

The price of doing business: severe injuries in wildland firefighters in the United States by activity performed and hazard encountered

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ABSTRACT

Background. Wildland firefighters are exposed to hazards when working which can, and do, result in serious injury or death. Understanding the activities in which firefighters are engaged when they are injured, the hazards to which they were exposed during that activity and the resulting injury severity is critical to manage the risk of serious injury to firefighters. **Aims.** This study aims to provide an assessment of wildland firefighter injuries. **Methods.** A set of 435 severe injuries in wildland firefighters in the United States from 2019 to 2023 was classified by activity being performed, hazard encountered and injury severity. Statistical summaries were used to contextualize the data and to examine the frequency and severity of these injuries. Proportional odds models tested the impact of activity, region and fire complexity on injury severity. **Key results.** Aviation activities are associated with higher injury severity; there is no statistically significant difference in injury severity among other activities. Region and fire type do not impact injury severity. Injury frequency and severity vary among hazards and associated activities. **Conclusions and Implications.** Given the hazard mitigations in place, reducing injury frequency and severity may be challenging without clearly defined agency level risk tolerances.

Keywords: fire suppression, hazards, occupational health and safety, risk, safety, wilderness medicine, wildfire, wildland firefighter.

Introduction

Hazards in the wildland fire environment are abundant, and despite active mitigation measures, in the United States (US), the Interagency Standards for Fire and Fire Aviation Operations states, ‘A firefighter, utilizing the best available science, equipment, training, and working within the scope of agency doctrine and policy can still suffer serious injury or death’ (National Interagency Fire Center 2024, p. 4). Federal and state agencies with responsibility for wildland firefighting manage these hazards through the application of risk management tools and processes, yet it is acknowledged that injuries to wildland firefighters are still probable. For example, in its Operational Risk Management Guide, the United States Department of Agriculture (USDA) Forest Service (the United States Forest Service (USFS); the agency employing the most wildland firefighters in the US) states, ‘[o]n a wildland fire, for example, risk managers deliberately expose employees to many hazards in order to meet incident objectives including the objective of no harm to employees.’ (Risk Management Council 2020, p. 2).

The acute hazards to which wildland firefighters are exposed include standing dead (snags) trees (Dunn *et al.* 2019), steep and uneven terrain (Rodríguez y Silva *et al.* 2020), aviation operations (Stonesifer *et al.* 2014) and hazards from hand tools and mechanized equipment routinely used in fire suppression activities (Britton *et al.* 2013a; Andrade and Walsh 2023). Firefighters are also often exposed to hazards associated with the combustion process, such as radiant heat and contact with flames, which has resulted in numerous severe burn injuries and fatalities (Butler *et al.* 2017; Page *et al.* 2019). High concentrations of smoke and particulate matter are abundant in the work environment, resulting in increased risk of lung cancer and cardiovascular disease in wildland

firefighters (Navarro *et al.* 2019). Even when ‘off duty,’ while on suppression assignments, sleep quality may be hampered by communal camp issues such as noise, ambient light, heat, smoke and dust (Aisbett *et al.* 2012). This compounds the high levels of mental stress and physical exertion (Owen 2017; Held *et al.* 2024). Taken in isolation, any of these hazards is a significant threat to human health and well-being; when combined in the work environment of wildland firefighters, severe injury and fatalities become inevitable. Compounding the hazards wildland firefighters face is the remote nature of wildland fires, resulting in significant travel times as firefighters navigate complicated terrain. This can lead to lengthy evacuation times should a firefighter be injured in the performance of their duties. Transport to definitive care can often be in excess of several hours, leading to a degradation of patient care and outcomes (Campbell *et al.* 2019, 2024).

In 2017 the USFS Fire and Aviation Management (FAM) Risk Management staff began collecting data on severe injuries (those resulting in emergency transport and/or hospital admission, or fatality) for USFS employees and USFS contractors that occur across the agency during wildland fire management operations; the data were archived starting in 2019. Originally developed to test potential reporting mechanisms that could provide for agency executive awareness as well as enhance organizational learning, these reports, called the ‘Weekly Summary,’ have evolved to be a snapshot of firefighter injuries to USFS employees or contractors throughout the fire year (Scott Sugg, former acting Branch Chief of Wildland Fire Risk Management in the USFS, pers. comm. 2024). The information reported in the Weekly Summary is preliminary, subject to change and may not include every event that meets the criteria for severe injury. Reports provide a short description of each injury, often including data on the nature of the injury as well as information around the mechanism leading to the injury, the activity being performed when the injury occurred, the hazard responsible for the injury and the severity of the injury. The capture rate of all severe injuries in this dataset is currently unknown; FAM staff responsible for data entry have estimated anywhere between 30 and 80% of all severe injuries are captured in this data (USFS Risk Management Council, pers. comm. 2024).

Previous research to examine and quantify wildland firefighter injuries has primarily been drawn from three types of data sources: (1) official reports filed by the injured wildland firefighter to fulfill occupational requirements or to receive workers compensation for the injury and related lost work time, (2) surveys of wildland firefighters specifically regarding injuries, and (3) counts of injuries from incident reporting subsystems. One group of studies on firefighters employed in the US by the Department of the Interior identified that the nature of injury and injured body part were significantly associated with the mechanism of injury (Britton *et al.* 2013a), injuries were more likely as fire complexity increases and as the number of responders increased (Britton *et al.* 2013b), and that job assignment

(handcrew, engine, etc.) was significantly associated with cause of and nature of injury (Britton *et al.* 2013c). In a study of Ontario, Canada based wildland firefighters, age, experience and personality (measured using the NEO-PI-3 questionnaire; measuring Neuroticism, Extraversion, Openness, Agreeableness and Conscientiousness) explained a high proportion of the variance in a predicted first aid injury, yet high stress alone explained 15% (Gordon and Larivière 2014). One survey-based approach found that slips, trips or falls were the most common injury reported, while supporting previous work that the nature of injury and mechanism of injury were significantly correlated with the body part injured (Moody *et al.* 2019). While investigation into epidemiology of injury is critical, little work has described firefighter injuries in terms of the task being performed when the injury occurred, the specific hazards which resulted in injury, or the resulting injury severity, knowledge that could be applied by wildland firefighters in their real-time assessment and mitigation of risks.

Understanding which hazards and activities are driving severe injuries should help agencies employing wildland firefighters understand which risk mitigations could play a role in decreasing both injury frequency and severity. Additionally, understanding the nature of hazards in the work environment of wildland firefighters could help agencies develop risk tolerances which can improve resource allocations, and thereby safety (Schmidt 2016). The basic goal of this work is to contextualize the nature and severity of injuries sustained by wildland firefighters, thereby helping to reduce injuries. In the field of occupational health and safety, risk to employees is often assessed by considering two main factors: (1) the likelihood of a hazard causing an injury, and (2) the consequences for the employee associated with that injury (Jensen 2020). Mitigations focused on an individual’s actions such as safety management and the use of personal protective equipment are common in the field of wildland fire and, for some hazards, they are critical in reducing either the likelihood of a hazard causing an injury, the severity of an injury, or both. For other hazards, higher level risk management mitigations may be more effective at reducing overall risk, generally by reducing the overall probability of an event occurring by limiting the amount of exposure to a hazard.

