Examining Information Networks On Two Fast-Moving Wildfires

by

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A thesis accepted and approved in partial fulfillment of the

requirements for the degree of

Master of Science

in Environmental Studies

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Summer 2025

THESIS ABSTRACT

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Master of Science in Environmental Studies

Title: Examining Information Networks On Two Large Fires

Preserving human health and safety during a wildfire event is a foremost priority for emergency mangers and fire professionals in fire-prone regions of the world. While most fire and emergency response organizations focus on promoting civilian evacuations as early as possible to maximize public safety, existing wildfire social science and disaster decision-making literature demonstrates that civilian evacuation decisions are influenced by a variety of factors that do not always end in a decision to evacuate early, or at all. In recent years, the incidence of extreme wildfire events that deviate from the norms of what both professionals and locals expect of wildfires in their area has increased. The case studies presented here utilize 123 semi-structured interviews and individual level social network analyses to explore how changing fire behavior and weather have influenced evacuee and professional decision-making on two wildfires, the 2022 Mill Fire in Weed, CA, USA where a fast-moving wildfire that started at a lumber mill burned 3,935 acres (1,592 hectares), destroyed 118 structures, and claimed two lives in a rural landscape with a legacy of livelihoods tied to logging over a span of three days, and the 2021 Caldor Fire that burned 221,835 acres and destroyed more than 1,000 structures in the Sierra Mountains and burned for several weeks. Both fires exhibited elements of extreme fire behavior and weather that influenced fire, emergency, and civilian decision-making. We found that the speed of a fire's progression impacts the information availability that the public can access in their threat assessment. On the Mill Fire, communities nearest the ignition point had no warning, often responding to environmental cues like smoke or seeing the fire or being notified by neighbors. Emergency alerts could not activate until emergency professionals were able to engage their emergency notification systems, which were outpaced by the wildfire's speed for the closest communities. Consequently, community members nearest the fire's origin tended to have smaller information networks and accessed fewer sources of information as compared to communities farther away that had more time to become notified and mine for data to inform their evacuation choices. Interviewees in both case studies valued official information from CalFire, the US Forest Service, and emergency services and preferred to get their information from those avenues, but largely reported lower scores on some measures due to the temporal resolution limitations official sources of information grapple with (e.g., needing to verify and get administrative approval to share information officially with the public). Due to this hurdle, most information shared by agencies was considered outdated by the time it was shared and not useful for making decisions about evacuations. However, Code Red Alerts were highly valued for triggering evacuations and making participants aware of wildfire events in their area. Despite the advantages of more frequent information, some participants noted concerns around the circulation of inaccurate or malevolent information on unofficial forums, especially in

community social media groups such as Facebook or Nextdoor. Finally, we observed how back-channel information (e.g. information not shared with the public through official government sources) was commonly sought out by the public and shared within social circles, demonstrating how unique sources of information become dispersed among the public. The utilization of back-channel information was prevalent on both fires and follows a broader trend in the realm of wildfire social science of increased information availability for the public to access and utilize to further assess firefighting efforts and their own personal risk. This master's thesis aims to understand information gathering and dissemination patterns through a network approach in the continuously.

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1. Introduction

Exposure to wildfires has become more prevalent and fire conditions more hazardous across many regions of the globe (Liu et al., 2010), increasing risks to human life and property. In the western United States, decades of wildfire suppression, exclusion of indigenous burning, exacerbating drought conditions, and growing human populations in fire-prone landscapes have increased civilian exposure to wildfires (Calkin et al., 2015; Lake, 2022). Wildfire response operations have recently struggled to respond to events with extreme fire behavior, such as rapid fire progression, resulting in harrowing evacuation experiences with high fatalities on incidents such as the 2018 Camp fire, the 2023 Maui fires, and the 2025 Los Angeles fires (Castleman et al., 2025; Grajdura et al., 2021; Kuligowski, 2021). The natural disaster and hazard literature describes how emergency response systems can be overwhelmed by the rapid onset of a hazard because of the time it takes to both coordinate a response to an incident, as well as the complexity of securing life safety (Grajdura et al., 2021). Similarly, disseminating accurate and useful information during an incident (e.g., wildfire event) can be challenging for emergency response systems designed to *respond* to the immediacy of the event to mitigate or abate the hazard rather than perform comprehensive messaging to maximize transparency of information dissemination to the public. While public communications from emergency managers certainly occur during a disaster, such as what protective actions to take, the usefulness of these messages may vary and not meet all the needs of the public. Considered in congruence with the fact that most people expect a notification from an official source to trigger wildfire evacuations (Kuligowski, 2021; McLennan et al., 2019; Whittaker & Handmer, 2010), it's important to understand how civilians are dealing with decision–making during dynamic, and often uncertain, fast-moving wildfire events.

Individuals can implement a variety of actions when under threat from a wildfire regardless of "mandatory" evacuation orders, including evacuation, sheltering in place, or staying and defending their property. A multitude of variables influence evacuation decisions, ranging from personal attributes (e.g., mobility challenges, firefighting training), situational characteristics (e.g., dangerous road conditions, too smoky to drive, defensible space), and other concerns (e.g., traffic, cattle to evacuate, concerns about being burned over during evacuation) (Edgeley & Paveglio, 2019; McCaffrey et al., 2018; Strahan et al., 2018). In addition to situational and biophysical characteristics, interventions such as notifications, alerts (McLennan et al., 2019; Sutton & Kuligowski, 2019; Waugh et al., 2025), and information gathering (Okeukwu-Ogbonnaya et al., 2024; Steelman et al., 2015) have been documented to have significant influences on civilian evacuation behaviors during wildfire incidents. Despite a broad literature on evacuation messaging and behavioral studies, little research exists on the nuances of communications amongst civilians and how they interface with fire management spheres (Okeukwu-Ogbonnaya et al., 2024). Simultaneously, the sphere of information civilians can access has expanded greatly with the popularization of smartphones and widespread adoption of social media platforms and messenger applications such as Facebook, Instagram, Next-door, and Twitter (now known as 'X') for both agencies and civilians to share fire-specific information.

Additionally, Fire-specific blogs, forums (e.g., Yubanet), videographers, and information tools such as Watchduty, which makes incident operations publicly available at a temporal and operational scale not previously seen. The advent of new technologies and modes of communication has been shown to shift the ways incident narratives form by giving the public more agency to produce an independent narrative on the fire's progression(Sutton et al., 2008). Rapidly developing technologies and changing information sharing capacities necessitate exploration into how changing tools and communication channels are enhancing (or hindering) civilian evacuations and safety during wildfires.

Prior to choosing a protective action, such as evacuating or staying and defending, an individual typically follows these steps: receive an alert, believe and confirm the threat is credible, personalize the threat, evaluate if protective action is necessary and feasible (typically followed by information search), and, finally, act (McLennan et al., 2019; Sutton & Kuligowski, 2019). This evacuation decision-making process can be time-intensive, making it essential that notifications reach the public in a timely manner so they can navigate the different phases and implement action(s) prior to being exposed to the threat. Delayed notifications in many instances may force civilians into a no-notice evacuation, such as during the 2018 Camp fire (Grajdura et al., 2021), where civilian abilities to take protective action are hindered due to information inaccuracies, too little time to implement the safest actions, and/or a lack of alternative lifesaving plans when evacuation is not possible due to the incredibly fast-moving urban conflagration. Even in circumstances where ample time is provided between alert or awareness of the hazard and the evacuation or protective action trigger, research shows that decision-makers often prioritize sources that are updated frequently (e.g., social media posts, scanners, and non-government sources)over information sources that are more official or trusted (e.g., twice-a-day briefings)(Dynes & Tierney, 1994; McLennan et al., 2019; Steelman et al., 2015). Information confirmation and verification is also a well-documented phenomenon, including by word-of-mouth or civilian-to-civilian communication in group chats (e.g., text chains, Nextdoor), phone calls, or knocking on neighbors' doors. . While numerous studies have examined information flow during a wildfire event at an incident command (e.g., official fire suppression) level, currently, there exists little literature documenting these complexities at a civilian level.

This research effort intends to address two issues in the wildfire evacuation literature: (1) rapid advancements of wildfire information sharing capabilities following with 2020 fire season in the US and abroad highlights a need for a current inventory of modern information on data uses, needs and trends to support civilian decision-making on wildfires, and (2) increases in fast-moving or challenging fire behavior highlights a need to better understand resident decision-making during "extreme" events or circumstances, including what information they found useful, what information was missing, and how that information influenced civilian decision-making.

2.1. Information sources used by civilians during hazards

A variety of information sources are utilized to guide civilian and professional responses to risks and natural hazard events. Researchers have documented strategies for emergency managers to craft engaging messages for the public. Ideally, these messages are timely, grab the attention of the public, are easily comprehensible, personable, trusted, accurate, spatially-relevant, and provide guidance on what protective action if any, is necessary (Sutton & Kuligowski, 2019). Failure to provide any or all of these characteristics, or to provide them insufficiently, leads the public to seek additional information from other sources, which may provide them with further insight to the threat at hand.

In this section, we discuss typical hazard response and information sources in three categories: official, unofficial, and blurring. The underlying reasons for collecting information from each of these categories will be explored in the coming section, and range from the public's trust and perception of a given information source to simply what is available.

