as fatigue and diet. Firefighters experience additional hazards that are rarely discussed. Routine but generally unacknowledged hazards include non-vegetation smoke, dust, chemicals in gear and equipment, and fuels and exhaust. Incident- and location-specific hazards include food and water quality concerns, hazards in government housing, and military, radiation, industrial, and mining hazards. Addressing these hazards is challenging because of both practical and cultural barriers.

Conclusion This exploratory cataloguing of the environmental health hazards faced by wildland firefighters is unlikely to be surprising to firefighters themselves, yet most of these hazards are underrecognized by land management agencies and researchers, and are incompletely mitigated in the work environment. Many of these hazards are (largely) invisible to those not working on the fireline or are only discussed in isolation, rather than as part of a cumulative or holistic understanding of firefighter health and safety. More attention by fire management agencies, fire leadership, and researchers is needed to the full range of hazards experienced by wildland firefighters.

Keywords Environmental health, Environmental and workplace hazards, Hazard mitigation, Wildland firefighter health and safety

Resumen

Antecedentes A pesar de la creciente atención que existe sobre la seguridad de los combatientes de incendios (i.e. brigadistas), se conoce poco sobre el conjunto de factores y los riesgos que implican en la salud ambiental que éstos experimentan en su trabajo. Investigaciones previas han documentado exposiciones a productos cancerígenos y de

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la combustión de subproductos que provocan humos, polvos, cenizas, los gases de escape de motores, las antorchas de ignición, y la ubicación de químicos específicos y peligros radiológicos. Con una mayor atención a los resultados sobre la salud de los brigadistas, muchas más investigaciones son necesarias para determinar los riesgos ambientales sobre la salud que ellos experimentan durante sus trabajos rutinarios y no rutinarios. La investigación cualitativa es la adecuada para realizar investigaciones exploratorias de los riesgos ambientales sobre la salud. Este estudio se basó en un trabajo etnográfico a largo plazo con brigadistas de incendios del sistema federal en Oregón, para identificar los riesgos en la salud que podrían experimentar estos brigadistas. Para ello, tomé datos detallados a campo durante una observación en la que participé trabajando como brigadista en una motobomba y con una cuadrilla pedestre. También participé como oyente en una reunión del grupo de manejo de incidentes, participé de reuniones y entrenamientos, y conduje 22 entrevistas semi- estructuradas. Analicé luego todos los datos con NVivo, un programa computacional que codifica datos cualitativos.

Resultados Los brigadistas, combatientes de incendios de vegetación, son conscientes de los riesgos que implica su trabajo, incluyendo la exposición a humos, al calor, y a los "factores humanos" inclusive la fatiga y la dieta. También experimentan riesgos adicionales que son raramente discutidos. Los riesgos rutinarios pero que generalmente no son reconocidos incluyen los humos no provenientes de la vegetación quemada, el polvo, los químicos en sus herramientas y equipo personal, y en combustibles y gases emitidos por motores. Los incidentes y riesgos específicos de su ubicación y estado, incluyen la preocupación por la calidad de los alimentos y del agua, los riesgos que implican los alojamientos y los riesgos militares, de la radiación, o de la industria y la minería. El enfocarse en esos riesgos es desafiante pues deben superarse barreras tanto prácticas como culturales.

Conclusiones Este catálogo exploratorio de riesgos ambientales sobre la salud que padecen los combatientes o brigadistas de incendios forestales, puede no ser sorprendente para ellos mismos, aunque los mismos riesgos son pobremente reconocidos por las agencias de manejo de recursos y por los investigadores, y son mitigados de manera incompleta en el ambiente de trabajo. Muchos de estos riesgos son (mayoritariamente) invisibles para aquellos que no trabajan en la línea de fuego o son solamente discutidos aisladamente, más que como parte de un entendimiento acumulativo y holístico sobre la salud y seguridad de los brigadistas. Más atención de las agencias de manejo, de los líderes en la gestión del fuego, e investigadores, es necesaria para entender el gran rango de riesgos que experimentan los brigadistas de incendios de vegetación.

Background

Wildland firefighting is a dangerous profession, in spite of extensive policies and initiatives intended to improve safety and decades of efforts to instill a "safety" or "learning" culture within firefighting agencies (Brown 2019; Pupulidy 2020; Flores and Haire 2021; Harris 2022; Cordner 2024). The physical risks from fires — such as burnover or entrapment — and the "common denominators" and frequent mechanisms of injuries and fatalities — from tree strikes to medical events — are well documented and integrated into many formal firefighter training programs (Wilson 1977; Holmstrom 2016; Page et al. 2019; Belval et al. 2024; NWCG 2025a). The occupational and environmental hazards experienced by wildland firefighters are receiving growing attention from researchers, agencies, firefighter organizations, and the public (Semmens et al. 2016; Navarro 2020; Ruby et al. 2023; Granberg et al. 2023; NWCG 2024a; IAWF 2025), yet exposures and health outcomes remain understudied (West et al. 2024; Held et al. 2024; Desservettaz et al. 2025).

The National Wildfire Coordinating Group (NWCG) has identified 32 environmental and workplace hazards experienced by wildland firefighters, including "physical, chemical, and biological hazards or workplace factors that are external to a person" (NWCG 2024a), p. 2). A recent systematic review summarized empirical evidence for wildland firefighters' routine occupational exposures to eight identified carcinogens: respirable particulate matter (PM), polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), crystalline silica, black carbon, asbestos, radionuclides, and metals (West et al. 2024; see also IARC 2023). A second recent review of environmental health risks concluded that wildland firefighters experience sustained and prolonged exposure to "wood smoke, particulate matter, ash, soil, heat, and prolonged physiological stress" (Held et al. 2024, p. 5). Wildland urban interface (WUI) smoke poses particular hazards: as examples, research on California's Palisades and Eaton Fires found that responding firefighters had higher levels of lead and mercury in their blood (Ozebek 2025), and firefighters responding to the 2023 Maui Wildfires had higher per- and polyfluoroalkyl (PFAS) levels in blood serum compared to other county employees (Beaucham et al. 2025).