In this paper, we provide three contributions to the existing literature on wildland firefighter injury. First, we cataloged the observations of injuries in the Weekly Summary to create a new dataset on firefighter injury that is fully compatible and comparable with previous studies. This dataset was categorized using an expanded framework of wildland firefighter injuries that allows injuries to be classified by activity performed when the injury occurred, the hazard to which the firefighter was exposed, and a metric and corresponding numerical index indicating injury severity. Our classifications were developed specifically for operational relevance, so that wildland firefighters and managers can understand the findings and apply them to their work.

Second, we used this framework to quantitatively examine firefighter injury severity by activity performed and hazard encountered. Specifically, we examined how injury severity varies among activities and hazards. Third, the contents of the Weekly Summary dataset were quantified and validated by comparing with multiple datasets used in previous research. We used these comparisons to contextualize how the weekly summaries might contribute to the broader field of research on wildland firefighter injuries and fatalities.

Methods

Data collection, classification, and contextualization

Weekly Summary narrative reports from 2019 to 2023 were aggregated into a tabular dataset that included a field for date, USFS region, national forest or unit name, US state, event type, incident name and resource type. The data were then categorized by injury mechanism, injury type, body part injured, activity category, hazard category and injury severity by two of the coauthors (E.B. and B.P.). See Fig. 1 for an example narrative summary and associated classifications.

Activity and hazard categories were developed by expert opinion of two of the co-authors who have both spent the majority of their careers as wildland firefighters with multiple federal agencies and have significant operational experience. The ‘activity’ category indicated what type of activity the individual was engaged in when the injury occurred. The ‘aviation’ activity category captured all aviation activities. An ‘environmental’ activity classification captured injuries that occurred due to hazards inherent within the environment, such as flora (e.g. Poison Ivy and Valley Fever), fauna (e.g. allergic reactions to insect stings) and gravity hazards (i.e. something falling on an individual), with no other indication of the activity being performed beyond the exposure to the environmental hazard. ‘Fireline’ activities were those that occurred during active fire management duties; injuries resulting from this activity were caused directly by the physical performance of fire management duties such as direct or indirect fireline construction, burnouts or mop-up. It is possible for injuries incurred during

fireline construction to be classified as environmental when the causal agent was not related to the human activity taking place in the area; for example, a tree that was untouched by humans or equipment falling on individuals engaged in fireline construction would still be classified as environmental because it was not the fireline construction responsible for causing the tree to fall. Injuries that occurred during ‘ground transportation’ activities were associated with transportation to, from, or around an incident including by vehicle, foot, or alternate means excluding aerial delivery. The ‘illness’ category captures medical conditions that were documented in the weekly summaries; for these injuries the nature of the environment or the tasks being performed did not appear to be the primary causal agent and assigning causality beyond the medical condition was difficult. Injuries which occurred or were caused by conditioning for work performance requirement was classified as occurring during ‘physical training’ activities. The final category of activity captures events that cannot be described by activities above (aviation, environment, fireline, ground transportation, illness or physical training); due to the contents of this dataset, we named this category ‘camp/staging/project work,’ which reflects the other activities in the data.

The ‘hazard’ category indicates the hazard to which the individual was exposed that resulted in injury. When in combination with the activity category, the hazard classification provides a relatively complete description of the injury cause. Thus, the hazard category has substantially more options than the activity category. While the hazard descriptions are self-explanatory, the interpretation of the event causing the injury was not always straightforward. For example, of the 465 incidents, 27 involved a chainsaw or driptorch. Many of these incidents involved both a slip, trip or fall and contact with the equipment. In these cases, if the equipment caused the slip, trip or fall, then we categorized the hazard as equipment. However, if the slip, trip or fall happened independently and the severity was made worse by the equipment, then the hazard was categorized as slip/trip/fall, with an additional category ‘specific hazard type’ that indicates when these combinations occur as well as document other details. We do not assess the specific hazard types further in this manuscript but included the data for safety and training purposes.

8/8/20XX R7 Example National Forest, Example Fire – burn injury. An engine crewmember experienced multiple burns to their face and neck from ember wash while performing holding activities during a burnout operation. The firefighter was transported via agency vehicle to a level 1 trauma center before being transported to a burn center, where they were diagnosed with second-degree/partial thickness burns. The individual was treated with a follow-up appointment at a burn center set for 8/15/20XX.

Fig. 1. An example Weekly Summary narrative report with highlighted fields showing how text was categorized. In orange: date, United States Forest Service (USFS) region, national forest or unit name, fire or incident name. Yellow: resource type, mechanism of injury, body part injured, activity performed, hazard encountered. Green: transportation type to definitive care, initial and subsequent care facility, clinical diagnosis. Blue: treatment duration information.

Table 1. A list of the injury severity categories and their corresponding numerical index value.

Severity category	Severity index numerical value
None	0.1
Treat and release	1
Minor hospitalization (1–2 days) or follow-up	10
Major hospitalization (2–5 days) or surgery	100
Life altering not fatal	1000
Fatal	10,000

The severity of each injury was classified into one of six categories using the following treatment duration or health outcomes: ‘none’, ‘treat and release’, ‘minor hospitalization (1–2 days) or follow-up’, ‘major hospitalization (2–5 days) or surgery’, ‘life altering not fatal’ or ‘fatal’ (also see Table 1). Each category was associated with a numerical index that scaled the six categories on an order of magnitude scale as shown in Table 1. Order of magnitude scaling was used for the numerical index as it represents the nonlinear relationship between categories; these scales are commonly used in process safety applications (Levine 2012; Azadeh-Fard et al. 2015; Duijm 2015; Schmidt 2016; Baybutt 2018). If assessed linearly, a fatality would be represented as only six times more consequential than no injury; order of magnitude scaling (that is, using a logarithmic scale) mitigates this issue. To assess the central tendency we considered geometric mean, median and mean. We used a simple mean due to the order of magnitude scaling of the index over the other two considered metrics which inappropriately classify the tendency on either linear or modality scale.

The activity, hazard and injury severity categorization for each injury was completed by two of the coauthors (E.B. and B.P.). The classification was further validated using a different set of classifications developed by another set of researchers also using this data: no discrepancies were found (Mateo Garcia, pers. comm. 2024). Classifications were generally quite straightforward with little ambiguity.

There are three main categories of fire management events for which injuries are reported for this dataset: fire suppression during the initial response phase ($n = 21$), fire suppression during the large fire/extended response phase ($n = 319$) and prescribed fire ($n = 21$). Other event kinds exist but do not refer to active fire application or suppression tasks, including: non-fire ($n = 18$, typically project work such as hazard tree removal), prepositioning ($n = 9$, staging in advance of elevated fire danger), training ($n = 5$) and unspecified ($n = 5$, no event kind specified in narrative). Event kind was typically identified within the narrative summary itself; in cases where it was unclear we referenced either the Wildland Fire Decision Support System (WFDSS, WFDSS 2025) or the ICS-209PLUS dataset (St. Denis et al. 2023) to

ascertain by date of injury whether the fire was in the initial response phase (within 24 h of detection) or large fire phase (over 24 h since detection or larger than 147 ha). WFDSS is a decision-support system required for all large wildfires that also captures many small fires. The Incident Command System Incident Status Summary (ICS-209) reports are filed on all large (> 147 ha) wildfires. The ICS-209PLUS dataset was further used to classify large fires by ‘fire complexity,’ which is determined by the type of incident management team that was managing the incident on the day of the injury.