2.1.1. Official–civilian-facing information

Official information sources are typically classified as having come directly from government agencies or experts (Kaye, 1995; Steelman et al., 2015; Sutton & Kuligowski, 2019). In the realm of wildland fire response, common examples include live and/or recorded public incident briefings, written incident updates, fire perimeter maps, evacuation alerts and orders, and road closure updates (McLennan et al., 2019; Steelman et al., 2015). Frequently updated fire perimeter maps and evacuation orders have been shown to be highly important to civilian decision-making during a wildfire incident (Taylor et al., 2007). Hazards such as wildfire and extreme weather events often challenge information and notification systems due to their unpredictability and rapidly changing nature. Reducing the time between risk onset and notifying civilians is a key factor shown and modeled to save lives during wildfires (Grajdura et al., 2021) and other hazards. As a result, utilization of national and regional technology-based notification systems has become best practice in the emergency management field, alleviating time, personnel, and safety concerns and rapidly notifying the larger public of a threat. Examples include the Integrated Public Alert and Warning System (IPAWS), the Federal Emergency Management Associations (FEMA's) nation-wide system for providing local, life-saving alerts via mobile phones and landlines (Wireless Emergency Alerts), radio and television (Emergency Alert System), and the National Oceanic and Atmospheric Association's Weather Radio (*Integrated Public Alert & Warning System | FEMA.Gov*, n.d.; US Department of Commerce, n.d.). A variety of phone-based notifications and applications are also available to help municipalities deliver notifications to civilians via text messages, email, and reverse 911 calls (e.g., Code Red, Perimeter). A limitation of these tools is that their effectiveness in rural areas can vary (e.g., poor cell phone coverage). Additionally, the electrical grid, cellular networks, and internet services can become intentionally or unintentionally compromised (e.g., de-energization for response safety), overwhelmed (e.g., bandwidth limitations), or damaged (e.g., cell tower and electric poles damaged by flames) during large-scale fires (Okeukwu-Ogbonnaya et al., 2024; Taylor et al., 2007). Privacy laws in some areas require that civilians opt into the emergency alert notification system, which can leave parts of the population out of the alert, including visitors and tourists who may not be aware of the need to enroll in order to receive a notification. Further, for these tools to be effective and useful in informing the public, they must be timely, spatially relevant, and accurate(Sutton & Kuligowski, 2019).

Although official information sources are often critiqued for a variety of reasons (see above), the public generally wants information from official sources and is more likely to act upon receiving official information due to their perceived credibility, expertise, and a perception that official sources are more likely to carry critical protective action steps than unofficial sources (Mileti et al., 2006; Steelman et al., 2015). In some instances, the public may distrust government information sources due to negative prior interactions (e.g., regulations, land management conflicts) or lack of interactions (i.e., no opportunities to build trust) (Olsen et al., 2010; Steelman et al., 2015). Public respect for and trust in federal or state employee expertise has also been shown to vary across wildfire-prone populations (Paveglio et al., 2018), along with variance or conflict in public risk messaging, can influence compliance with or consideration of advisories or “expert” prescriptions (Burger et al., 2013).

The public’s primary interest when gathering information during a hazard event is identifying and evaluating locally accurate, timely, and relevant information pertinent to the threat they are facing (Burns et al., 2010; McLennan et al., 2019). Providing timely information has been documented as a challenge on incidents where official needs to vet information and verify protective action orders before releasing updates may result in communications being irrelevant to the information consumer (i.e., civilians) by the time the new information is released (Sorensen, 2000; Taylor et al., 2007). When official information sources are unable to meet these critical criteria (i.e., timely, locally accurate, and relevant), the public will often delay taking protective action and/or turn to less official channels to supplement their information needs (McLennan et al., 2019). Increasingly, government entities such as local sheriffs, fire departments, and land management agencies have turned to traditionally unofficial platforms such as Facebook to publish incident updates (Burns et al., 2010; McLennan et al., 2019; Sutton et al., 2008). This blurring between official and unofficial information channels will be discussed in the sections ahead.

2.1.2. Unofficial information sources

Outside of official government messaging, the public also has access to a diverse range of information sources that can be classified as “unofficial” as they are not published by an official agency or incident professional. Unofficial information sources can include communications from or with informal social networks. Informal social networks can take a variety of forms, including in-person or virtual interactions with friends, family, and neighbors; interaction with strangers via online forums (e.g., Reddit); and mass media (e.g., television news broadcasts and news websites) (Steelman et al., 2015). Since the advent of affordable personal cellular devices in the mid-2000s, the variety of information that the public can access has diversified and grown significantly(Rodríguez et al., 2007; Sutton et al., 2008). Online forums, non-government websites, social media sites, and communications with friends and family via cell networks have become a common means of information gathering with the wide adoption of cell phones (Sutton et al., 2008). These new means of accessing information give the public "back-channel" means of viewing the incident. "Back-channel" information is defined in the literature as information that would otherwise be "behind the scenes" of an incident or information market and not readily available to the public, and must be obtained through irregular means (McCarthy & Boyd, 2005; Sutton et al., 2008). In a wildfire or other disaster contexts, back-channel information allows the incident narrative to develop outside of official and vetted communication networks via peer-to-peer communications. Back-channel information can include pictures, videos, conversations overheard at a public meeting, or recorded snippets of incident radio traffic posted by non-government actors (Sutton et al., 2008). While problematic in the eyes of some who fear the impact of spreading inaccurate or rumorous information, the widespread adoption and use of cell phones gave the public the means to share, verify (or nullify), and access incident-related information outside of their role as passive consumers of incident updates provided by the government (McCarthy & Boyd, 2005; Sutton et al., 2008). Prominent information-sharing platforms like Facebook have proven to play a key role in keeping the public informed during developing disasters, specifically by providing readily accessible and frequently updated information (Okeukwu-Ogbonnaya et al., 2024). Researchers have documented how back-channel information proliferation allows the public to increase their situational awareness and safety outside of the constraints of official updates; in some cases, interest in back-channel information gathering and sharing was a function that arose out of eroded trust of official information providers' failure to provide sufficient information on previous fires (Sorensen, 2000; Sutton et al., 2008). In others, it reflects a desire to be as informed as possible and a willingness to synthesize all available information in order to make the best decision, a phase of information gathering known as "information mining.". As modeled by Sutton (2019), continuous information gathering may occur in a loop of gathering information to fill information gaps that aid in further assessment of risk.

Across the field of disaster research, from hurricanes to wildfires, researchers find that some of the most often accessed information sources are living, unofficial information sources, especially friends and family (Burger et al., 2013; Steelman et al., 2015). While technology-related information sources (e.g., wildfire information platforms made accessible by personal devices) can help reduce the burden of information mining and verification, these sources are susceptible to failure during extreme conditions (e.g., de-energization, loss of cell phone reception) and can be inaccessible for long durations once the interruption of services occurs. Close social ties, such as friends, family, and neighbors, can be more accessible and resilient due to their lack of reliance on redundant power sources to continue functioning as a well-trusted source of information (Burger et al., 2013).

2.1.3. The blurring of information sources

The arbitrary line of what is "official" and "unofficial" information has become increasingly difficult to define; for example, government agencies have turned to publishing incident updates and briefings on what were previously considered unofficial information sources, such as Facebook, Twitter (now X), and Instagram, increasing these platforms' reliability as distributors of legitimate information (Burns et al., 2010; McLennan et al., 2019; Sutton et al., 2008). This social infrastructure can help emergency managers access public constituents with more detailed information than with other platforms, such as IPAWS and alert messaging software, which often limit the characters or words in a message and do not allow the inclusion of images; images in particular have been demonstrated to be useful tools for conveying risk information in comparison to written word (Sutton & Kuligowski, 2019; Waugh et al., 2025). During major incidents, public information officers may utilize their agency's social media platforms to disseminate information to individuals how may be impacted or at risk and/or launch a dedicated page for the incident to publish updates, pictures, live video briefings, screenshots of evacuation orders and warnings maps, and guidance on how to return home safely (Chambers, 2015).

Back-channel information sources, such as amateur radio and scanners, further complicate distinguishing a source as "official" or "unofficial". For example, civilian radios (e.g., ham or general mobile radio groups) and radio scanners (e.g., scanner websites like Broadcastify, or a physical handheld scanner) allow the public to listen in on, transcribe, and distribute incident communications immediately, creating opportunities for operational discussions to enter the public realm in advance of agency verification or official announcements (Dynes & Tierney, 1994; Sutton et al., 2008). New technologies, more attuned methods of mining for information, and a more fire-experienced public have resulted in further complex diffusions of information amongst the public.

Understanding the diffusion of information through complex social networks is further complicated when considering how an individual's close social ties diffuse the information they have gathered. During a wildfire, some of the most used and trusted sources of information for an individual are their close friends, family, and neighbors, who may be accessed in-person, digitally, or via phone call(Burger et al., 2013; Steelman et al., 2015). These close social ties are dynamic actors, as they'll pull information from a wide range of sources, both official and unofficial, and ultimately disseminate what they have gathered and deemed important to their own close social circles. Understanding the flow and complexities of information diffusion within the public realm on major wildfires becomes key in assessing how individuals at risk synthesize information. This research effort aims to study information network dynamics on "extreme" wildfire incidents where elements of fire behavior (e.g., rate of spread, significant deviation from modeled projections) broke emergency management plans and potentially challenged the resilience and utility of both formal and informal information networks for civilian decision-makers operating under uncertainty. The complexity of this question leads us to pursue a social network approach.

2.2 Social network analysis and its applications in disasters.

The core function of network analysis is to map the relational ties between nodes; from a network perspective, nodes can be any observable unit, such as people, economies, diseases, or religions (Light & Moody, 2020). The ability to map such diverse units lends network theory to a wide variety of research fields, including but not limited to epidemiology, power transmission, criminology, and disaster management (Borgatti et al., 2009; Christakis, 2009; Freeman et al., 1992). When the observed unit of a network study is primarily people and their ties, the analysis is typically referred to as a social network analysis (SNA).

The primary components of an SNA date back to the mid-1700s (Freeman et al., 1992). An SNA at its core is an adjacency matrix of interactions between social actors derived from assessing how a participant (an ego) interacts with people (alters) (Hogan et al., 2007). The ties between actors ultimately drive the formation and understanding of a network. Ties have been broadly categorized into four types: similarities of nodes (e.g., shared traits), social relations (e.g., kinship, organizational roles, cognitive perceptions), interactions (e.g., sex with, talked to, helped), and flows (e.g., information, beliefs, resources) (Borgatti et al., 2009). These ties can also be directed; for example, an alter may tell an ego where to find an evacuation shelter, but the ego does not have any information for the alter (Light & Moody, 2020). While the quantitative approach of counting and mapping ties (edges) between egos and alters is critical to SNA methodology, SNAs are still ultimately rooted in a qualitative endeavor of the researcher to identify patterns of social connections (Freeman et al., 1992; Steelman et al., 2014).