Moving from exposures to health, research on wildland firefighters' health outcomes is limited but suggests cause for concern. In 2023, the International Agency for Research on Cancer (IARC) concluded that occupational exposure as a structural or wildland firefighter is "carcinogenic to humans," with sufficient evidence for mesothelioma and bladder cancer, and more limited evidence for melanoma, non-Hodgkin lymphoma, and colon, prostate, and testis cancers (IARC 2023, p. 717). While IARC focused primarily on structural firefighters, the report noted that wildland fires produce many of the same toxic combustion byproducts as structure fires, and WUI fires involve "simultaneously fighting structure and vegetation fires" (IARC 2023, p. 48; see also DeBono et al. 2023). Studies specific to wildland firefighters have found an 8–43% increased risk of lung cancer and a 16–30% increased risk of cardiovascular disease mortality (Navarro et al. 2019). Exposure to smoke and heat can cause acute changes in mental health and cognitive function, which compound with exposure to trauma and other social stressors to impact brain health (White 2025). Exposure to wildland fire smoke among wildland firefighters and the general population has been linked to acute and chronic health effects, including respiratory and cardiovascular illnesses, reproductive harm, and certain cancers (Navarro et al. 2019; West et al. 2024; Held et al. 2024; Ha et al. 2024; Desservettaz et al. 2025; Töpperwien et al. 2025). Wildland firefighters also experience elevated rates of physical injuries, heat-related injuries, reproductive harm such as miscarriages, and occupationally related illnesses (e.g., Butler et al. 2017; Jung et al. 2021; García-Heras et al. 2022; Granberg et al. 2023). Following recent legislative activities, some federal wildland firefighters in the United States are eligible for presumptive illness coverage for certain diseases (USFS 2023), including payments for cancer diagnosis or death (Cornyn 2025).

Wildland firefighters face myriad mental health hazards, including exposure to trauma, socioeconomic stress, isolation, conflict with loved ones, and off-season struggles, including population-specific barriers to care (Thompson 2014; Smith et al. 2022; Cooper and Duncan 2023). They experience higher rates of negative mental health outcomes, including post-traumatic stress disorder (PTSD), depression, anxiety, and substance use disorder, though limitations in the existing literature prevent clear comparisons with other populations (O'Brien and Campbell 2021; USFS 2022); Ruby et al. 2023; Granberg et al. 2023; IAWF 2025); Wagner et al. 2025). While mental health outcomes are typically understood and addressed as individual-level medical or psychological problems, a growing body of research shows that environmental hazards and occupational conditions are associated with measurable mental health outcomes (NASEM 2021).

Occupational hazards for wildland firefighters are a growing concern, as the positive feedback loop between aggressive suppression and future wildfire risk creates a "wildfire paradox" or "firefighting trap" (Withen 2015; Calkin et al. 2015; Ingalsbee 2017; Held et al. 2024). As Ruby and colleagues (2023) note, "as the incidence and intensity of the fire season and wildfires are expected to increase, it can be anticipated that [wildland firefighters] will face a larger physical and emotional burden" (p. 4612). Yet wildland fire's well-documented masculine, risk-tolerant, and hierarchical culture may discourage a focus on health and wellbeing (Desmond 2007; Pacholok 2013; Eriksen 2014, 2024; Eriksen et al. 2016; Brown 2019; Smith et al. 2022; Granberg et al. 2023; Padamsey et al. 2024), particularly health effects from chronic hazards, such as cancer, as opposed to acute hazards, such as entrapment. For example, survey respondents to the US Forest Service's "Life First" safety initiative described how hazardous working conditions and sources of "unnecessary exposure to risks" were routinized "and therefore unremarkable" (Flores and Haire 2022, p. 932).

Compared to structural firefighting, the risks of working as a wildland firefighter are less well studied (DeBono et al. 2023; Held et al. 2024) for several reasons. Wildland firefighters are a largely seasonal workforce; they are spread across numerous agencies and employer categories; they move between employers frequently, while structural firefighters may work for a single agency for their entire career; and relatively few wildland firefighters are unionized, compared to the highly unionized structural firefighting workforce. The lack of cohesive union advocacy has dampened attention to their health and safety, while complex occupational patterns and discontinuities in medical care make it hard to track wildland firefighters through their "multi-dimensional careers" (Held et al. 2024, p. 1). Additionally, wildland firefighters engage in a broad variety of tasks, ranging from less arduous camp work to arduous suppression activities (West et al. 2020). Job tasks interact with environmental factors, such as wind, and organizational factors, such as crew type, to predict exposures to hazards (Reinhardt and Broyles 2019; Broyles et al. 2019; Navarro et al. 2021; West et al. 2024).

Wildland firefighter health research has largely focused on inhalation exposures to wildfire smoke and its components, including carbon monoxide, PM, VOCs, PAHs, and metal(oid)s (Broyles 2013; Teixeira et al. 2024; Desservettaz et al. 2025). There is limited research on other hazards and exposure pathways, such as silica and VOC exposures from dust and ash, inhalation exposures

from engine exhaust and ignition devices, and location-specific exposure to asbestos and radionuclides (Carvalho et al. 2014; Eriksen 2021; West et al. 2024). Even relatively well-studied areas are limited; for example, research on smoke exposure has examined certain types of cancers and acute health effects, including lung and cardiac outcomes, with little attention to eye or throat-related effects (Held et al. 2024; Jaiswal et al. 2024). Most research is cross-sectional and unable to disentangle short- versus long-term effects, leading to "substantial gaps" (Held et al., p. 8). The existing research is almost entirely quantitative. Epidemiological and exposure assessment studies are designed to test concrete, pre-established hypotheses, while surveys of firefighters' self-reported experiences and outcomes largely use close-ended questions. Several studies have used interviews or open-ended survey questions to investigate mental health impacts, lingering physical impacts or illnesses after responses, exposure to hazardous equipment or facilities, and ocular impacts (e.g., Smith et al. 2022; VanderPyl and Eisen 2022; Granberg et al. 2023; Padamsey et al. 2024; Jaiswal et al. 2024; DeBusschere et al. 2025). However, no known qualitative studies focus on wildland firefighters' exposures to a broad range of environmental health hazards.

Methods

Given the substantial but understudied occupational risks experienced by wildland firefighters, this study asks: What routine and non-routine environmental health hazards do wildland firefighters experience on the job? I use qualitative methods of participant observation and semi-structured interviews. Qualitative research can identify patterns and nuances across cases and give voice to people's lived experiences (Ragin and Amoroso 2018) and is well-suited for exploratory investigations. In environmental health research, qualitative methods are useful for identifying exposures not previously considered by researchers and for understanding people's experiences with those exposures (Brown 2003; Scammell 2010). Ethnographic research, which involves long-term and immersive participant observation, is a valuable but underutilized method in occupational health and safety research (Durbin et al. 2024, p. 2). Compared to surveys or interviews alone, ethnography is better able to uncover what people actually do, not just what they say they do (Jerolmack and Khan 2014), and can identify aspects of people's experiences that are routine or taken for granted.

The data for this paper come from a larger project about wildland fire risk management and firefighter safety (Cordner 2021, 2024; De'Arman et al. 2024). I have conducted participant observation research since 2015 with firefighters and fire managers in a federal fire management organization in Oregon that I call the "Mountain View" district, a pseudonym to protect confidentiality. The project received IRB approval from Whitman College.

I completed the required initial and ongoing coursework and physical tests to receive my Incident Qualification Card (Red Card) as a Firefighter Type 2 (FFT2), allowing me to fill in on engines and handcrews with the Mountain View district. In addition to these routine fill-in roles, I accompanied an Incident Management Team (IMT) on complex incidents, shadowed other fire professionals including fuels and prevention technicians and public information officers, and attended trainings, meetings, and community events related to wildland fire. I am also a volunteer wildland firefighter with my local county fire department, which informs my understanding of wildland firefighter health and safety but contributes no data to this analysis.