We compared injury counts from the ICS-209PLUS dataset with the Weekly Summary, as well as fire characteristics on the day of the injury. We used data from the Incident Management Situation Reports (IMSR; Nguyen et al. 2024) to compare the total number of personnel on large wildfires each day during the fire season against Weekly Summary injury dates. We also compared previously published research datasets to the Weekly Summary dataset. We classified and compared the Weekly Summary dataset with injury mechanism, injury type and injury body part fields identified in (Britton et al. 2013a) and applied to data from the Department of Interior’s Safety Management Information System (SMIS). We compared previous work based on ICS-209 reports across seasonality, region and fire complexity to Weekly Summary data (Britton et al. 2013b; St. Denis et al. 2023), as well as against the data collected using the Injury Surveillance of WildLand FireFighters survey (ISWLFF) with compatible categorization of the Weekly Summary dataset (Moody et al. 2019). We also compared the contents of the Weekly Summary to the National Wildfire Coordinating Group (NWC) fatality dataset from 2001 to 2012 (Butler et al. 2017).

Statistical analyses

We use statistical summaries to examine the frequency of activities and hazards occurring across the dataset. Because hazard categories may map to more than one activity category, we use a Sankey diagram (Bogart 2024) to visualize the contents of the Weekly Summary by activity and hazard categories. We use bar charts to visualize the counts of the data by activity category and event type as well as the injury severity across activity categories, using the *ggplot2* library in R (Wickham 2016; R Core Team 2024).

We fit proportional odds models to predict the severity of an injury based upon the activity category, event type and region associated with each injury assuming a logit distribution (McCullagh 1980); we used the *clm* function within the *ordinal* library to fit the models (Christensen 2023). As the statistical test to check if the proportional odds assumption is met is very conservative, we visually tested the proportional odds assumption using slopes of individual logistic regression models (Harrell 2001). For the proportional odds models, to reduce the number of predicted categories as well as removing categories with very few observations, we folded

the 'none' category into the 'treat and release' category, and folded the 'life altering' category into the 'major hospitalization' category. We only included observations where the event type fell into the fire suppression or prescribed fire categories. The results of two proportional odds models are presented using graphs to compare mean predictions on the latent (or logit) scale to examine overall impact of each factor on mean injury severity. We compared proportional odds models with different predictors using Akaike Information Criterion (AIC) (Burnham and Anderson 2004).

Due to of the large number of hazard categories and therefore small sample sizes in each, opportunities for meaningful statistical analyses are limited. However, the injury severity index provides us with a mechanism with which to provide an initial examination of injury severities across hazard and activity combinations. We calculated the mean of the injury severity index for each hazard/activity category pair as well as the proportion of the injuries in the Weekly Summary that fell into the hazard/activity category. We graphed the frequency and average severity index on a scatterplot, with each hazard/activity pair represented by a single point to summarize results for operational audiences.

Statistical comparisons between Weekly Summary data and previous research data sets were implemented using Pearson's Chi-squared test for count data (Agresti 2018) in R using the *chisq.test* function within the *stats* package (R Core Team 2024). The *P*-value associated with Pearson's Chi-squared test indicates the probability that the differences between the counts in each category occurred by chance. To further contextualize the dataset, we drew data on injuries from the ICS-209PLUS database for the years 2019–2023. This allowed us to compare the ICS-209 injury rate (injuries recorded in the ICS-209s per day each person worked) with the Weekly Summary injury rate (injuries recorded in the Weekly Summary per day each

USFS employee worked). For the Weekly Summary injury rate, we counted all personnel classified within the ICS-209 data as 'private' personnel (i.e. personnel on fires not employed by any governmental or non-profit entity) as USFS contractors as we had no way to separate out USFS contractors from other contractors; this provides us with a true lower bound on a severe injury rate on large wildland fires for USFS employees and contractors.

Results

From 23 March 2019, through to 31 December 2023, a total of 465 injuries were documented through the Weekly Summary. These years range from an abnormally quiet US wildland fire season (2019) to extremely active (2020 and 2021) (National Interagency Coordination Center 2020, 2021, 2022, 2023, 2024; Belval *et al.* 2022; Thompson *et al.* 2023). The 2022 and 2023 fire seasons were both quieter fire seasons when compared to the previous 10 years (National Interagency Coordination Center 2022, 2023). These fire season characteristics are reflected in the IMSR data (Fig. 2, Nguyen *et al.* 2024), which is provided for visual comparison with the dates associated with injuries reported in the Weekly Summary. There are occurrences within the dataset of multiple injuries from a single event. Of the 6 days in the dataset that have more than four injuries reported, three of the days are associated with motor vehicle accidents, each accident having multiple injuries (30 April 2019, 27 November 2022, and 11 July 2021), two of the days are associated with a fire behavior event with multiple injuries (6 August 2021 and 22 July 2021) and only 1 day is associated with multiple unrelated injury incidents associated with a single accident (13 September 2019). Most fire suppression injury reports are from the Western United States (331/346), while nearly half

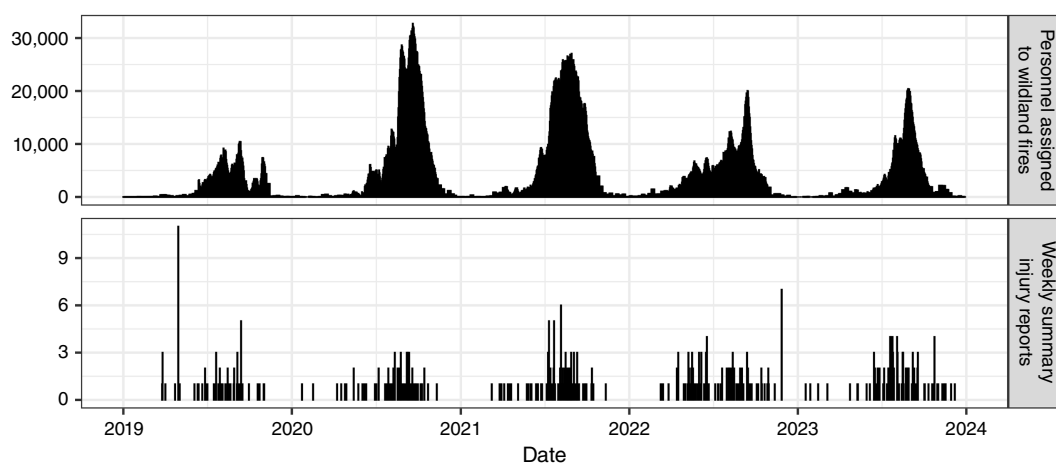


Fig. 2. Bar chart showing the number of personnel deployed to wildland fire incidents daily from 1 January 2019 through to 31 December 2023 (top) and the number of injuries reported as having occurred on each day as reported in the Weekly Summary dataset (bottom).