SNA methods have found a home in the impactful research on disaster management and communications(Jones & Faas, 2017). SNAs enable researchers to examine complex social relationships within and outside of organizations, as well as to map information flow. In the context of disaster research, it is understood that an individual's social ties can significantly exacerbate or mitigate the impact of a hazard (Jones & Faas, 2017). Through an SNA, we can begin to understand who the key individuals are that shape the incident narrative on a meso-scale, and with a connectionist approach, we can understand the flow and diffusion of information (Light & Moody, 2020). SNA methodologies have been used extensively to study communications within incident management teams (IMT) (B. Nowell et al., 2018; B. L. Nowell et al., 2017; Steelman et al., 2014). Additionally, some examples of attempts to map civilian networks exist in other hazards literature (Hocevar, 2023; Okeukwu-Ogbonnaya et al., 2024) . However, little literature exists examining the emergent network of civilian communications during a wildfire and how they interface with formal institutional networks. Mapping these network dynamics would allow us to understand:

1) What information do residents seek under a wildfire threat?

2) How is information accessed and diffused amongst the public?

3. Methods

We used a mixed-methods case study approach with the sampling objective of maximum variation sites. A semi-structured interview protocol was utilized to collect rich qualitative data, while a quantitative, social network analysis survey was designed to provide the data to ultimately present the participant with a network map at the conclusion of their interview. Individual interview networks would later be compiled into a larger sociogram that represents the information networks on each case study fire. Mixed-methods research is demonstrated to provide practical and increasingly valid results by leveraging different data types and providing opportunities for verification (Palinkas et al., 2015). Study sites would be chosen with specific criteria outlined below, and ideally, hold significant variation from one another to maximize the comparative analysis. The research herein was approved by the Institutional Review Board via protocol #00001378.

3.1. Site selection

Prospective case study wildfire events were considered based on the following criteria: prospective fires must (1) have exhibited an element of extreme fire weather or behavior, (2) triggered civilian evacuations and a multi-jurisdictional response, (3) impacted multiple geographic communities, and occurred in the last two years (2021-2022); the final criteria was included to maximize civilians' and professionals' abilities to accurately recall event details on a trauma sensitive timeline, while also staying out of the way of recovery efforts as not to put additional strain on post-fire communities (Gaillard & Gomez, 2015). Based on these rules, we identified the 2021 Caldor and 2022 Mill fires due to their abilities to provide lessons addressing gaps in the current wildfire literature, including model-breaking fire behavior (e.g., the Caldor fire jumped the summit of the Sierra range, which was considered impossible) (Avitt, 2021; Thompson, 2021), northern California case studies, and impacts to socially diverse, working-class populations.

3.1.1. 2022 Mill Fire, Siskiyou County, California

The town of Weed is located in northern California's Siskiyou County, with a population of approximately 2,570 residents (*Weed City, California - Census Bureau Profile*, n.d.). Post-colonization, Weed began as a lumber town, headed by its founder and mill operator, Abner Weed. The mill drew immigrant and Black laborers leaving Louisiana and Mississippi in the 1920s (Browning, 2022), many of whom opted to stay in Weed and created a thriving, multi-generational Black neighborhood known as Lincoln Heights, an uncommon feature in rural Northern California. Presently, the Mill is operated by Roseburg Forestry Products, headquartered in Roseburg, Oregon. Weed's vegetation primarily comprises chaparral, mixed conifer forest, and pasturelands that result in frequent fires in the region. Since 2000, there have been 23 wildfire incidents within a 35-mile radius of Weed, with the majority of fires occurring during September (*Fire Perimeters | CAL FIRE*, n.d.). When aided by strong prevailing southern winds, wildfires in this region have the potential to grow rapidly and exhibit extreme fire behavior. The 2014 Boles Fire, fanned by 40-mile-an-hour southerly winds, burned 470 acres and destroyed 150 structures in downtown Weed in September of 2014 (*Boles Fire | CAL FIRE*, n.d.). In 2021, the Lava Fire burned for multiple days east of Weed in the lava flats surrounding the base of Mount Shasta, ultimately burning 26,409 acres and destroying 2 homes (*Lava Fire | CAL FIRE*, n.d.) Each fire has triggered evacuations for either the town of Weed or neighboring suburban developments in northern Carrick and Lake Shastina (Figure 1).

The Mill Fire ignited at 12:45 pm on September 2nd, 2022, from within a storage shed on Roseburg property due to operations at the Mill (Macht, 2023). Fire weather conditions at the time were aligned to produce a fire with dangerous potential. Max daytime temperature reached 107°F, relative humidity reached a minimum of 4%, and strong winds were pushing out of the south (*Mill Fire | CAL FIRE*, n.d.). Within 7 minutes of ignition, homes could be seen burning from AlertWest cameras, and audio transcripts of radio communications acknowledged an immediate need for structure protection in Lincoln Heights. Official evacuation orders would not be issued until 1:20pm, approximately half an hour after ignition. The 2022 Mill fire burned 3,939 acres over roughly 4 hours; 118 structures were destroyed, and 2 deaths occurred during the fire (CalFire, 2022). Most structure loss and all loss of life occurred in the neighborhood of Lincoln Heights.

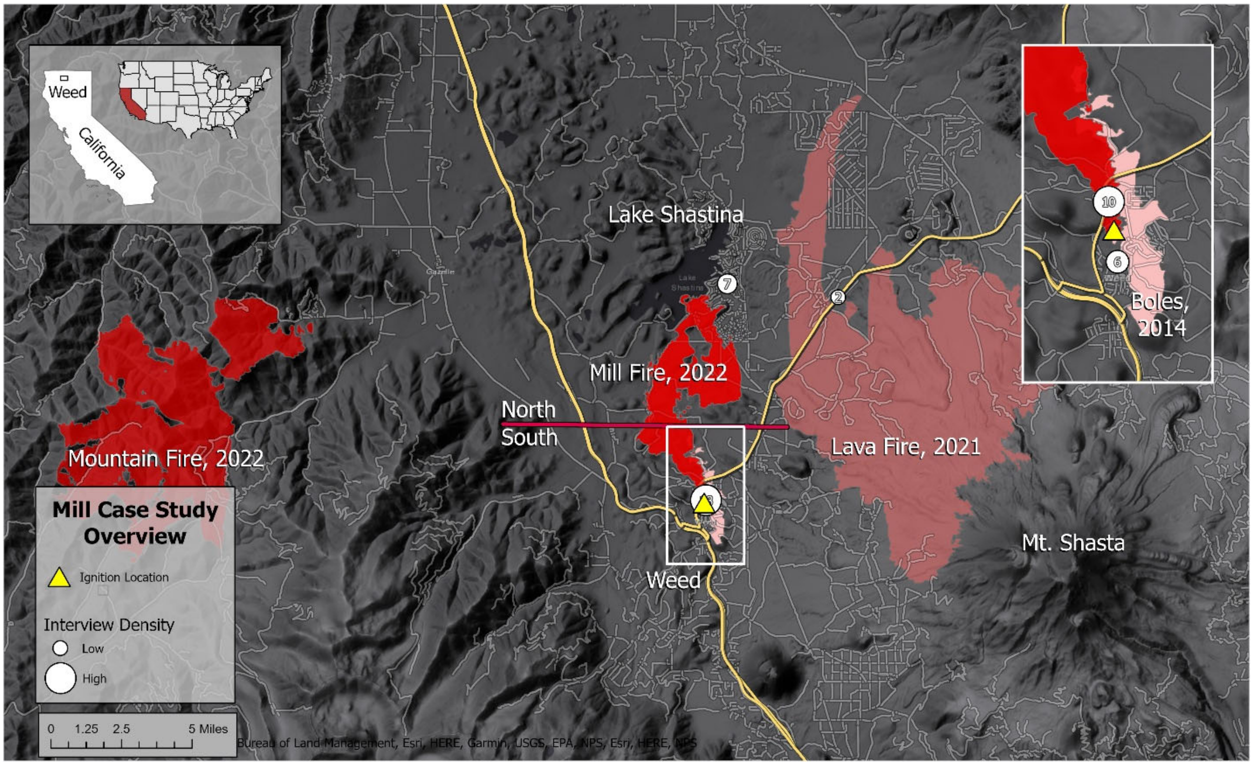

Figure 1: Mill Fire Case Overview, Siskiyou County, CA, United States. recent fire perimeters and Mill fire perimeter outlined in red and annotated. Approximate interview locations are represented as white circles. Ignition source represented as a yellow triangle.
SOURCE: CalFire, US Census

3.1.2. 2021 Caldor Fire, El Dorado and Amador County, California.