During my fieldwork, I took detailed "jottings" (Emerson et al. 2011) in a small notebook, including shorthand notes, sensory descriptions, and direct quotes. I typed and expanded these fieldnotes as soon as possible after each day's fieldwork, typically that same evening. In addition to informal conversations throughout my ethnographic research, I conducted 22 semi-structured interviews with firefighters, fire managers, and other experts, including wildfire researchers and fire-adapted community specialists. After receiving informed consent, I recorded interviews digitally with the permission of interviewees, or took extensive notes if they declined recording. I transcribed interviews and removed names and other identifying information.

I coded fieldnotes and interviews in NVivo 14, a software program for analyzing qualitative data. Following Deterding and Waters' (2021) "flexible coding" approach, I conducted two rounds of coding to identify overarching "index" codes and then more focused "analytic" codes within those index codes. This analysis draws on the "environmental hazards," "environment," and "firefighter safety and health" index codes and 17 associated analytic codes. After coding, I identified patterns and themes in the compiled text segments, returning to the transcripts or fieldnotes as needed for elaboration or clarification. When using data from my fieldnotes or interviews in this paper, text in 'single quotes' comes directly from typed fieldnotes, while text in "double quotes" is verbatim quotations from field jottings or interview transcripts. This allows me to differentiate between people's own words ("verbatim quotations") and my recollection or summary of their words ('fieldnote quotations'), an important layer of fidelity to the people with whom I spent time. When useful, I also reference other examples from media, agency, or peer-reviewed sources to contextualize my

qualitative examples, but I did not conduct a systematic content analysis of these documents.

Results

The wildland firefighters I worked with through my research were broadly aware of widely discussed environmental health hazards, including smoke, heat, and human factors. Additionally, I identify two other broad categories of environmental health hazards: routine but unacknowledged, and incident- and location-specific hazards.

Widely recognized hazards

Wildland firefighters expressed general awareness of many of the commonly identified hazards of their work. Smoke, heat, and human factors came up frequently in conversations and interviews and were topics of formal trainings.

First, smoke was the most widely discussed and acknowledged on-the-job health hazard. Smoke hazards and mitigation are frequently covered in required NWCG firefighter training in the United States, from the foundational S-130 "Firefighter Training" course to the annual RT-130 "Wildland Fire Safety Training Annual Refresher" required for firefighters to maintain their Incident Qualification Card (NWCG 2025a). This formal attention to smoke makes sense given how frequently wildland firefighters are directly exposed to smoke. My fieldnotes are filled with descriptions of smoke: the sights and smells of smoky days, whether I could or could not see nearby landscape markers, and the physical experiences of working in smoke. For example, describing working downwind or "holding" on a small prescribed fire, I wrote in my fieldnotes, 'on the downwind side of even this small amount of fire, the smoke was thick and grey, heavy enough to burn my eyes and make my lungs crave fresh air.'

The firefighters with whom I worked told stories of working long shifts in heavy smoke, sometimes also sleeping in smoky air if fire camps were "smoked out." A fifth-year firefighter on an engine described his experience on a fire in heavy timber "where night and day were the same and you couldn't see 25 feet away from you." In addition to causing short-term effects including 'puffy, scratchy eyes, a sore throat, and shortness of breath, [he] said, "it wears on you mentally, too"'.

While the US Environmental Protection Agency (EPA) (2023) recommends that even healthy people reduce outdoor activities when the air quality index (AQI) is above 150, this is not reasonable in a wildland fire environment. Even when the AQI is not extremely elevated, routine work can include exposure to unsafe levels of smoke. For example, one day I filled in on a Mountain View engine. The district had no active wildfires but was impacted by wildfire smoke from neighboring jurisdictions. While we drove around the forest, people looked at smoke apps on their phones. The assistant engine captain had us guess the AQI a few times: the first time it was 160 and the second was 186.

Wildland firefighters described various practices to reduce smoke exposure. Given the dirty and sweaty conditions firefighters worked in and the physical exertion required of them, technological solutions such as wildland-specific respirators were generally seen as impractical. People were aware of technological initiatives to develop wildland respirators, but 'not everyone would wear it.' (In September 2025, N95 respirators were made available on large incidents but only for non-arduous work [NIFC 2025].) Rather, to reduce smoke exposure, firefighters talked about rotating places and duties to reduce the duration of individuals' and crews' exposures, or changing plans and practices to reduce overall smoke exposure. For example, a retired Type 1 Incident Commander (IC) said that fire managers 'have gotten smarter about limiting smoke exposure, making changes in where you locate people on the fire, rotating them out of heavy smoke areas, and limiting exposure during mop-up.' Similarly, when I asked two assistant captains how they dealt with smoky conditions, they traded suggestions about staffing and using other tools to reduce exposure: 'to avoid smoke, they can bump farther out into the green, since when you're holding your job is to make sure the fire doesn't spot into the green. You can also swap out people who are patrolling, and you can do more with UTVs or ATVs [utility- or all-terrain vehicles] instead of having a whole crew in there.' These firefighters described using crew positioning in unburned areas farther from the fireline ("bumping" farther into "the green") to reduce smoke exposures.

Second, heat was, unsurprisingly, a common topic for firefighters. Many wildland firefighters work where hot and dry summers are normal, and they can additionally experience extreme heat on incidents. "Heat Stresses" and "Heat Disorders" are dedicated topics in the "6 Minutes for Safety" training modules produced by NWCG and are commonly discussed by crews and firefighters during daily briefings and trainings (NWCG 2024b). After covering Heat Disorders in a morning briefing, a Mountain View Assistant Fire Management Officer (AFMO) asked if anyone had experienced a heat illness; one handcrew member described how he 'got to the top of the hill and my eyes rolled into the back of my head.' While leading a training on structure protection, a captain in a mixed structure and wildland department described his experience on an off-district fire in Arizona 'in 115 degree heat

with 6% RH [relative humidity]… Eventually they pulled the firefighters off structure protection because no matter how much water they drank they couldn't get them to pee white.'

Firefighters routinely use behavioral and avoidance strategies to address the heat. For example, as I described in my fieldnotes, on one 'really hot' June day on an engine, 'we tried to stay cool by standing in the shade when the truck was parked. When we were driving around, we had all the windows open or the AC on, and the three of us in the back rolled our pants up to our knees.' Yet exertion in extremely hot conditions is unavoidable during wildfire response.