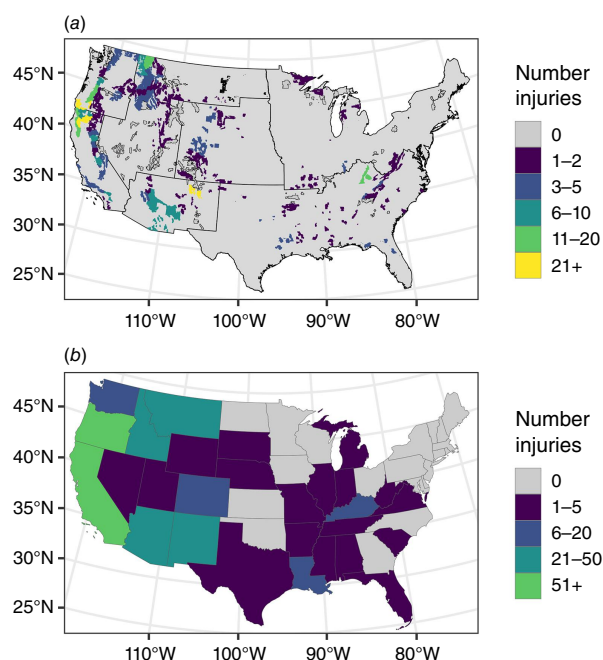


Fig. 3. (a) The number of injuries associated with each national forest for those injuries that can be associated with a national forest within the contiguous United States. (b) The number of injuries associated with each state within the contiguous United States.

of prescribed fire reports are from the Eastern and Southern Regions (18/40).

Eighty-two percent (82%) of the injuries reported were clearly associated with activities taking place on or on behalf of a national forest in the contiguous US. The number of injuries associated with each national forest in the contiguous US is shown in Fig. 3a. The Sante Fe National Forest is associated with the highest number of injuries: 91% of these injuries (30 out of 33) were attributed exclusively to the 2022 Hermit's Peak/Calf Canyon fire. This fire also shows up in the ICS-209PLUS data with the highest number of total (responder and public) injuries reported on any single fire in the years 2014–2023 (St. Denis et al. 2023). The two other national forests with more than 21 injuries are the Shasta-Trinity National Forest (25 injuries) and Rogue River-Siskiyou National Forests (22 injuries). The injuries on these two national forests were not driven by a single event, rather, these 47 injuries were distributed across 32 incidents. In general, injuries are greater on national forests with higher levels of wildfire activity and higher numbers of employees. Fig. 3b shows the number of injuries associated with each state. All of the injuries could be linked to a state; if they were associated with a national forest that spans states, the injury was attributed to the state in which the headquarters is located unless otherwise specified in the report. The states associated with the highest number of injuries are California and Oregon, followed by Montana, Idaho, Arizona and New Mexico.

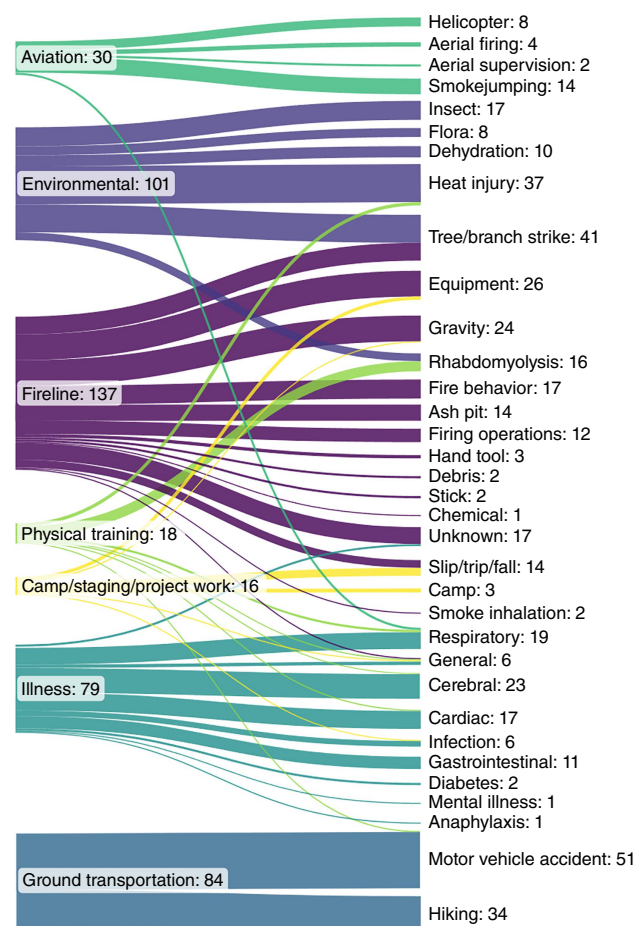


Fig. 4. Diagram of activity and hazard categories that individual reports were assigned for the entire Weekly Summary dataset. While some hazards are unique to an activity (e.g. smokejumping hazard within aviation activity), others occur across activities (e.g. heat injury hazards occurring within both environmental and physical training activity categories). Each report is assigned one activity category and one hazard category.

Hazard categories can occur across multiple activities. A schematic of activity and hazard categories is shown in Fig. 4. Most hazard categories are associated with only a single activity category, sometimes simply by the hazard definition. For example, the Smokejumping, Helicopter, Aerial Firing, and Aerial Supervision hazards can only be associated with the Aerial activity category by definition. Similarly, (ground) Motor Vehicle Transport and Hiking are only associated with the Ground Transportation activity category (with one exception addressed below). Other hazards may be able to be associated with multiple activities but overlap between activity categories is not observed within this dataset. For example, Smoke Inhalation, Exposure to Chemical agents or Debris could happen while at Camp/Staging/Project work, but in the dataset they are only observed in injuries occurring during a Fireline related activity.

Of all the hazard categories developed for this dataset, 14 span two or more activity categories. The physical training activity category alone results in five hazards spanning activity categories. This is because we chose to categorize illness-related incidents that occurred during physical training into the physical training category (as opposed to the illness category); we wanted to capture incidents where the illness may have been catalyzed by the physical exertion required by the physical training activity. Our goal was to have this data be operationally useful, and it was important to us to be able to separate the physical training injuries from other activities. When the injuries associated with the physical training activity category are removed from the data as well as the 'general' and 'unknown' hazard categories, the number of hazards associated with two or more activities drops to seven: tree/branch strike, equipment, gravity, slip/trip/fall, respiratory, infection and smoke inhalation. Tree/branch strike hazards occur within both fireline and environmental activity categories but there is a critical difference between the two activity categories. A tree/branch strike hazard occurring within the fireline activity category indicates that a person was felling a tree which catalyzed the injury, whereas this same hazard within the environmental

activity category indicates the person was impacted by this hazard with no human involvement as the initiator of the event. Equipment, gravity and slip/trip/fall hazards are observed both when engaged in fireline activities and when at camp/staging/project work; the differences between activity types for these hazards appear less meaningful than the difference between hazards that cross the environmental and fireline activity categories.

The reports of injury data in the Weekly Summary come, for the most part, from operations to suppress large fires. Initial response to wildland fire (initial attack; $n = 21$) and prescribed fire operations ($n = 40$) comprises a small subset of the data; while there are 325 injuries recorded that occurred on 165 large fires, there are only 40 injuries reported which occurred on 35 prescribed fires. However, most defined activity types (aviation, environmental, fireline, ground transportation, and illness) are associated with at least one injury on prescribed fires and camp/staging/project work events (Fig. 5a).

The counts of injury reports by activity category and injury severity are shown in Fig. 5b. There are a high number of environmental injuries in the treat and release severity category, with the number of injuries in the environmental category decreasing quickly as severity increases.