The Caldor fire ignited on August 14th of 2021 near the town of Omo Ranch in El Dorado County, California. The surrounding area includes the communities of Pollock Pines and Grizzly Flats, both located in the lower elevations of the Sierras. The Caldor fire was initially managed under United States Forest Service (USFS) incident command. The fire saw minimal growth within the first day; simultaneously, the Dixie fire, which, at the time, was the largest fire in California and was still actively growing. The day after ignition, the Caldor fire grew exponentially towards the town of Grizzly Flats, ultimately destroying nearly all structures within the community. The Caldor fire continued its progression up the slopes of the Sierras, eventually crossing over the Sierra Crest, a feat previously thought impossible, as the low amounts of vegetation and high granite composition of the slopes were considered an effective fuel break to slow and halt fire progression (Thompson, 2021). To achieve this feat, the Caldor fire followed the canyons along the South Fork American River, which contained more vegetation and geographies that focused up canyon winds at the Tahoe Basin. As the fire began to threaten the densely populated South Lake Tahoe basin, incident managers decided to evacuate the basin, which has a population of approximately 56,000 people (*Tahoe Demographics*, n.d.). The Caldor fire would then narrowly avoid burning into the basin and spent the remaining days of its active burning period of 69 days burning slowly into the southwest of the basin's slopes. Ultimately, the Caldor fire burned 221,835 acres, destroyed 1,005 structures, injured 16 firefighters and 5 civilians (*Caldor Fire | CAL FIRE*, n.d.). In multiple instances, the Caldor fire exhibited extreme fire behavior as it aligned with fuels, topography, and weather, resulting in critically fast runs (Avitt, 2021). Luckily, no lives were lost; however, the town of Grizzly Flats saw severe damage, with most of the town being destroyed, and it has since faced difficulties rebuilding. Additionally, the ski resort Sierra-at-Tahoe, which is a significant driver of tourism and economic activity in the basin, saw significant damage. The Tahoe Basin itself is home to a diverse population that encompasses those working in the San Francisco Bay Area's tech sector who own weekend properties in the Basin, as well as service providers for the Basin.

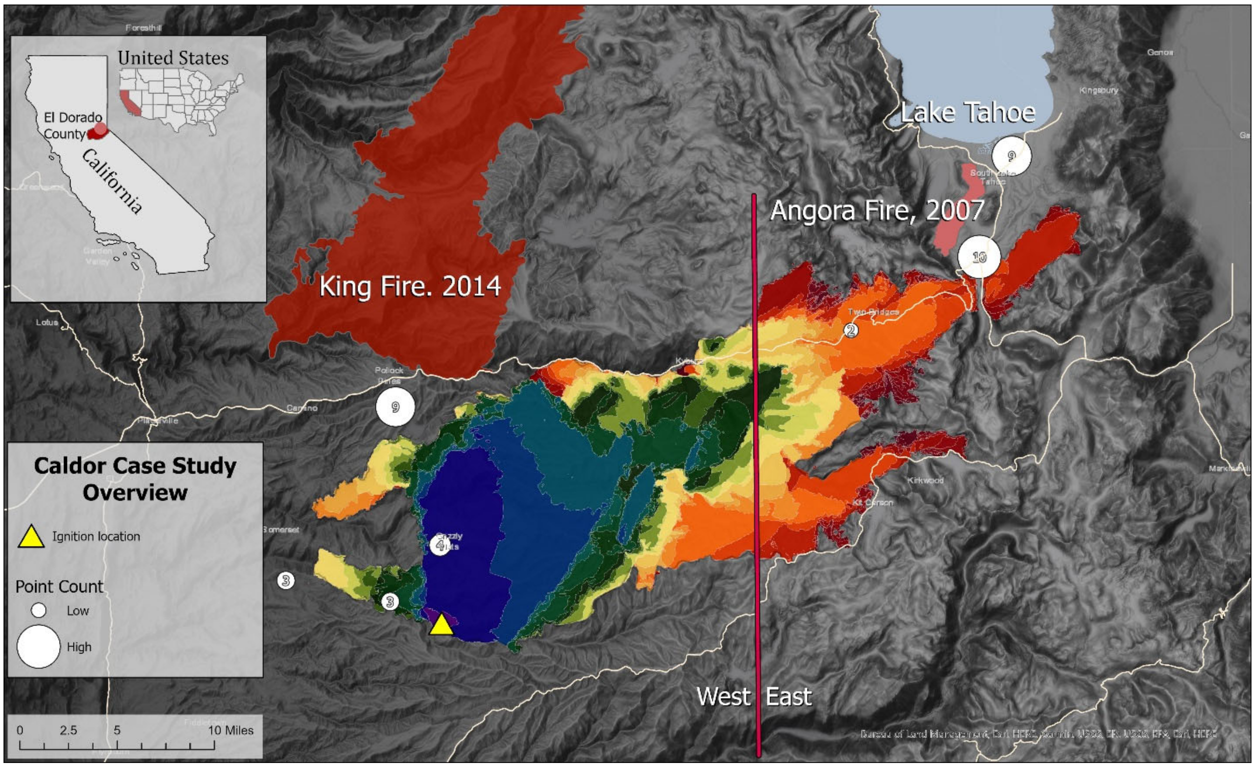

Figure 2: Caldor Fire Case Study Overview, El Dorado County, CA, United States. Caldor fire daily perimeter map in stepped colors, cooler tones indicating perimeters closer to fires ignition. Recent fires in red and annotated with name and year. Approximate interview locations represented as white circles. Ignition point represented as a yellow triangle. Zonal division of interview zones marked by red line.
SOURCE: Calfire, MTSB, US Census

3.2. *Study design and implementation*

3.2.1. Bounding The Network

Defining who is 'in' or 'out' of our study is a necessary step in study design to ensure that our network data collection is thorough and allows us to present accurate results. This definition is often referred to as a network boundary. The literature on network boundaries outlines 3 common approaches to setting boundaries (B. Nowell et al., 2018). (1) bounding via actor characteristics, which classifies someone as in or out based on known priori attributes such as being affiliated with the IMT or being a community Firewise leader; (2) bounding via relations, where next interviewees are nominated based on who a participant interacts with; and (3) bounding via events, in this case, which qualifies network members via common experiences (i.e., fire suppression organization or evacuee). For this study, a hybrid of all three approaches was utilized, which is not uncommon in network research (Nowell et al., 2018). Our hybrid approach had a primary reliance on event bounding. For event-focused approaches, researchers must define when the event is 'over' to temporally bound the event. For this study, the event was to be considered over when evacuation orders were lifted and residents were allowed to repopulate the burned areas. This decision was made in order to incorporate civilian information-seeking and providing behaviors after they leave the area of immediate danger. This temporal scope was later refined during the analysis paper, as in this paper, the network data is limited to when the participant leaves the threat area; future publications will incorporate the wider dataset that includes post-evac and recovery data.

3.2.2. Recruitment

Recruitment began in October of 2023 for Mill and July 2024 for Caldor. Participants were recruited via a mix of purposive (intentional selection of participants, i.e. community leaders), firefighters), convenience (non-probability sampling, i.e. posting recruitment flyers in public spaces), and snowball sampling (participants nominate the next participant). Researchers posted flyers in Facebook groups, Firewise community email groups, and other digital common spaces to schedule interviews before entering the field. Upon entering, researchers continued recruitment efforts by going door-to-door in residential areas to hand out flyers and answer questions about the study. Researchers continued by hanging flyers in common spaces, speaking with local business owners, congregations, and activists to invite locals to participate in the study. Researchers also spent time volunteering, speaking at local events, and tabling at farmers' markets to build a rapport with potential study communities. For example, further efforts to build trust and encourage participation from communities impacted by the Mill fire were necessary, as ongoing legal deliberations between Roseburg Forestry Products, the owner/operator of the mill that ignited the Mill fire, and the town of Weed were and are still ongoing. The University of Oregon's spatial proximity to Roseburg Forestry Products headquarters in Roseburg, Oregon, made some residents skeptical of our intentions and potential relations to the mill. We were able to address community member concerns through these less formal interactions. Similarly, researchers tabled at festivals and put on events to entertain children while speaking with parents to encourage participation from new or young families who'd had children during or around the Caldor event and were under-represented in our study until intentional efforts were made to recruit them. Research could only move at the speed of trust, which in post-fire communities must be tenderly maintained and upheld throughout the entirety of the research process.

3.2.3. Interview and SNA design and implementation

Researchers developed a semi-structured, mixed-method interview protocol to guide data collection efforts. A semi-structured interview protocol was selected because it allowed researchers to gather rich qualitative data in an explorative manner about a little-known phenomenon. Semi-structured interview protocols are particularly helpful in exploratory research efforts because they allow researchers the flexibility to ask follow-up questions about unanticipated topics or skip questions in the protocol based on a participant's expertise or unique background (Bryman, 2012). For example, professionals who stated they did not have a role in sharing wildfire information with the public were not asked the questions on the protocol related to public-facing communications. This study's protocol was divided into two phases: (1) qualitative interviews and (2) mixed-method network building. The first phase (i.e., interview protocol questions) included standard questions such as a participant's tenure in the community, role in the community, experience(s) with previous fires, and their experience with the case study fire. Data collection typically occurred in teams of two, with one researcher leading the interview (i.e., interview-lead) and the other leading the network mapping exercise (i.e., network-lead). To begin mapping the network, researchers asked where participants were seeking and providing fire-related information to/from during the incident. Identifying the flow of information between two nodes allows the creation of a directed network. Several follow-up questions were used to collect information about each node (e.g., frequency of use, perceptions of trust, how useful the information was, and if it met their needs). The network lead inputs each new individual or information platform the participant lists as a node during the interview-lead's questioning in Network Canvas (*Network Canvas*, n.d.), an open-source social network data collection tool. Allowing residents to openly recall actors, a method known as free name generation, was chosen due to the complexity and emergent nature of assessing resident-based information networks. Free name generation is not ideal due to issues of participant burden and recall bias, and has been found to underestimate the true size of a network (Varda, 2017). However, due to the exploratory nature of this study, researchers could not possibly anticipate each possible response a resident could give and generate a roster, as one might be able to with an incident manager network. In the second phase of the interview, the network-lead turned their laptop to the participant to verify with the participant that the recorded nodes are accurate and representative of all interactions they had during the fire. After verifying or editing to ensure network completeness, the researchers would present a Likert-scale-based survey on individual information node attributes within Network Canvas to the respondent. Survey questions can be seen in Table 1. As participants filled out the survey, interviewers would probe with follow-up questions to better understand the reasons for participants' high or low rankings of different information sources.