Finally, human factors such as fatigue and nutrition were frequently discussed in relation to firefighters' health. These factors are different from the external, environmental hazards of smoke and heat, but they are widely acknowledged by researchers and fire management agencies as important for firefighter health (e.g., Wallace-Webb et al. 2025). Firefighters receive formal training related to nutrition and fatigue, including 6 Minutes for Safety on "Firefighter Nutrition" and "Fatigue and Stress" (NWCG 2024b). As a training officer explained, 'there is growing research higher up on firefighter health, diet, and bodies. "It used to be that all you needed to go out on the fireline was coffee and chew, and you were good to go." Now they're paying more attention to what the firefighter needs.' Though one of my initial FFT2 instructors suggested 'limiting caffeine consumption,' consumption of coffee and energy drinks is ubiquitous. In addition to coffees or energy drinks brought from home, firefighters on the Mountain View district would sometimes do "store stops" at convenience stores or coffee stands for snacks, energy drinks, coffee, and nicotine products; many firefighters packed instant coffee and cans of nicotine products in their overnight bags; and every engine had a JetBoil camp stove so people could boil water for coffee. Firefighters have limited control over dietary choices on extended and complex incidents, as I discuss in greater detail below.

Fatigue was another frequently experienced and discussed hazard. When I explained to one firefighter my interest in risk management, he replied, 'like how we're "drunk idiots" after a 29-hour shift?' While official policy dictates a 2–1 work-rest ratio requiring eight-hours off after a 16-h shift, this requirement can be surpassed during initial attack (IA). One experienced firefighter shared stories about fatigue and risk after working long days: 'in pre-season, you learn about people's attitudes and work ethics, and then you see the decline in their attitude when they are fatigued. If you are working IA on a fire, they will really try to get you a replacement after 30 hours on the line.' I heard innumerable stories of people working 24+ hour shifts during emerging incidents, and I personally worked on IAs that violated the work-rest ratio. A recent survey of federal wildland firefighters found that such violations were common: two thirds of surveyed firefighters had violated the work-rest ratio more than three times in the previous year and a quarter had violated it more than 10 times (Granberg et al. 2023).

Thus, wildland firefighters are aware of major environmental and health hazards identified by fire management agencies and studied by researchers. Through my ethnographic research, I identified two other broad categories of hazards that firefighters experienced, but that are not part of this general knowledge base and are not the focus of routine training and mitigation: hazards that are *routine but receive little acknowledgement*, and hazards that are *specific to an incident or location*. While these conditions are likely not surprising to firefighters or fire managers themselves, they are underrecognized as potential hazards by researchers, agencies, policy makers, and the public. Furthermore, many of these hazards are routinized, normalized, or minimized through comparison with more acute hazards, particularly those related to fire behavior, while others are partially mitigated through informal training or ad hoc practices.

Routine but unacknowledged hazards

Wildland firefighters are routinely exposed to several categories of hazards that are largely unacknowledged: non-vegetation smoke, dust, chemicals in their personal protective equipment (PPE) and other gear, engine exhaust, and fuels and oils.

Non-vegetation smoke

Wildland firefighters can be exposed to complex WUI smoke. When I completed an NWCG course on operations in the WUI, the instructor emphasized "toxic smoke" from propane and heating oil tanks, burning vehicles, chemicals and fluids, and illicit drugs; 'there are a lot of carcinogens in car fires or house fires.' The "Red Book," which sets interagency standards for wildfire operations, states that "wildland firefighters will not take direct suppression action" on non-wildland fires (DOI and USDA 2024, p. 158). Despite this policy, firefighters can be exposed to complex non-vegetation smoke in many ways. First, regardless of the official prohibition, they sometimes directly engage in non-vegetation fire suppression. For example, I was part of an engine crew that was first on-scene of a car fire along a highway cutting through the Mountain View district. When we arrived, the car's hood was fully engulfed in flames. The engine captain and another firefighter sprayed foam directly into the windows, on the hood, and onto the ground below the car. After knocking down the flames,

they then worked to open the steaming hood, first with tools and then with gloved hands. As I wrote in my fieldnotes, 'we kept our heads away from the smoke as much as possible, but I still got a bit of the nasty, chemical, rubber-tasting smoke. It was like it coated my tongue with burnt rubber.' Later on, we stood about 20 feet from the fire:

> *but we could still smell it… I asked if they thought they were well trained for this. [The engine captain] said, "not really, this is one of those low frequency, high risk events. The training we get is just classroom and talking through how you'd deal with a car fire." None of them had ever suppressed a car fire before. [The other firefighter] said he'd received zero training in his two years on what to do with a car fire situation.*

Wildland firefighters also frequently respond to wildland fires that burn non-vegetation materials. On one large incident, I chatted with operations people about a "hazmat house" within the fire's footprint that had 'a 10 lb bucket of some chemical… and 2 empty dynamite boxes used as storage units.' Another firefighter described working on a fire that burned down his crew's station, incinerating 'engines, buildings, RoundUp [an herbicide], spray paint, propane tanks, bar oil… and all their personal possessions.' He described the smoke as thick and recalled 'coughing up black stuff for a couple of days and had to get an inhaler to open his lungs up.' While this experience is extreme, it represents the intensity of potential WUI hazards.

As non-resident camper encampments have become more common and established on some federal lands (Cerveny and Baur 2020; Derrien et al. 2023), possessions and garbage pose increasing hazards to firefighters. For example, a crew captain described responding to a fire in an encampment 'that was literally a pile of trash burning in a hole in the ground.' To reduce their exposures to the smoke, the firefighters 'fiber-taped a hose to a tree so it sprayed water into the hole,' allowing them to 'empty their engine into the fire' farther from the smoke. Fires have also burned through illicit cannabis cultivation operations, exposing firefighters to hazards such as chemicals, garbage, and plants, as well as violence (USFS 2025a).

Hazardous smoke is also a concern during prescribed fire or pile burning. As an AFMO told me, with a prescribed fire, 'you're holding and mopping up in that smoke for days, but no one did a sweep of the unit to make sure there wasn't garbage or other things that would be bad to burn.' Another concerning exposure comes from the intentional use of plastic in slash piles. In some geographic areas, thick plastic is laid over the pile and additional woody debris is added to the top. A firefighter explained 'that the plastic keeps the wood underneath dry so the fire will carry really well' when the piles are ignited later. Burning plastic can release dioxins, furans, halogenated flame retardants, phthalates, toxic metals, PAHs, and bisphenols, which are associated with a range of harmful health outcomes (Velis and Cook 2021). Body positioning and awareness of the wind may reduce, but not eliminate, exposure to smoke from pile burning. For example, on a day spent burning piles with several fuels technicians, I wrote in my fieldnotes, 'the burning piles gave off a ton of smoke and a strong wind swirled around in the small clearing, sending smoke everywhere. Usually I could hold my breath in the smoke long enough to either wait for clean air to be blown in or to step outside of the smoke, but a few times the smoke was so consuming that it burned my eyes and took away sight completely.' Even with individual-level mitigations, smoke exposure cannot be fully avoided.