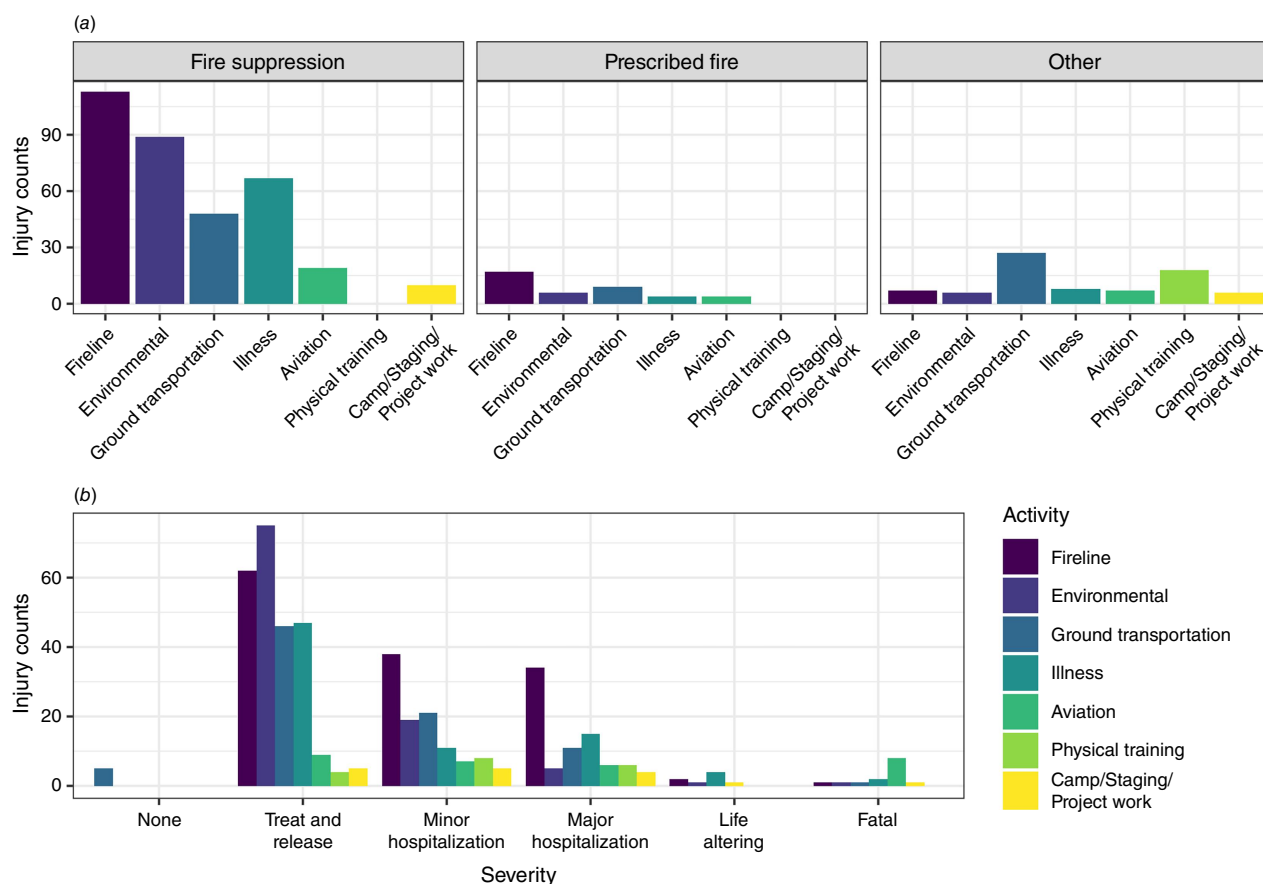


Fig. 5. The counts of injuries occurring during each event type by activity type (a) and the injury severity (b) across all injuries by activity type as archived in the Weekly Summary reports (January 2019–December 2023).

In contrast, injuries associated with fireline activities, ground transportation, and illness do not drop off as quickly as injury severity increases. The injury severity distribution by aviation activity is quite unlike the other activities, with very few injuries overall, but comprising the majority of the fatal injuries recorded (8 of 14). Injuries incurred during camp/staging/project work are similarly sparse, but more evenly spread across the injury severity categories.

We examined the relationship between activity category and severity further using proportional odds models. The results from two proportional odds models are shown in Fig. 6 and Table 2. We found that neither region nor fire complexity was a statistically significant predictor of injury severity and the inclusion of either region, fire complexity, or both decrease model fit as measured by AIC. Results from the model that includes both fire complexity and activity category demonstrate that fire complexity is not significant (Fig. 6a, Table 2). When the proportional odds models are estimated, the categories are assumed to be derived from a latent (or hidden) continuous scale; our models use the logit scale. Specifically, the proportional odds model is exploiting the fact that there is variation in severity within categories. For example, both 1 day in the hospital and 2 days fall into the same category, though there is a difference between the two. The model estimates thresholds associated with this latent scale for predicting into which category an observation will

fall, along with a set of coefficients associated with each predictor level (in our case, all of our predictors are categorical). Responses on the logit scale can be useful for visualizing which category the model would predict for an injury given specific values of predictor variables. Fig. 6a shows predictions estimated across all fire complexities and activity categories as averages on the latent scale. While complexity has little effect, activity category has a strong effect. Aviation activities resulting in injuries are likely to be more severe than those resulting from any other activity. Camp/staging/project work incurred injuries are predicted to be second most severe after aviation ones, though large confidence intervals are associated with this estimation due to small sample sizes. Injuries associated with fireline, ground transportation, and illness are predicted to fall into the mid to lower end of the minor hospitalization category, with the confidence intervals on ground transportation and illness reaching into the treat and release category.

Fig. 6b shows results from the proportional odds model estimated with activity category as the only predictor. The results are very similar to those shown in Fig. 6a, but here we show the estimated probability associated with an injury falling within each individual severity category across activity categories.

Fig. 7 shows the relative frequency and average severity index associated with the injury activity/hazard pairs