Table 1. Quantitative survey measures used in second phase of interviews via Network Canvas

Question	Scale
Was this information you sought out or provided?	Multiple options (select all that apply): Received, searched, sent.
How frequently did you interact with this information source?	Select the best option: Once, multiple times, every few days, daily, twice a day, multiple times a day, hourly, more frequently than hourly.
How important was this information source to your decision-making?	Likert Scale 0-5: Not important at all - very important.
How detailed was the information source?	Likert Scale 0-5: Not detailed at all - very detailed.
How well did this information source meet your needs?	Likert Scale 0-5: Not detailed at all - very detailed.
How easy was it to access this information source?	Likert Scale 0-5: Very difficult - very easy.
How easy was it to understand this information source?	Likert Scale 0-5: Very difficult - very easy.
How accurate was the information from this information source?	Likert Scale 0-5: Very inaccurate - very accurate.
How trustworthy was this information source?	Likert Scale 0-5: Very untrustworthy - very trustworthy.

Interview times ranged from 25 minutes to 3 hours and lasted an average of 50 minutes. Ultimately, 10 incident professionals and 40 civilians were interviewed and surveyed as part of the Mill fire case study (n=50). The Caldor fire case study included 56 civilians and 17 professional and key informant interviews (n=73).

4. Analysis

The data was exported from Network Canvas as and imported into Gephi (*Gephi - The Open Graph Viz Platform*, n.d.), ver. 0.10.1, an open-source social network visualization and analysis tool. The data from each interview were cleaned, and ties were made between nodes across different individual networks (ego maps) to produce a larger sociogram. Direct identifiers and attributes that could lead to the identification of our participants were removed as per the IRB protocol, and interviewees were renamed to a convention that protects their identity, a practice in line with broader network research (Adams et al., 2019; Jones & Faas, 2017). Civilians were labeled with the C, professionals as P (I.E. firefighters outside of incident command roles), key informants as K, and leaders of the incident management team/incident command staff as ICCS. A number was placed after the node type identifier (C, P, K, ICCS) to create unique interview identifiers.

To mitigate recall challenges, such as identifying individuals during brief or stressful single interactions (e.g, a firefighter speaking on a loudspeaker to evacuate) or identifying individual social actors on large social media platforms such as Facebook or Instagram, efforts were made to speak to other network members to attempt to verify individual identities. For example, a fire captain may be asked to confirm who might have been out in a given community in a given instance, issuing evacuation orders. Further, many interviewees used their phones to return to Facebook groups or screenshots in their phone photo application to verify or clarify the specific details related to the information sources (i.e., node) they interacted with. However, some participants did not have these archives to assist with recall, and the chaos of the early initial attack response was too volatile to confirm which individual from a fire response team had knocked on a particular door, and/or the psychological burden of detail-recall would prompt participants to opt out of answering these questions. These limitations are not uncommon in trauma research(Sachschal et al., 2019). To mitigate this concern of recall accuracy, we opted to recode more general data to create a two-mode network where hubs of information, such as in-field emergency managers or social media, represent nodes that we could not confirm were linked to a particular individual. Close social ties between members of the public and emergency managers, such as instances where a next-door neighbor is also an incident commander, would be categorized as a member of the public interacting with the hub of in-field emergency manager or fire professional if specific names/roles were recalled. This slightly skews various network statistics for hubs of information, which will be discussed more in the limitations.

The workspace in Gephi was formatted as a directed graph, with node size being determined by betweenness centrality, a network measure that assesses how often a node lies on the shortest path between other nodes. A high betweenness centrality score indicates a node that acts as a bridge of information between others (Light & Moody, 2020). Within Gephi, the network diameter and average degree tools produce measurements of each network, such as betweenness centrality, and in/out degree measures on a per-node level.

The data exported from Network Canvas also contained the node-linked survey data that will serve as a network diagnostic tool and be used for descriptive statistics for each event. This data was cleaned to remove missing values and bin responses into information categories to then be brought into SPSS, (IBM SPSS) version. 30, for statistical testing. Information categories were created iteratively, meaning that as new instances of information were described in an interview, the lead researcher determined whether it fit into an already existing bin or needed to be placed in a new bin that better represented its unique characteristics and uses during the wildfire incident. Once consistent and exhaustive rules were established, earlier interviews were reviewed to ensure compliance with the final version of node assignment criteria. Close social ties represented by friends, family members, and immediate or larger community neighbors were binned as one information category encompassing “friends, family and neighbors” due to a lack of variation detected between the subcategories, as well as variation in interviewee definitions of “neighbors” or “friends”. For example, neighbors were often also described in the interview as “friends,” and the information characteristics received from or shared with neighbors often did not vary from “friends.” Other studies also group informal community relationships into one category for analysis (Steelman et al., 2015) Social media sources that emerged during data collection, including Facebook, Instagram, Nextdoor, and Twitter (now X), and were traceable to individuals, community-led (e.g., Firewise, Neighborhood Watch), or event-based, were binned as “social media”. Social media accounts that were verified as run and updated by agencies were assigned a separate bin titled “agency social media.” In part, this was grounded in qualitative data where professional interviewees (including public information officers (PIO)) described agency efforts to provide unity and consistency to information searchers by replicating the same information across all their websites and social media accounts. Civilians often experienced this consistency by describing how visiting different websites often did not yield new information, even when the expertise of the agency shifted.

Information gathered by our public sample was sorted into pre-evacuation and during-evacuation stages based on qualitative interview data, wherein participants would provide their incident narrative alongside what information sources they were using at each stage.

This research presented herein analyzes only the quantitative data collected during the social network analysis portion of the data collection effort on the Mill and Caldor fires. The qualitative interview data will be utilized in future mixed-method studies.

5. Results

5.1. What information do residents seek and use under wildfire threat?

We found that residents threatened by the Mill fire interacted with fewer information source types (six) prior to making an evacuation decision than residents threatened by the Caldor fire (See Table 1). Four (4) information source types were utilized by participants from both fires, specifically (1) friends, family, and neighbors; (2) emergency managers; (3) CodeRed; and (4) social media through personal or civilian group pages (i.e., non-agency social media) (see Table 2**)**. Two information sources mentioned during Mill interviews, WatchDuty and Zonehaven, were either not available at the time of the Caldor fire (e.g., WatchDuty was recently launched and still very new in August 2021) or not present in the area (e.g., county contracts for public-facing evacuation mapping products in California include an array of vendors, such as Perimeter and Zonehaven (renamed Genesys in 2023)). Caldor fire participants accessed twelve (12) different information types, representing a more diverse array of information types than emerged during the Mill incident , including local and extra-local news outlets, online situational awareness tools (e.g., Flightradar24, AlertWest, Broadcastify) agency briefings, agency social media, scanners and radios, and agency websites. In addition to gathering information from a broader array of information sources prior to implementing evacuation decisions, participants on the Caldor fire utilized more information sources (M=5.96, SD=3.57) than Mill participants (M=1.87, SD=1.84). This is demonstrated by Figure 4 which illustrates how the spread of information gathered by our sampled population on the Caldor incident is, on average higher than on the Mill incident. A notable outlier on the Caldor fire had collected 16 individual sources of information prior to evacuation, such as AlertWest, online radio scanners, multiple close social ties, and social media. On the Mill fire, the average amount of information collected skewed towards the lower quartile of the box plot. Together, these findings indicate a potential difference between participants' abilities to gather information prior to evacuating from the two different fires and serve as the basis for further statistical investigation.

The frequency of use and characteristics of information sources utilized by our participants are summarized in Table 1. Family, friends, and neighbors were consistently utilized as by our respondents on both fires (Mill=95%, Caldor=98%) and across all 73 Caldor interviews, there were a reported 109 instances of friends, family, and neighbors being used to gather information, while across all 50 Mill interviews, this type of information was used 70 times. This demonstrates the prevalence of friends, family, and neighbors as a source of information used on both fires. The next most accessed information sources varied by fire, with 43% and 39% of Caldor participants accessing information from non-local news sources and online situational awareness tools, respectively. Emergency managers appeared as the next most accessed information type, with 39% of Caldor and 27% of Mill participants interacting with an emergency professional in-person or indirectly prior to or during the evacuation process (e.g., hearing a public announcement from a megaphone). The CodeRed Alert messages were received by phone call or text by 34% and 20% of our participants on the Caldor and Mill fires, respectively, prior to completing their evacuation actions. Non-government social media was more prominent in our Caldor participant information networks (30%) than in our Mill participants' (10%). Incident briefings accounted for only 27% of the Caldor information usage and did not appear in the information networks of our Mill fire participants until after the primary threat was over. This was likely due to the rapid progression nature of the fire forward progression of the fire halting after the first 4 hours since the initial attack began. Agency websites (18%), agency social media (16%), and scanners/radio groups (11%) were only reported in our Caldor participants' information networks. WatchDuty, while still too new to appear in our evacuation information networks for the Caldor fire, did appear to a small degree in our Mill Fire sample (10%).

We found that the information sources participants most commonly interacted with were not always considered the best across metrics. For example, when asked how important an information source was for informing their evacuation decision-making, the most commonly referenced information category of friends, family, and neighbors appeared somewhat important overall on the Mill fire (M=3.19, SD=1.90) and Caldor fire(M=2.87, SD=1.85). The large standard deviations for the friends, family, and neighbors category on both fires also highlights the variability within the friends, family, and neighbors category, with certain individuals being perceived of as having highly important and influential information and others having little. The in-field emergency managers were seen as important on Caldor (M=3.35, SD=1.64) and less important on the Mill (M=2.27, SD=1.71). The high standard deviation on these sources, especially Mill, may be related to when and how in-field emergency managers interacted with the public. For example, a firefighter knocking on your door to issue an immediate evacuation order may be perceived as more important than a PIO standing at a informational kiosk providing a broad incident update. Non-government social media was also reported as important (M=3.12, SD=1.51) to moderately important (M=4.00, SD=1.41) on the Caldor and Mill, respectively. High standard deviation persists in these findings. Which shows that while some participants found social media to be highly beneficial, others found it to be incredibly misleading and non useful for informing their threat assessment. The higher rating of social media on the Mill may have to do with lower usage overall (%) . Lastly, participants reported high importance scores for CodeRed for guiding their decision-making during the wildfire on both Caldor (M=4.28, SD=1.42) and Mill (M=4.10, SD=1.29)incidents.