Dust

Wildland firefighters are routinely exposed to high amounts of airborne dust, which can contain mineral, metallic, chemical, and mold components, and is a respiratory hazard even at low doses (WHO 1999). This is routine during driving. From my rural background and conservation jobs before becoming a sociologist, I had enough of a "country habitus" (Desmond 2007) to know to quickly roll up windows when vehicles approached on dusty roads. This practice was strictly followed by wildland firefighters, who rolled up windows as vehicles and their dust clouds passed. These fieldnotes from a day spent with an engine exemplify the ubiquity of dust exposure: 'It was really dusty. The engine would put up a cloud of dust in front of it when it was driving really slowly. A few times we ended up behind slow moving cars, who put up a constant stream of dust. My nose was dry and always felt like it had crusty boogers.' Vehicles' air filters were checked and blown out regularly; after one off-district fire, a Fire Management Officer's (FMO) vehicle's engine had to be completely rebuilt after becoming clogged with particularly fine "moon dust."

Though I never heard dust covered in official training courses or morning briefing as a hazard, firefighters themselves expressed concern about their exposure to dust. For example, one tender operator with over 30 years of fire experience named dust as a top hazard: 'dust is a really big deal. You're exposed to it all the time and there must be all kinds of stuff in it.'

Chemicals in gear and equipment

Wildland firefighters are routinely exposed to hazardous chemicals in their PPE, other gear, foam, and retardant.

Firefighters typically wear their Nomex pants all day long, possibly excluding physical training (PT) time when at their home district (though sometimes PPE is worn for hikes or other PT), and their Nomex shirt — their "yellows" — whenever within an active fire perimeter. At Mountain View, people typically wore exercise or street clothes for morning briefing and PT, and then they changed into forest green Nomex pants — their "greens" — for the rest of the workday. Meals in the field were often eaten either sitting in the truck or on the ground, with food sometimes placed directly on greens. Thus, through food-to-textile ingestion and dermal exposure, firefighters are chronically exposed to any chemicals in or contaminants on their PPE.

A recent study by the National Institute of Standards and Technology (NIST) measured PFAS in multiple wildland PPE textiles, finding total levels of PFAS in some wildland PPE higher than PFAS levels in structural firefighter gloves or hoods (Thompson et al. 2024). PFAS are a broad class of chemicals associated with various cancers, hypertension, heightened cholesterol, reproductive issues, and reduced immune function (Fenton et al. 2020; NASEM 2022); US Epa 2024). Concerns over PFAS exposure and toxicity have led to state-level bans on intentionally added PFAS in textiles or structural firefighting PPE (Safer States 2024). In currently unpublished research, applied nuclear physicist Dr. Graham Peaslee, an expert on chemicals in firefighter PPE (Peaslee et al. 2020; Young et al. 2021; Muensterman et al. 2022), measured certain compounds in four wildland PPE garments (G. Peaslee, University of Notre Dame, Notre Dame, Indiana, USA, personal communication 2025). Dr. Peaslee's tests found only trace amounts of total fluorine, indicating either cross-contamination with PFAS from some other gear "rubbing off" onto the PPE or fluorine as a contaminant of another halogenated product. However, these tests found measurable bromine in all PPE and high levels of bromine on one PPE jacket, likely indicating the intentional use of brominated flame retardants (Peaslee personal communication). Brominated flame retardants are carcinogenic and toxic to multiple organ systems (Xiong et al. 2019; Shen et al. 2024).

Once worn on incidents, PPE can be further contaminated by "hazardous chemicals from smoke, soot, and ash, as well as naturally occurring compounds" (NWCG 2025). While the NWCG advises firefighters to decontaminate and launder their PPE "as frequently as possible" and to bring extra sets on assignments (NWCG 2025), in practice this is both logistically complicated and culturally difficult. As a 2024 US Forest Service (USFS) blog discussed, a "dirty yellow" is culturally glorified and often worn with pride: "it's frequently considered a tangible, wearable sign" of hard work and "calls for respect" (USFS 2024). This same blog encouraged readers to think of dirty Nomex as "contaminated," not "cool." Despite formal training and leadership encouragement to wash PPE, in practice, dirty PPE is ubiquitous. Experienced firefighters told me about finishing an assignment with their yellows so stiff with dried sweat, dirt, and soot that their PPE would stand up on their own (see also Padamsey et al. 2024, p. 7), and others affectionately teased a fellow crew member wearing a new, bright yellow "banana" shirt.

Wildland firefighters can also be exposed to retardants and foams. Though in theory aerial retardant drops should never hit firefighters directly, being "painted red" happens due to communication challenges between aviation and ground resources, confusion during emerging incidents, or pilot or firefighter mistakes. For example, I worked on the IA of a Mountain View fire in thick timber, and aviation resources were ordered. After the Lead plane buzzed by, our captain pointed to the smoke marking the intended location for the retardant drop. As I described in my fieldnotes:

> *a dozen or so seconds later, there was an air tanker dropping red slurry onto the trees just in front of us. We were close enough that we could hear the soft rain-like sound of the retardant landing on logs. We found out later that [two other firefighters] were close enough that they were hit by a load of retardant; their hardhats, packs, and even the lids of their water bottles were dusted with rust-colored drops.*

Long-term wildland retardants currently used by the USFS are described by the manufacturer as hazardous to the respiratory system, skin, eyes, and gastrointestinal system (USFS 2025b), and first aid measures suggested following exposure, such as rinsing eyes or washing skin with water, may be impossible in field conditions. Retardants also contain concentrations of heavy metals significantly above drinking water regulatory limits (Schammel et al. 2024).

Firefighters can also be dermally exposed to firefighting foams used on many engines. Wildland engines are often equipped with Class A foam, which acts as a surfactant to suppress fires and prevent re-ignition. (Class A foams do not contain intentionally added PFAS, unlike Class B foams used for suppressing flammable fuel fires.) Class A foams approved by land management agencies carry safety warnings for skin and eye irritation, allergic reactions, skin corrosion, respiratory irritation, and central nervous system damage (USDA 2025). The Class A foam used on the Mountain View district was labeled with "DANGER," "causes skin irritation," "causes serious eye damage," and instructions about washing exposed eyes and skin thoroughly. Yet dermal exposure was certainly possible, even outside suppression activities. For

example, on one ride-along with a Fuels Technician, I was asked to clean out an empty foam container and fill it with water to douse campfires, tasks I completed with ungloved hands. On another instance, after our engine crew cleaned up a garbage-filled abandoned camp, the engine captain 'set up light foam out of the engine and we washed our hands with foam, then rinsed with clear water [from the same engine]. Then we had lunch sitting on top of the engine.'