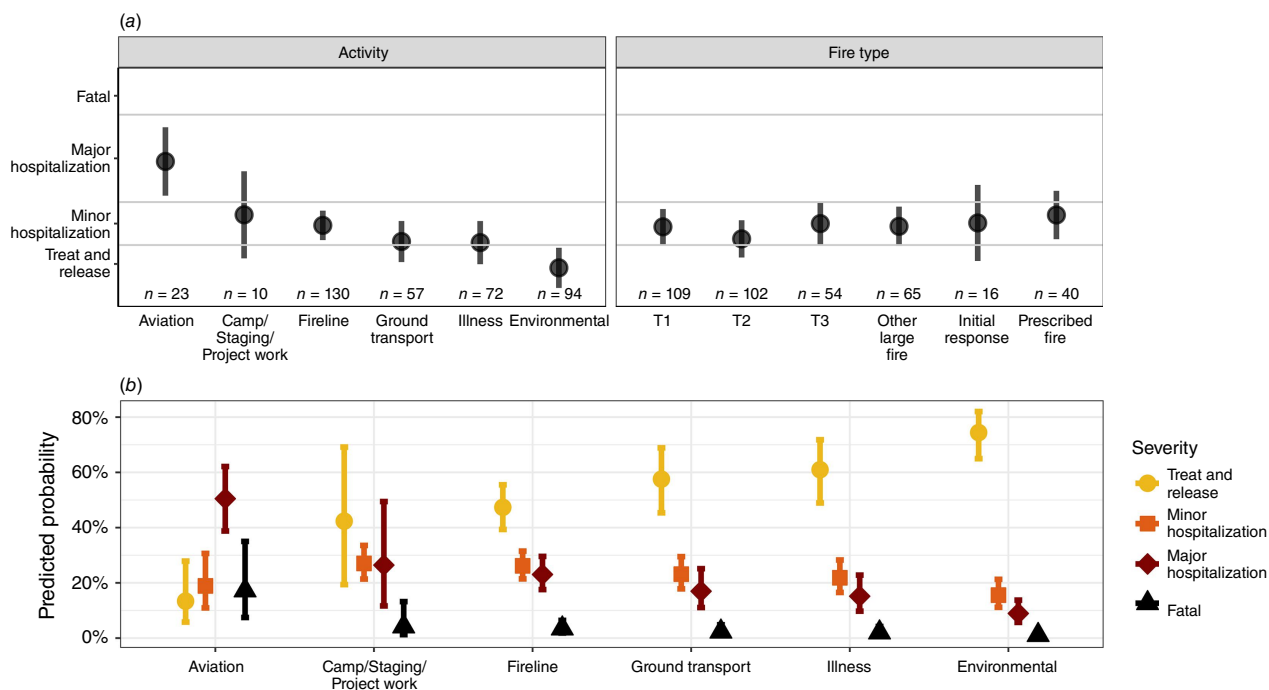


Fig. 6. (a) The predicted injury severity on the latent (logit) scale as estimated by a proportional odds model where injury severity is predicted by activity category and fire type (model 1 in Table 2); predictions are made for activity categories averaged across all fire types (left) and for fire types averaged across all activity categories (right). (b) The predicted probabilities of an injury being in each severity category as estimated by a proportional odds model where injury severity is predicted by activity category only (model 2 in Table 2).

Table 2. Results from two proportional odds models predicting the severity of an injury given the activity being performed (included in both models 1 and 2) and fire complexity (included in only model 1).

	(Model 1: Activity and fire complexity)	(Model 2: Activity without fire complexity)
Activity category variables		
Camp/Staging/Project	-1.411* (0.752)	-1.559** (0.730)
Fireline	-1.690*** (0.513)	-1.762*** (0.488)
Ground transport	-2.117*** (0.545)	-2.172*** (0.526)
Illness	-2.146*** (0.563)	-2.314*** (0.525)
Environmental	-2.813*** (0.548)	-2.935*** (0.519)
Fire complexity variables		
Type 1 fires	-0.103 (0.548)	
Type 2 fires	-0.421 (0.556)	
Type 3 fires	-0.017 (0.576)	
Other large fires	-0.090 (0.555)	
Prescribed fires	0.21 (0.582)	
Threshold coefficients		
Treat and release minor hospitalization	-1.9044 (0.6099)	-1.8679 (0.4680)
Minor hospitalization major hospitalization	-0.7681 (0.6047)	-0.7412 (0.4622)
Major hospitalization fatal	1.5440 (0.6256)	1.5680 (0.4845)
AIC	812	805.5
Number observations	386	386
Log likelihood	-393.022	-394.737

Note: * $P < 0.1$; ** $P < 0.05$; *** $P < 0.01$, standard errors in parentheses.

occurring in the Weekly Summary dataset. A few notable hazard/activity pairs could only be included in Fig. 7 using a different scale due to their high average injury severity index value; without utilizing a different scale in the upper section of the graph the few highest severity hazard/activity pairs dwarf the other average severity index values and obscure the other patterns. Slip/trip/falls occurring during camp/staging/project work are quite high in their average severity index value (1590). Four aviation-related hazards in this dataset are also high enough in severity that they do not show on this graph. Aviation-related injuries overall have an average severity of 2689. Notably, tree/branch strike hazards span both environmental and fireline activity categories, but were nearly twice as frequent in the environmental activity while being over an order of magnitude more severe as well. This was in part due to one life altering injury and one fatal injury occurring due to an environmental tree/branch strike. Injuries due to fire behavior while individuals were engaged in fireline activities are associated with a relatively average

injury severity index. Motor vehicle accidents are associated with a higher frequency of occurrence than any other activity/hazard pair, with a relatively high average injury severity. Note that while Fig. 7 is useful for examining injury frequency and severity, it does not provide an estimate of injury rates by activity or hazard, as this dataset does not include any data reflecting the exposure time associated with any activity or hazard.

The Weekly Summary data differ from previously analyzed datasets over most dimensions across which we could compare, with P -values from the Pearson Chi-squared tests being < 0.0001 for most tests and no P -value exceeding 0.1542 (see Table 3 for a full set of comparison P -values). When we further examined the results of the comparisons, we found that the differences between the datasets are aligned with the fact that the Weekly Summary generally skews towards injuries that are more severe than those in SMIS (Britton *et al.* 2013a, 2013c), the ISWLFF (Moody *et al.* 2019), and both ICS-209 data sets (Britton *et al.* 2013b; St. Denis *et al.* 2023) but less severe than the NWCG fatalities data set (Butler *et al.* 2017). For example, the injury mechanism for the injuries in SMIS and the ISWLFF included a lower proportion of struck by/against and transport than the Weekly Summary; both of these mechanisms are associated with relatively high severity injuries.

When the Weekly Summary data are joined to the ICS-209PLUS data, we find that for the subset of fires that have an injury reported in the Weekly Summary, 13.4% of the injuries reported in the ICS-209PLUS on those fires appear in the Weekly Summary. For all fires appearing in the ICS-209PLUS dataset, 5.1% of all injuries reported in the ICS-209PLUS appear in the Weekly Summary. This is consistent with reporting requirements for both sources: the ICS-209 reporting requirements include a lower severity threshold for reporting of injuries than the Weekly Summary and report injuries for all firefighters on wildland fires rather than just FS employees and contractors. The ICS-209 injury rate is 0.0006 injuries for each person per day (i.e. six people in each 1000 are injured per work day). The Weekly Summary injury rate is 0.00006 injuries per person per day (i.e. six people in each 10,000 are injured per work day). Thus, there is an order of magnitude difference between the number of injuries reported in the ICS-209s and those reported in the Weekly Summary.

Discussion

Wildland firefighters are subjected to numerous acute hazards that differ by activity they perform as part of their job duties. Indeed, within the Weekly Summary dataset we found that injuries incurred while performing fireline related activities were responsible for 29% of all reports (137/465). However, other activities, while resulting in injuries less frequently, do result in comparable injury severities. Across