We found further evidence of the potential influence of the pace of fire progression on the information-seeking behaviors of our participants in examining the prevalence of no-notice evacuation reports. In the Mill sample population, 16 of our 40 civilian participants reported receiving no warning of the fire before beginning to evacuate, forcing them to gather information via observations, in-field interactions, and while on the move out of the fire threat area. This is in stark contrast to the experiences reported by our Caldor participants, where we observed 0 instances of no-notice evacuations. Caldor participants collected more information (72%) prior to evacuating, while Mill participants only accessed 36% of the reported information in their information networks prior to evacuating. Mill participants accessed the majority of their information (64%) while evacuating, while Caldor participants accessed a smaller proportion (38%). were able to access the majority of their fire-related information (figure 3).

The T-test conducted by researchers to compare the average information intake between the two fires returned back a significance value <0.001 (F= 14.628) which further proves that there is a statistically significant difference in the amount of information taken by our sample population on the Mill and Caldor fires.

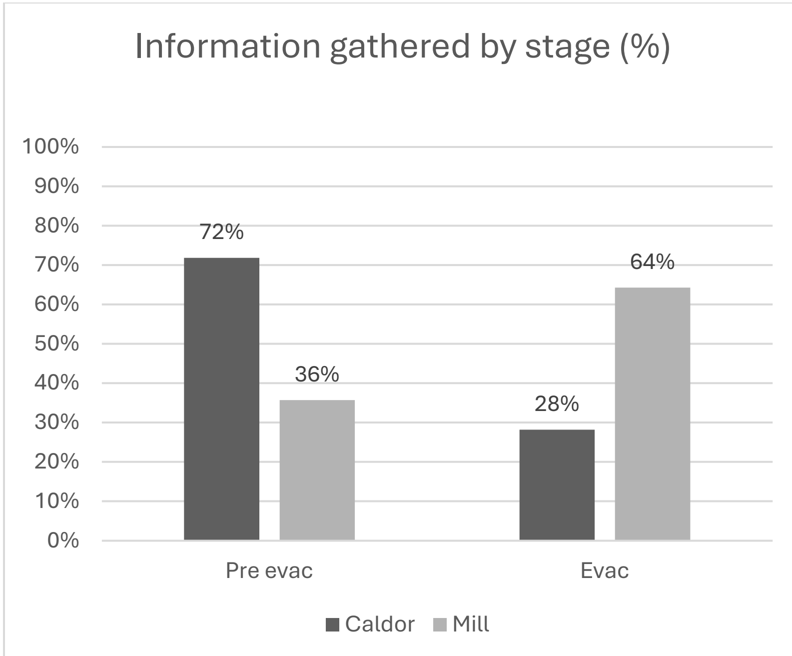

Figure 3: Information gathered by the evacuation stage on the Mill and Caldor fires.

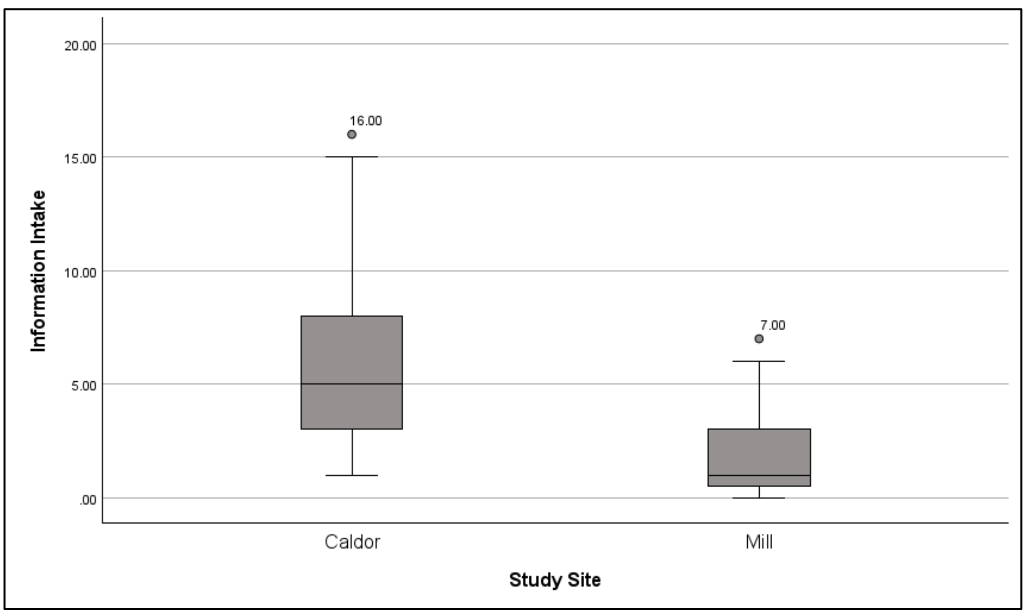

Figure 4: Comparative box plot of information gathered on both the Mill and Caldor fires.

Further testing was conducted to examine whether there was a difference in information intake within the fires themselves. Examining this potential relationship allows us to gain insight into how fire progression might be influencing information availability and public behavior. Given this, we examined whether information-gathering patterns differed between participants closer to the origin in both incidents. On the Mill fire, a North grouping and a South grouping were established, with the South grouping being closer to the fire's origin than the North, figure

1. An independent t-test was run comparing information intake between the group further from the fire origin, the North group, and the group close to the fire origin, the South group. No statistically significant difference was found through this test (F=9.121, p=0.730), which is not outside of the researchers' expectations. This non-significant finding will be further discussed later.

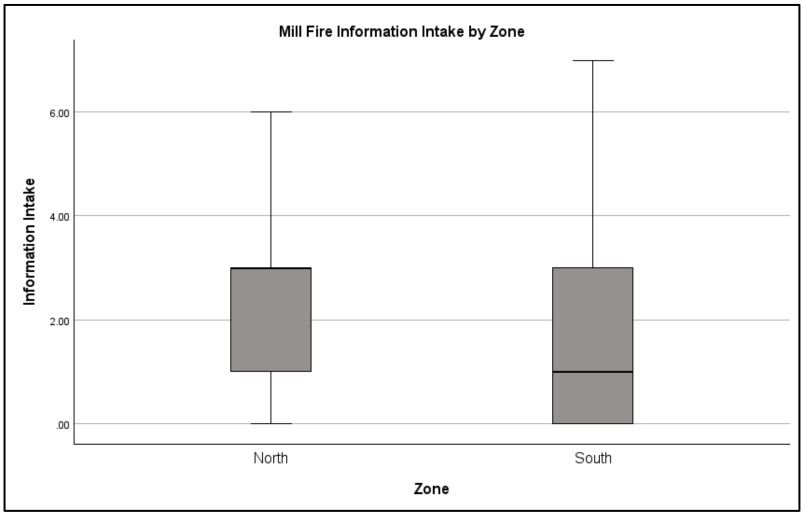

Figure 5: Comparative box plot of information intake between the North, closer to ignition, and South, further from ignition, zones of the Mill fire.

A similar comparison attempt was made for the Caldor fire. Participants were designated to one of two groups, the group close to the fires' origin East group, and a group further from the fires' origin West group, see figure 2. Again, an independent t-test was run, and again, no statistically significant difference was found between the two zones (F=2.677, p=0.108). Observationally, researchers do note what appears to be a slight trend occurring in the box and whisker plot depicting the differences between information intake by zone. While not a statistically significant difference, this observation warrants further examination, which will be brought up in the discussion section.

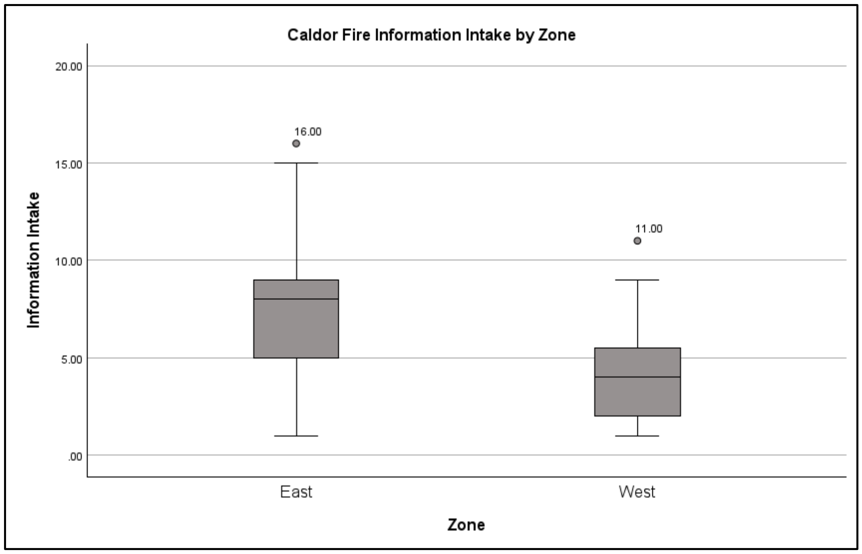

Figure 6: Comparative box plots of information intakes between the east zone, further from ignition, and the west zone, closer to ignition.