Another hazard is the smoke released when using fusees, handheld ignition torches used in prescribed fire, backfires, and burnouts. The "Firing Devices" unit of S-130 lists "emit noxious fumes" as one of fusees' "disadvantages" (NWCG 2025b). Firefighters widely recognized fusee smoke as something to be avoided, and experienced firefighters provided training in individual-level risk mitigation that went beyond formal policies. During my initial S-130 course, our instructor taught us to hold our breath while igniting fusees to avoid the fumes; as we practiced striking the fusees, one of my classmates 'got a lung-full lighting her [fusee], and said she could still taste it at dinner that night.' Earlier fusees contained perchlorate, a chemical used in munitions and rocket fuel that disrupts hormones and harms human development (Steber et al. 2010). The fusee brand used by US federal agencies has been perchlorate-free since 2015 but contains multiple other toxic chemicals listed by the manufacturer as hazardous for skin, eye, and respiratory irritation (Orion 2020).

A final category of chemical hazards results from atypical projects done by wildland firefighters at their home bases or districts. For example, an engine crew I worked with was tasked with applying a heavy-duty stain to newly built benches at a public Mountain View building. We stained benches wearing rubber gloves but with no breathing protection. Firefighters may also apply pesticides as part of routine grounds maintenance, though it is unlikely they receive formal pesticide applicator training. Year-round permanent employees may experience more of these hazards and more atypical hazards. For example, an FMO told me that during one off-season, several firefighters remodeled their office floors, taking out multiple layers of flooring with no respiratory protection. Only afterwards did they learn from an engineering colleague that the flooring contained asbestos.

Fuels and exhaust

Wildland firefighters experience routine exposures to hazardous substances and exhaust from vehicles and other equipment, including chainsaws, small engines, and ignition devices. As Mountain View firefighters operated and maintained vehicles and equipment, they could experience (near) daily dermal and inhalation exposures to diesel fuel, gasoline, engine oil, transmission oil, mixed fuel (gas and oil) for small engines, and chainsaw bar oil. Checking and refilling vehicle fuels was done without gloves, as were some aspects of chainsaw or other small engine maintenance because of required dexterity. I described one chainsaw task in detail in my fieldnotes: the assistant engine captain asked me and another firefighter to 'top off the Dolmar's fuel [for the chainsaw]… [We] both had bare hands opening and closing the fuel cannisters, attaching the hose, etc. I definitely got fuel on my hands and could smell the strong smell of mixed fuel.'

Wildland firefighters are routinely exposed to vehicle exhaust. Diesel exhaust is a known carcinogen, and gasoline engine exhaust is possibly carcinogenic (IARC 2012); Benbrahim-Tallaa et al. 2012; West et al. 2024). Depending on station configuration, some vehicles may be parked inside, exposing firefighters to exhaust while vehicles idle. One Mountain View firefighter compared their exposures to those of structure firefighters: it's 'just like structure engines, since they're parked and started inside… The buildings don't necessarily have good ventilation systems, and there isn't money to retrofit them.' Wildland firefighters can also be exposed to exhaust throughout their shifts while driving around patrolling for fires, when vehicles idle while on incidents, or while running tender or engine pumps. Regulatory and union advocacy work has raised awareness about exhaust exposure for structural firefighters (IAFF 2025), but this issue is less recognized for wildland firefighters.

Wildland firefighters are also exposed to two-cycle engine exhaust during routine work, including chainsaw, water pump, or other motorized brush or cutting tools, and to diesel or mixed fuel fumes and smoke during firing operations with ignition devices such as drip torches. Sawyers have close and continuous exposure to mixed fuel fumes and exhaust, while swampers and other crew members have more diffuse and intermittent exposure. In addition to exhaust, sawyers and swampers can be exposed to airborne wood dust, a respiratory irritant and carcinogen (OSHA 2025). Similarly, operators of water pumps have close and continuous exposures to mixed fuel exhaust. While a rigorous time-use study of wildland firefighters delimited saw work as only a small percentage of daily work across the full workforce (West et al. 2020), working as a sawyer or pump operator is a role likely assigned to select personnel for partial or full shifts, possibly day-after-day, meaning that some firefighters would have much higher exposures than average. During prescribed fires or burning operations, firing personnel might carry a drip torch for most of their shift, experiencing dermal exposure to fuel each time they refilled and continuous fuel vapor and smoke exposure while burning.

These hazards can be intensified by faulty equipment. Several times during my fieldwork, I observed particularly smoky emissions from saws or brush cutters that firefighters attributed to incorrectly mixed fuel. Improperly maintained equipment can also increase emissions. For example, during one afternoon clearing brush, I swamped while two other firefighters used brush cutters; one 'blade was really dull and smoked a lot.' These examples show how work assignments and equipment issues can greatly increase firefighters' exposures to these hazards.

Incident- and location-specific hazards

Wildland firefighters also experience hazards specific to their work location or incident.

Food and water hazards

Wildland firefighters can receive hazardous food and water on extended or complex incidents. Wildland firefighting is extremely physically taxing, with research estimating that firefighters need to consume 4–6000 cal per day (Ruby et al. 2023; NWCG 2025c). I heard innumerable complaints from firefighters about food on large incidents, ranging from nutritionally insufficient to downright hazardous, including the rhetorically infamous "rainbow meat," moldy bread, rotten food, and food with animal damage. As one example, a firefighter recounted his experience on an extended incident:

> *the food was really bad at [the fire]. They ran out of lunch one day and they didn't get lunch till 3pm, and then it was a single deli sandwich, a bag of chips, and a soda. The next morning, they didn't get breakfast but the lady showed them a garbage bag of croissants and said, the "critters got into this last night", so [he] looked for one without visible bites out of it.*

Firefighters also have high water intake needs of 6–10 L per day (Ruby et al. 2023). When working on their home unit, firefighters can refill their own bottles or drink bottled water from a frequently restocked cooler. When working on extended incidents, the available drinking water may be of questionable quality: water from plastic storage jugs stored atop their engines for days or weeks, water bottles sitting out in the sun for an unknown length of time, or water treated with iodine or other disinfecting agents. Levels of potentially hazardous compounds from plastic bottles, such as bisphenols, microplastics, and phthalates, increase over time and in sun or heat (Ravanbakhsh et al. 2023; Massahi et al. 2025), meaning that firefighters may be exposed to high levels of these contaminants through the water provided to them on incidents.

Government housing

Numerous wildland firefighters described hazardous conditions in the government housing available in some locations. While living in government housing is typically optional, it may be perceived to be the only realistic housing option for extremely remote stations or the only affordable housing option for expensive cost of living locations.

Some government housing facilities are poorly maintained. Firefighters mentioned hazards including asbestos, black mold, lead, animal and insect infestation, broken appliances, leaking roofs, and filth. For example, a former hotshot described living in the barracks for his hotshot crew 'and how gross they were… There are mice and rats everywhere.' Another firefighter worried that if they complained about conditions in their government housing, the facility would not be repaired and instead would be "red tagged" and closed entirely. Hazardous government housing has also impacted other agency employees, as in the case of Yellowstone National Park employees and their children who were exposed to high levels of lead from government housing (Mohr 2025). A recent survey of federal wildland firefighters identified facility hazards including "black mold, rodents, faulty electrical, vehicle breakdowns, cramped and outdated facilities, building flooding, lack of heat in buildings, [and] broken windows," and noted that firefighters lacked confidence that reporting would lead to needed repairs (DeBusschere et al. 2025, p. 143).