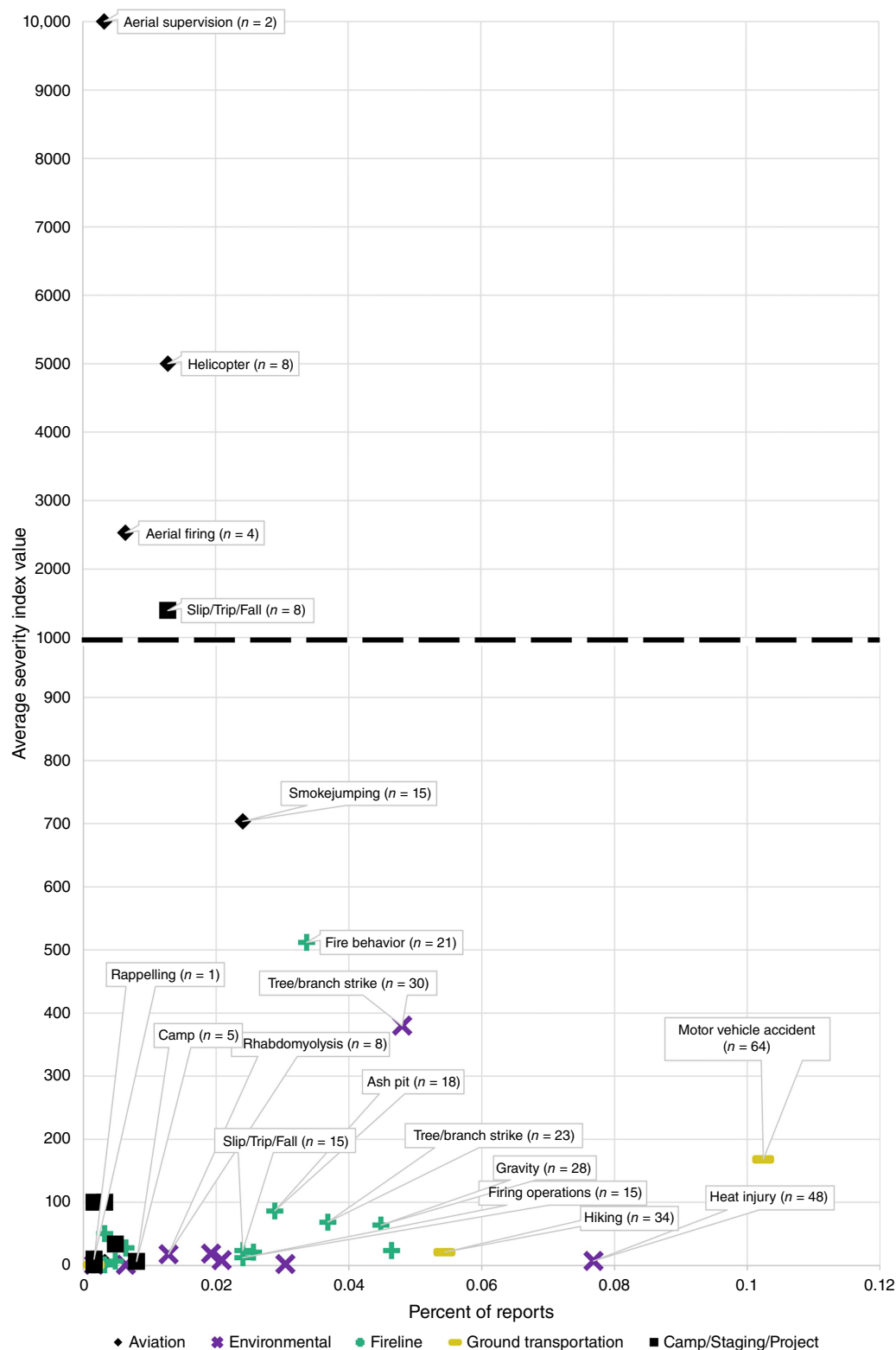


Fig. 7. Scatterplot showing the relative severity and frequency of hazard categories as reported in this dataset. Injury occurrence is the number of events in either event type relative to the total number of events. Average injury severity is the average of the injuries in the hazard category for the given event type. To show both the patterns present in the lower severity data as well as the highest severity activity/hazard pairs, the y-axis shifts at 1000.

Table 3. The *P*-values associated with Pearson Chi-squared tests performed to examine similarities and differences between the Weekly Summaries and previously published datasets.

Category type	SMIS (2003–2007)	ISWLFF	ICS-209s (2003–2007; T1/2 fires only)	ICS-209s (2014–2023)	NWCG fatalities (2001–2012)
Injury mechanism	<0.0001	<0.0001			<0.0001
Injury type	<0.0001	<0.0001			
Body part	<0.0001	<0.0001			
Seasonality	0.026		<0.0001	<0.0001	
Crew type		<0.0001			
Incident complexity			<0.0001	<0.0001	
Region			<0.0001	0.1542	

activity categories, average injury severity was relatively similar for fireline, ground transportation, camp/staging/project work, and illness categories.

We observe that, in general, the observations of injuries in the Weekly Summary line up with times during which many individuals are on the ground (Fig. 2). In addition, the spatial and temporal occurrence of reported injuries occurring on fire suppression and prescribed fires matches fire occurrence records found within the fire occurrence database (Short 2022) and the Forest Service Activity Tracking System (U.S. Forest Service 2024), with fewer prescribed fire injuries appearing in this dataset. This pattern also likely reflects that USFS personnel spend substantially less time on prescribed fires in comparison with the number of hours spent on wildland fire suppression, with higher levels of prescribed burning occurring in the eastern and southern regions and higher levels of suppression occurring in the western US region. There are also additional mitigation measures that can be taken during prescribed fires due to lessened time constraints, which may lead to fewer injuries during the time spent on that activity, though our results indicate that the severity of injuries received does not significantly differ between fire types. The high levels of injuries reported in California and Oregon align with the high levels of USFS employees stationed in these states, as well as the high levels of fire activity and corresponding exposure that take place in these states. California is associated with 32% of the reported injuries while it has over 50% of the USFS's fire employees. This may demonstrate some of the reporting biases present in this data: California (Region 5) only has a single Risk Management Officer, who is responsible for tracking injuries for the region's Weekly Summary data in addition to other duties, while regions with substantially smaller numbers of fire employees also have one Risk Management Officer.

Comparing injury severities between hazards that span activities offers insights into the work environment of wildland

firefighters. For example, in the tree/branch strike hazard category, not only are injuries an order of magnitude more severe when the tree falls without an individual acting upon it (environmental activity category), but also is more frequent than an unintended outcome from felling a tree (fireline activity category). Additionally, the Weekly Summary dataset provides some evidence that national forests with taller trees, as is common on the US West Coast (LANDFIRE 2024), have incurred a higher frequency and severity of tree/branch strike injuries than other areas of the country, where the height of the tree (or, the intensity of the hazard), is lower. Of note, the two forests with the highest average severity of tree/branch strike injuries are the Willamette National Forest in Oregon (5000) and the Six Rivers National Forest in California (500). Both of these forests have two tree/branch strike hazards induced injuries in the dataset, both of which fall in the environmental activity category.

These two forests are more broadly a part of the Southern Oregon/Northern California geography, an area which is responsible for 27% of all Weekly Summary reports (122/465) from 9 out of 76 (11%) national forests with reports. These nine forests (Willamette, Rogue River-Siskiyou, Plumas, Six Rivers, Umpqua, Mendocino, Lassen, Klamath and Shasta-Trinity) not only experience relatively high fire activity annually, and therefore relatively high firefighter assignment and exposure, they also are replete with extreme terrain and towering trees (LANDFIRE 2024), increasing the intensity of the hazards that the firefighters face relative to other areas of the nation.

Aviation activities had the highest predicted severity as assessed by our proportional odds model, followed by camp/staging/project work activities. While aviation activity related injuries were infrequent in our dataset (30/465, 6%), they had a substantially higher average severity index than all other activity categories combined (2881: 247). Previous research has developed exposure indices including estimated base rates of aviation accidents by aircraft type

(Stonesifer *et al.* 2014). In the cases of hazards that can be engineered to specific tolerances, such as with crewed aviation, the primary way to reduce risk to individuals is to reduce the exposure, or amount of time they are proximal to a hazard (Stonesifer *et al.* 2021).