	Usage across sample (#,%)		Total occurance		Importance M (SD)		Needs met M (SD)		Detailed M(SD)		Trust M (SD)		Access M(SD)		Understand M(SD)	
Information type	**Caldor**	**Mill**	**Caldor**	**Mill**	**Caldor**	**Mill**	**Caldor**	**Mill**	**Caldor**	**Mill**	**Caldor**	**Mill**	**Caldor**	**Mill**	**Caldor**	**Mill**
Family, friends, neighbors	(55) 98%	(38) 95%	109	70	2.87 (1.85)	3.19 (1.90)	3.59 (1.07)	3.98 (1.16)	3.75 (1.13)	4.20 (1.00)	4.45 (0.83)	4.66 (0.61)	4.35 (0.95)	4.40 (0.99)	4.67 (0.67)	4.67 (0.74)
News	(24) 43%		35		2.52 (1.36)		2.93 (1.18)		3.39 (1.26)		4.07 (1.04)		4.14 (1.21)		4.46 (1.04)	
Online situational awareness tools	(22) 39%		41		3.50 (1.37)		3.74 (0.96)		3.90 (1.01)		4.26 (1.06)		4.52 (0.63)		4.58 (0.92)	
d emergency managers	(22) 39%	(11) 28%	38	15	3.35 (1.64)	2.27 (1.71)	3.64 (1.13)	3.55 (1.63)	3.82 (1.39)	3.27 (1.42)	4.68 (0.82)	4.67 (0.50)	4.07 (1.27)	3.36 (1.80)	4.57 (1.00)	4.20 (1.40)
CodeRed	(19) 34%	(8) 20%	34	10	4.28 (1.42)	4.10 (1.29)	4.21 (1.10)	3.00 (1.49)	3.96 (1.32)	3.80 (1.23)	4.96 (0.19)	4.44 (1.13)	4.71 (0.46)	3.50 (1.51)	4.86 (0.59)	4.44 (1.01)
Non-agency social media	(17) 30%	(4) 10%	27	8	3.12 (1.51)	4.00 (1.41)	3.13 (0.92)	2.83 (1.17)	3.30 (1.33)	5.00 (1.00)	3.52 (1.20)	4.50 (0.71)	4.74 (0.54)	5.00 (0.00)	4.74 (0.62)	5.00 (0.00)
Briefing	(15) 27%		23		3.95 (1.00)		3.76 (0.70)		4.33 (0.58)		4.62 (0.74)		3.81 (1.03)		4.35 (0.67)	
Agency websites	(10) 18%		18		3.36 (1.34)		4.10 (0.88)		4.30 (1.06)		5.00 (0.00)		4.60 (0.97)		4.90 (0.32)	
Agency social media	(10) 18%		13		3.83 (1.34)		3.73 (0.90)		4.00 (1.10)		4.73 (0.47)		4.73 (0.47)		4.91 (0.30)	
Extra-Local news	(9) 16%		10		4.00 (1.25)		3.89 (1.17)		4.33 (1.00)		4.56 (0.53)		4.67 (0.50)		4.56 (0.73)	
Scanners and radio groups	(7) 13%		14		4.36 (1.43)		3.33 (0.71)		4 (1)		4.67 (0.50)		4.78 (0.44)		3.89 (1.45)	
Inciweb	(6) 11%		6		3.50 (1.52)		3.60 (0.55)		4.00 (1.22)		5.00 (0.00)		4.60 (0.55)		4.20 (1.30)	
Watchduty		(4) 10%		5		5.00 (0.0)		4.50 (0.58)		5.00 (5.23)		4.75 (0.50)		4.50 (0.58)		4.75 (0.50)
Zone Haven		(2) 5%		2		2.00 (1.77		4.50 (0.71)		3.00 (1.41)		3.17 (1.47)		4.00 (1.55)		3.50 (1.52)

Table 1: Descriptive statistics of information used on both the Caldor and the Mill fire.

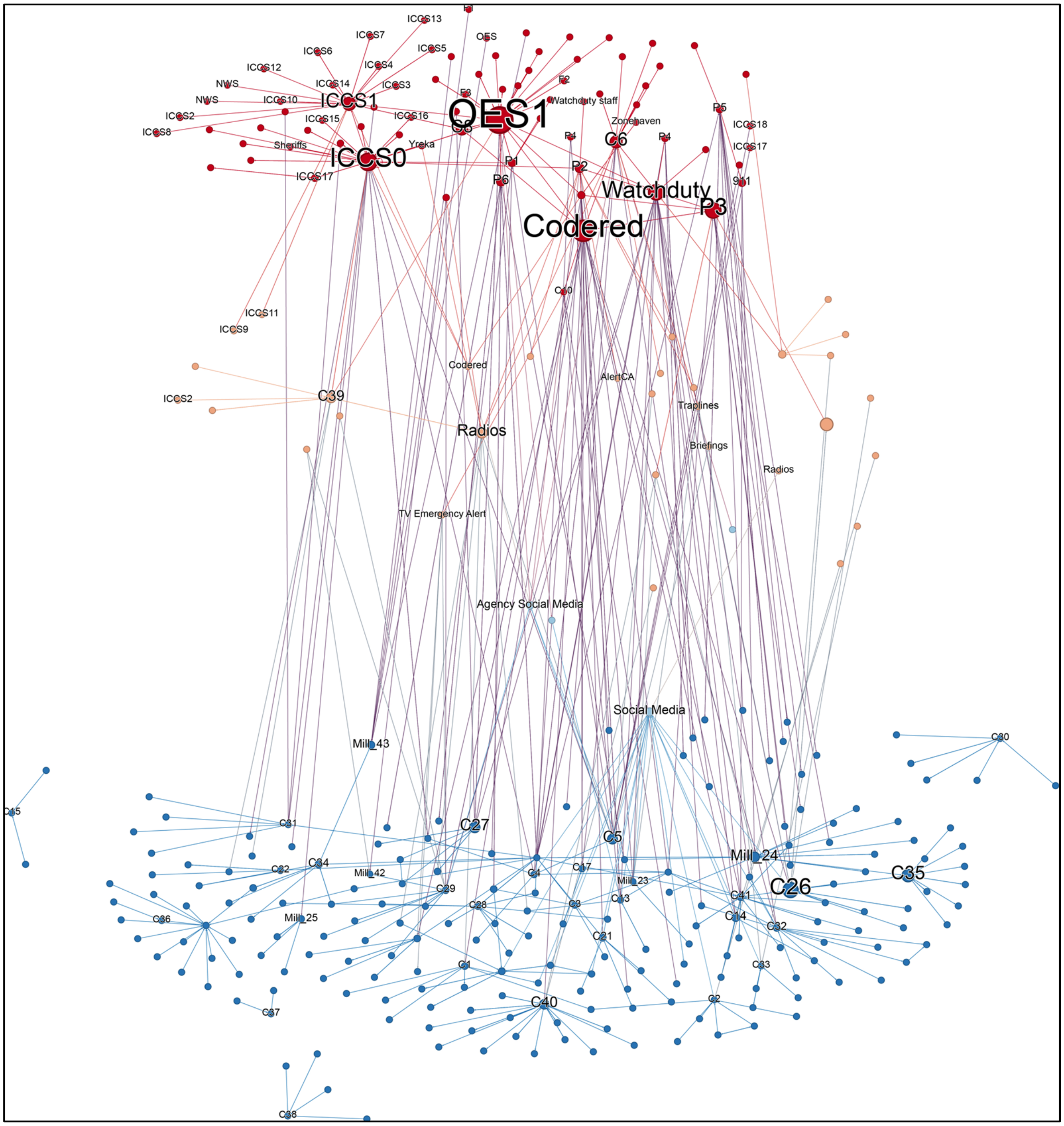

Figure 7: Mill 3d Sociogram. Dark red indicates most official sources, dark blue indicates members of the public.

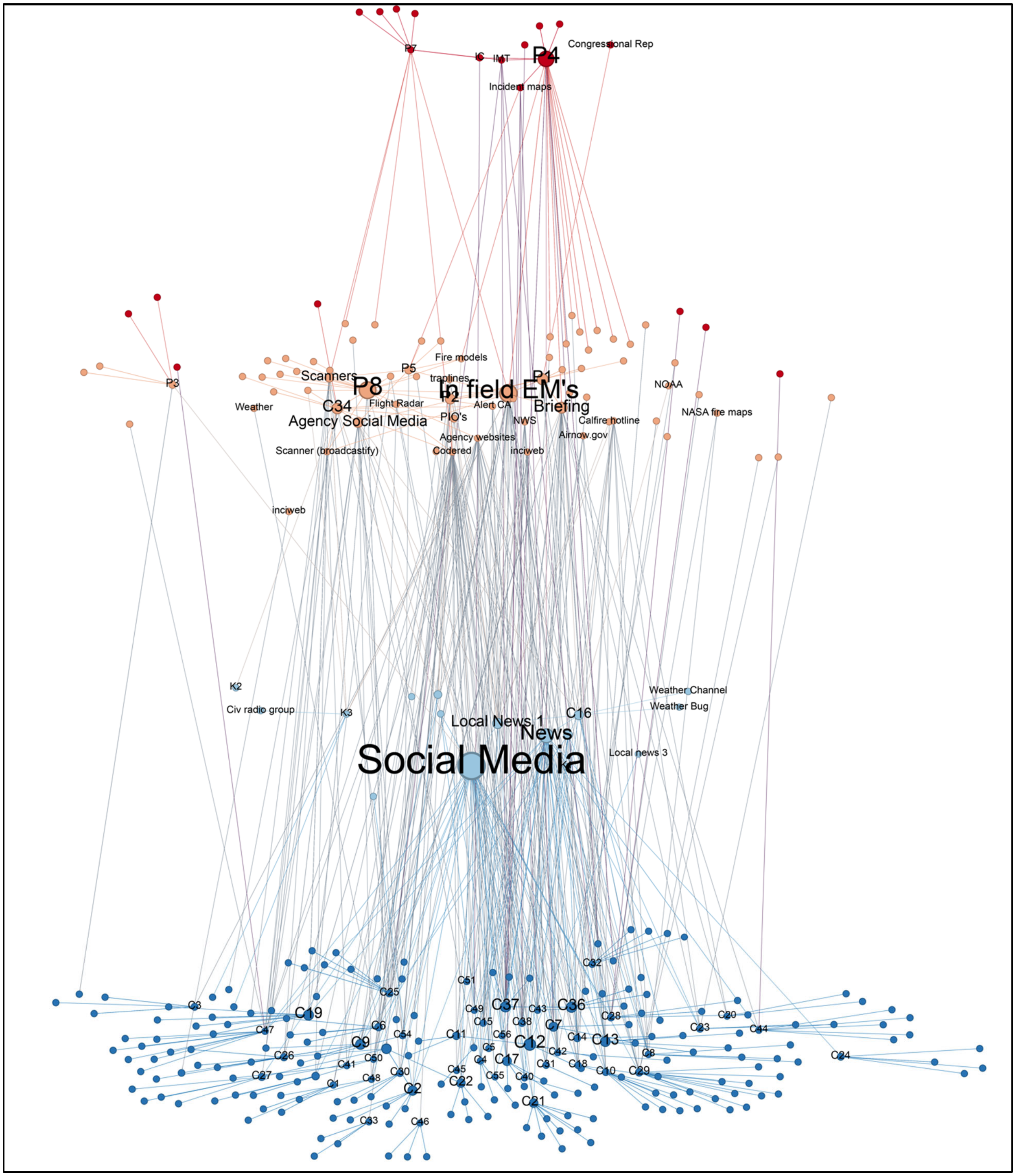

Figure 8: Caldor 3d Sociogram. Dark red indicates most official sources, dark blue indicates members of the public.