Military, radiation, mining, and industrial hazards

Incidents can have locally specific environmental health hazards. Wildfires respect no jurisdictional boundaries and can burn onto military facilities, industrial sites, and waste facilities, exposing firefighters to hazards ranging from unexploded ordinance to toxic waste. For example, the IMT that I shadowed managed a fire adjacent to a former US nuclear weapons location. During an operations briefing, a Division Supervisor joked that, because of radioactivity, "the good news is, you won't need a light stick." Fires such as the 2000 Cerro Grande fire or 2020 fires in the Chernobyl Exclusion Zone have burned through sites with concerning levels of radioactivity (Wolfe et al. 2004; Eriksen 2021), and firefighters on the 2023 Pole Mountain Prescribed Fire discovered unexploded ordinance (E-632 Engine Boss 2023).

Fires can also burn in areas with abandoned or active mining operations. There are an estimated 500,000 abandoned coal mines in the United States (US DoI OIG 2023) and 390,000 abandoned hardrock mine features on federal land (US GAO 2020). On another large incident, an Agency Administrator highlighted abandoned mines as a safety issue: 'beware of mining pits. This area has

been mined for more than a hundred years… He went to the big fire map on the wall and pointed out all the purple spots [showing] silver and uranium mines.' Mining locations or geographic areas with naturally occurring asbestos can also pose an inhalation hazard to firefighters. For example, in 2023 a fire burned through the Libby Asbestos Superfund site in Montana (MTN News 2023); thankfully, air monitoring found no detectable asbestos (EMSL Analytical, Inc.2023). Previous research on other incidents has found that wildland firefighter exposure to asbestos can exceed health-based thresholds (West et al. 2024, p. 759).

Barriers to addressing environmental health hazards

Wildland firefighters face numerous environmental health hazards from both routine and location- or incident-specific aspects of their work. Firefighters are generally "taught to mitigate many environmental hazards" through training and certification (NWCG 2024a, p. 2). There are dozens of current trainings related to environmental hazard mitigation in the 2024 Red Book, Incident Response Pocket Guide (IRPG), and 6 Minutes for Safety (NWCG 2024a), but the majority cover physical hazards such as fire behavior, vehicles, or extreme weather, with less attention to chemical hazards. Following a "hierarchy of controls" method could reduce firefighters' exposures to hazards (OSHA 2023). Elimination of the hazard is the most effective control, but this is impossible for many hazards in the wildland fire environment. Controls related to improved PPE and administrative controls are less effective and face both practical and cultural challenges.

First, interventions to reduce hazards are challenged by practical considerations. The work environment for wildland firefighters offers a unique combination of "physiological, psychological, performance, and safety demands," including long and unpredictable shifts in remote, isolated, and rugged locations with limited infrastructure, making guidelines intended for structure firefighters impractical for wildland firefighters (Held et al. 2024, p. 2; see also Ruby et al. 2023; West et al. 2024). Some hazards, such as wearing Nomex, running a chainsaw, or maintaining vehicles, are necessary parts of the job. Perhaps it is not inevitable that required PPE will contain toxic chemicals, or that caterers will sometimes provide unsafe food, but that is the lived reality of wildland firefighters today. Location-specific hazards, such as mining or legacy nuclear sites, can only be completely avoided by not responding to incidents in or near those locations. Similarly, the USFS's Wildland Fire Metareview concluded that significantly reducing risk to firefighters from physical hazards and fire behavior would require a fundamental — and widely unpalatable — transformation in operations (USFS 2022, p. 45). These practical considerations mean that some hazards cannot be removed without fundamentally changing the nature of wildland firefighting, an intervention that seems unlikely given a reinvigorated focus on aggressive direct suppression by federal agencies (Shultz 2025).

Practical considerations also limit opportunities to reduce exposures. One particularly important exposure route for wildland firefighters is incidental ingestion of toxicants on the hands. It is necessary to consume food on the fireline, but it may be impossible to wash hands with soap and water, meaning that substances on the hands are routinely ingested during eating and other hand-to-mouth activities. From my observations, it was extremely common to eat in the field without hand cleaning, though hand sanitizing after certain types of bathroom activities, like using a porta-potty or outhouse, was widely practiced. For example, one day I shadowed a hotshot crew on a thinning project. As the sawyers finished the last few minutes of cutting for the morning, the crew superintendent and I chatted about their lunch plans, and he joked, "two things you don't mess with for firefighters are food and sleep." At noon, everyone stopped working and gathered near the crew buggies to refuel and clean their chainsaws, filling them with mixed fuel and bar oil, sharpening the saw teeth, and carefully cleaning components with an air compressor. Once all the saws were filled, cleaned, and put away, everyone sat in the shade on the side of the road and ate lunch, without washing hands. Any substances on the hands, including dirt, soot, bar oil, and mixed fuel, could have been ingested along with their meal.

Despite these practical constraints, hazard mitigation should be prioritized, though a full analysis of mitigation feasibility and efficacy is beyond the scope of this paper. For example, some hazards of small engine exhaust can be reduced by ensuring that equipment is properly maintained and functioning, and person-level exposures to small engine exhaust can be reduced by rotating people between positions. Simple handwashing stations or use of personal wipes may help to reduce dermal and incidental ingestion exposure, though IARC's evaluation of carcinogens and firefighting noted that "skin-cleansing wipes… will not remove all contaminants from the skin" (IARC 2023, p. 134). Previous exposure research has found that enhanced cleanliness on wildland incidents, such as handwashing, daily showers, and changing out of dirty Nomex, is associated with lower levels of PAH exposure (Cherry et al. 2019, 2021). However, these protocols may be impossible on extended or remote incidents.

Second, cultural factors mean that wildland firefighters may be reluctant to acknowledge or address hazards, particularly those that are routine and normalized. Despite extensive work developing a safety or learning culture in land management agencies, wildland firefighter culture remains risk tolerant and biased towards action (Desmond 2007; Brown 2019; Pupulidy 2020; Flores and Haire 2021; US Forest Service 2022). Firefighters are trained to think about risks as relative, potentially leading them to devalue chronic risks. For example, when I was initially taught about shelter deployments during my initial FFT2 training, the instructor noted the importance of carrying your GPS device, because sometimes retardants could be dropped 'right near where you are if you're deploying.' When a classmate asked if the retardants were toxic, the instructor replied, 'We're breathing in smoke all the time. "It's a life-or-death situation" if you're deploying, so don't worry about the retardants.' The chronic effects of retardant exposures were explained as insignificant compared to both the chronic exposure to smoke and the acute risk of burnover. This aligns with other observations that the inherently hazardous nature of wildland firefighting contributes to routinization or normalization of risks, which in turn can increase risk tolerance (Pupulidy 2020; Flores and Haire 2022).