Our results do not indicate that incident complexity or incident kind affect severity, though previous research has found incident complexity may influence injury frequency (Britton *et al.* 2013b). In particular, we did not find evidence that outcomes were less severe during prescribed fires than large wildfires. Because prescribed fires are planned in advance there is often more time to prepare for prescribed fire activities and weather and the resulting fire behavior conditions are often less severe during prescribed fires. However, the nature of the work is similar to wildfire in terms of activities performed and hazards encountered. Hazard trees will be cut, firelines constructed and fire will burn across the landscape – albeit at a potentially reduced intensity. One item of note is that aviation fatalities reported in the data during prescribed fire events represent all injuries and fatalities for aerial firing in the dataset. As of December 2024, federal employees performing aerial firing from crewed aviation on prescribed fires are afforded Hazard Pay (a 25% pay premium for engaging in hazardous tasks), while in general prescribed fire activities outside of this exception are not.

While the differences between the Weekly Summary and other research indicate that the Weekly Summary contents are not capturing the same spectrum of injuries as previously collected datasets, the differences between the datasets align with the different data collection methods. Both SMIS and ISWLFF are likely to be capturing a large proportion of the less severe injuries in wildland firefighters than the Weekly Summary (Britton *et al.* 2013a, 2013c; Moody *et al.* 2019). Conversely, the NWCG fatality dataset is capturing only the highest severity injuries (Butler *et al.* 2017). While the SMIS data and the ISWLFF were captured at different points in time than the Weekly Summary, there has been no technological changes in fire suppression capabilities that we would expect to impact the content of the datasets. Thus, the Weekly Summary data are useful for demonstrating the types of hazards encountered by wildland fire practitioners in recent years when performing different activities, as well as exploring the severity of injuries arising from different activities and hazards encountered across different event types; many of these characteristics have been previously unexplored in the literature.

Acquiring high quality data on wildland fire operations has long been a challenge for researchers (Thompson *et al.* 2018; Belval *et al.* 2020). While the data contained within the Weekly Summary helps provide a snapshot into the severe injuries that impact wildland firefighters, use of the dataset is limited by the reporting pipeline. The data are not a census of injuries and are not systematically sampled, rather, reporting biases likely impact the contents of the dataset. Thus,

analyses looking at issues such as temporal trends in injury rates may not be reliable when using this dataset. This is not unique to the Weekly Summary dataset. A closer look at the ICS-209PLUS injury data indicated that even that dataset may have critical information gaps. For example, we found 17 instances where there was an injury reported in the Weekly Summary dataset but not reported in the ICS-209PLUS dataset. Additionally, of the 40 incidents in the ICS-209PLUS data with over 19,500 worker days across the duration of the incident, five incidents managed by non-federal agencies report zero injuries, which seems highly improbable given the overall rate of 0.0006 injuries per person per day in the dataset.

While the Weekly Summary data combined with the ICS-209PLUS data allowed us to calculate a lower bound on severe injury rates, additional data would need to be collected on the amount of time firefighters spent engaged in each activity category or exposed to any given hazard to facilitate any effort to calculate injury rates associated with exposure time beyond annual summaries. However, even without being able to calculate injuries per exposure time, we could observe that the majority of the incidents included within the Weekly Summary dataset would be challenging to mitigate through individual level safety actions and are likely to be mitigated only by agency level risk tolerances that impact employee exposure. For example, the Weekly Summary included incidents such as stepping into a hidden ash pit, slipping during hiking, tree strikes that are not a part of fireline construction, illness occurring in remote areas, and malfunctioning equipment. Instances such as these did not appear to be associated with safety mitigation failures (e.g. protective equipment failing, human behavior outside of safety norms). That said, the Weekly Summary does provide an additional data source for those interested in finding leverage points where safety mitigation measures might be effective.

While reducing exposure time is one control that agencies can use to reduce injuries, there are other ways to mitigate the acute hazards identified here. For example, leveraging pre-season planning tools such as predetermining potential acceptable locations for firelines (such as potential operational delineations) is one avenue to reduce the intensity of hazards firefighters may face, since that allows managers to pre-identify firelines that can be located in areas along roads which have the potential to not only reduce fire behavior and improve suppression effectiveness, but also allow for additional control over other hazards such as those overhead during incident response (Thompson *et al.* 2021). An additional benefit of such preplanning may be that the number of responders necessary to contain a fire is lower. This is due to potential increased effectiveness of firelines given their location in areas of where it is more likely a fire will stop, and potential lower number of individuals and resources to construct the fireline given potential operational delineation locations in areas where it is easier to implement suppression operations. Leveraging this pre-season planning with

structured decision making frameworks in response has the potential to improve suppression effectiveness, but also to reduce exposure of firefighters to significant hazards (Thompson *et al.* 2022). There are several relatively new analytical tools that facilitate such pre-season planning in the US. For example, the Risk Management Assistance Dashboard hosts a suite of risk management tools including geospatial layers and assessment tools (Calkin *et al.* 2021; USDA Forest Service Strategic Analytics Branch (SAB) 2025). As these tools are further disseminated and become more familiar to managers, we hope they will facilitate preplanning efforts as well as more risk-informed suppression strategies.

Finally, long term health impacts are not examined in this dataset but remain critically important to wildland firefighter health and well-being. Smoke inhalation is absent as a hazard resulting in an injury during large fires and only one incident was reported for prescribed fires in this data. Other additional exposures that may lead to cancers and chronic permanent physical injuries over time are also absent. Given the long-term, cumulative impacts of smoke inhalation, the Weekly Summary reports are likely not the best indicator of this hazard type. While both prescribed and wildland fires subject responders to smoke, acute impacts appear less prevalent than other hazards in this dataset. Short and long-term impacts of smoke inhalation on fire practitioner morbidity and mortality are discussed in detail in other research (e.g. Navarro *et al.* 2019; Hwang *et al.* 2023).

Conclusion

This research aids in contextualizing the nature of the acute hazards by activity to which wildland firefighters are exposed, so that they can more fully identify, assess and mitigate their exposure to reduce injuries and fatalities. However, wildland firefighters are already trained to assume that their occupation is an inherently dangerous one; the activities that are done and the environments in which they are placed in are inherently hazardous and there are already some mitigations in place. Without either limiting the number of individuals exposed to hazards or limiting their engagement to areas with less hazard or lower intensity hazard to begin with, the frequency and severity of many of these injuries cannot be prevented or eliminated. Keeping people off the fireline and out of the woods to reduce exposure may be incompatible with legislation, policy and organizational missions. Thus, protecting the safety of wildland firefighters cannot be solely reliant upon individual or real-time risk management, but must also include clearly defined organizational risk tolerances and appetites. A lower bound on the current set of agency level risk tolerances around severe injuries can be inferred from the Weekly Summary dataset. While the work presented here has identified many hazards and their associated consequences and relative frequencies, this work alone cannot address how acceptable the

number of, and severity of injuries in the Weekly Summary may or may not be. Determinizing whether the number and severity of injuries reported in the Weekly Summary are tolerable, or not, can only be achieved with clearly articulated agency level risk tolerances. We anticipate that future work may leverage this effort that identifies the hazards, their frequencies and consequences to provide additional insight into the tradeoffs between risks to firefighters and the goals associated with the suppression work with which they are assigned.

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Data availability. Due to concerns about details of injuries and the surrounding circumstances unintentionally identifying individuals, the original Weekly Summary dataset is only available by direct request to the corresponding author.

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