Furthermore, the routine nature of some of these hazards hinders identification and action. A firefighter who is routinely exposed to vegetation smoke may be less likely to recognize the hazards of also being exposed to vehicle or small engine exhaust. Indeed, my first 2 years of fieldnotes contain very little commentary on inhalation hazards other than smoke and no mention of dermal exposures to toxicants; I interpret this as being because I was trained to see these hazards as a routine part of the job and thus not worthy of special attention. As an assistant engine captain told me, 'something bad is going to happen no matter what, so why try to avoid things' such as chemical exposures. Important cultural shifts towards health protection, including precautionary individual-level actions such as more frequent PPE laundering and operational-level practices such as rotating people out of smokier areas, have made ground across the fire service but face uneven adoption and resistance from a "toxic" and highly masculine organizational culture (Padamsey et al. 2024; see also Eriksen 2024).

Relatedly, some fire managers expressed concern about overwhelming new firefighters by placing too much emphasis on health concerns. Although firefighter training today involves extensive attention to risk, particularly around acute risks such as burnover and driving, experienced firefighters simultaneously expressed their personal concerns about toxicant exposures and their managerial fears of overwhelming and harming the mental health of newer firefighters. One AFMO described this tension:

> *you take a new person and spend two weeks training them and scaring them and saying everything will kill them, and then they say, no thank you! But you have to tell them about the risks now that we know about them… The Red Book says that supervisors can't knowingly put people at risk, so what you should you?*

These cultural and leadership challenges may also hinder identification and mitigation of some routine and incident-specific hazards.

Discussion

This paper has drawn on qualitative research with wildland firefighters to identify environmental health hazards experienced on the job. Firefighters show broad awareness of the smoke, heat, and human factor hazards that have received the most attention from fire management agencies and researchers. In addition, I identified two broad categories of hazards that wildland firefighters regularly experienced. Routine but unacknowledged hazards include non-vegetation smoke, dust, chemicals in PPE and other equipment, and fuel and exhaust from engines and equipment. Incident- and location-specific hazards include hazardous food and water on large incidents, hazards in government housing, and hazards from military, mining, or industrial sites. The everyday nature of routine hazards masks their potential to harm health, and many of these hazards are functionally unavoidable parts of the job or of incident response. As noted above, these hazards are likely unsurprising to firefighters or fire managers themselves, but they are largely invisible to researchers, agencies, policy makers, and the public, and they are inadequately included in current training and risk mitigation policies and practices.

I have largely focused on inhalation, ingestion, or dermal exposures to environmental and health hazards, but other hazards matter as well, including noise (e.g., from chainsaws), animals (e.g., aggressive dogs), insects (e.g., bees), plants (e.g., poison oak), infectious disease (e.g., "camp crud"), and interpersonal hazards (e.g., interpersonal violence). For example, a well-maintained chainsaw produces 125 decibels of noise, above OSHA's permissible noise level for an 8-hour workday of 90 decibels (OSHA 2008). During my research, I observed that even if sawyers and swampers ubiquitously wore ear protection, not all proximate crewmembers wore ear protection. Firefighters also experience concerning levels of threatening behavior, violence, and unwanted sexual contact and assault while working (Granberg et al. 2023, p. 1668).

With its focus on hazard, this study is not a risk assessment intended to quantify risk or determine the levels of exposures that could contribute to negative health outcomes. It is also not an industrial hygiene study intended to identify interventions or evaluate their effectiveness. Those areas of research are also needed, and this qualitative analysis provides a valuable foundation for future research and mitigations. Many hazards are not widely recognized, are (largely) invisible to those not working on the fireline, or are only discussed in isolation, rather than as part of a cumulative or holistic understanding of firefighter health and safety. By expanding the accounting of hazards to include those that are less visible or recognized, this analysis can direct agency and employer attention, firefighter awareness, and future research towards a broader array of hazards.

This study draws on participant observation with federal firefighters in a single fire management organization in the Pacific Northwest, though hazards vary significantly across firefighter job and employer types (Navarro et al. 2021). This qualitative identification is limited based on the types of work I observed or was told about in interviews and ethnographic conversations. This study also focuses on federal operational wildland firefighters, neglecting Held et al.'s (2024) call to attend to the broader "interconnected web of actors" that participate in and support wildland fire operations, such as dispatchers (Verble et al. 2024) or incarcerated firefighters (VanderPyl and Eisen 2022). This research also focuses on the hazards experienced by professional (paid) firefighters, though previous research has found differences between professional and volunteer firefighters' understanding of hazardous exposures, PPE protocols, and decontamination practices (Padamsey et al. 2024). Professional and volunteer firefighters have different initial and ongoing training requirements, receive different gear, and occupy different social and material positions within their fire organizations, and therefore may experience different exposures to environmental health hazards and understand those hazards differently.

Conclusion

The health and safety of wildland firefighters must be a top priority, not just during incident response but throughout a firefighter's career and lifetime. Understanding occupational risks requires attention not only to highly visible hazards such as smoke and heat, but also to hazards that have thus far received less attention because they are routine, relatively invisible to non-practitioners, or specific to particular locations or incidents. As wildland firefighters experience longer and more severe fire seasons (Iglesias et al. 2022; Kelley et al. 2025), their exposures to any environmental health hazards increase, necessitating comprehensive exposure assessment and risk mitigation.

Abbreviations

AFMO	Assistant Fire Management Officer
AQI	Air quality index
ATV	All terrain vehicle
DOI	Department of Interior
EPA	US Environmental Protection Agency
FMO	Fire Management Officer
GAO	Government Accountability Office
IA	Initial attack
IAFF	International Association of Fire Fighters
IARC	International Agency for Research on Cancer
IC	Incident Commander
IMT	Incident Management Team
IRPG	Incident Response Pocket Guide
NIST	National Institute of Standards and Technology
NWCG	National Wildland Coordinating Group
OIG	Office of Inspector General
OSHA	Occupational Safety and Health Administration
PAHs	Polycyclic aromatic hydrocarbons
PFAS	Per- and polyfluoroalkyl substances
PM	Particular matter
PPE	Personal protective equipment
PT	Physical training
PTSD	Post-traumatic stress disorder
RH	Relative humidity
USFS	United States Forest Service
UTV	Utility terrain vehicle
VOCs	Volatile organic compounds
WUI	Wildland urban interface

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Authors' contributions

AC designed the study, conducted the research, analyzed the data, and wrote and revised the manuscript.

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Data availability

Original data are not available because of the need to protect the confidentiality of research participants and locations.

Declarations

Ethics approval and consent to participate

This research was reviewed and approved by the Whitman College Institutional Review Board (#IRB 14/15-65). Informed consent was obtained from all participants.

Consent for publication

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Competing interests

The author declares no competing interests.

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