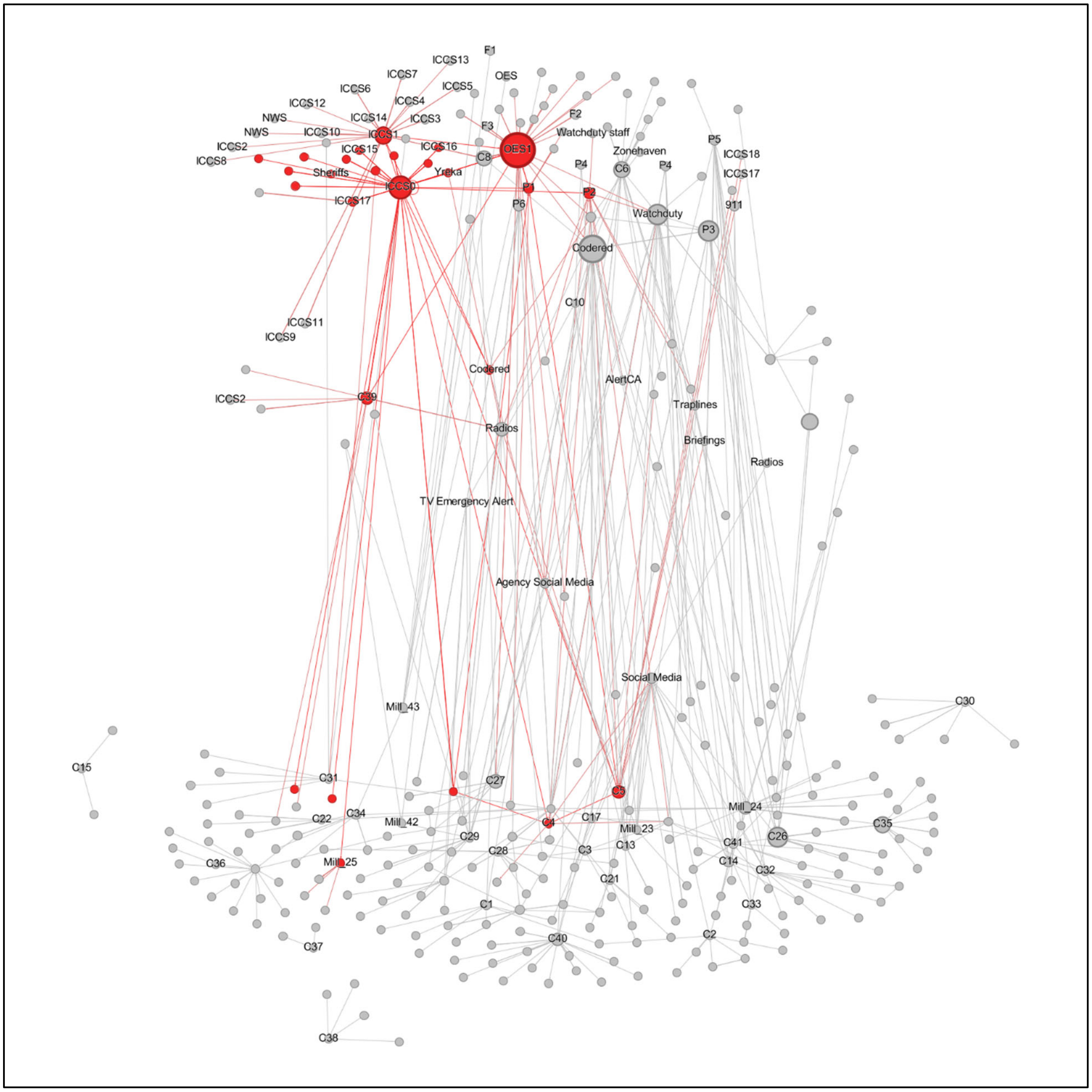

Figure 9: Mill 3d sociogram, high level incident manager and direct social ties highlighted in red.

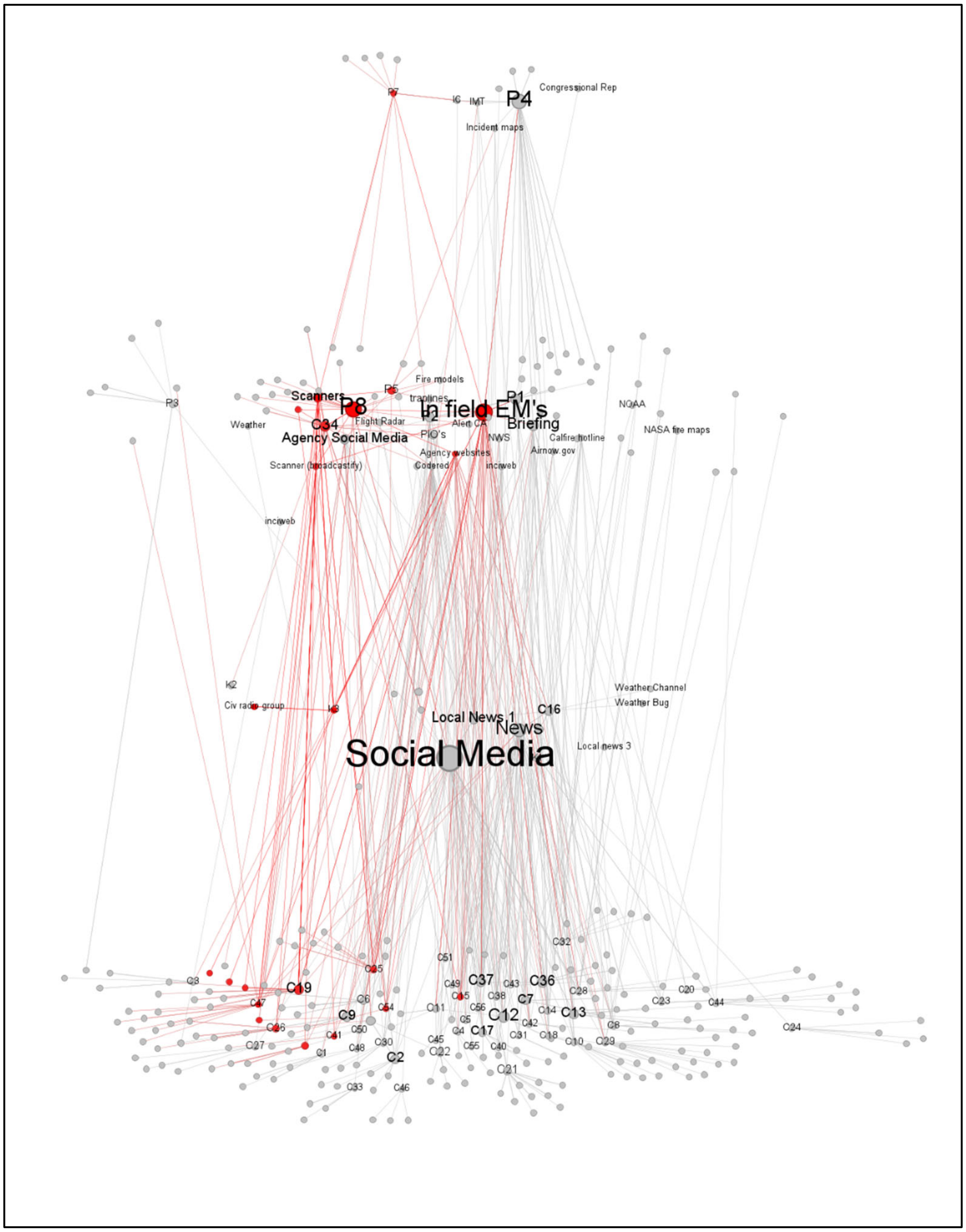

Figure 10: Caldor 3d sociogram, online/physical scanners and direct ties highlighted in red.

5.2. How is information supplied and diffused during a wildfire?

The sociograms above represent both professional and civilian social network data. They were constructed in a 3D view, where the 'officialness' of a node is responsible for its vertical placement in the layout. Incident commanders, public information officers, and official agency information platforms are found near the top of the figure, while less official sources such as social media and civilians are found near the bottom of the figure. This layout was not necessarily designed to dictate the validity of each source, but rather to demonstrate a hierarchical model of information flow as it is typically understood, where incident managers will send information to civilians through various channels. By comparatively examining the two sociograms, we come upon interesting findings regarding how a fire's behavior influences information networks.

On the Caldor fire, we observed several important features within the sociogram, such as significant hubs of information diffusion and a diverse range of information sources. Significant drivers of information diffusion in the Caldor network were CodeRed, social media, and public-facing briefings. These hubs, although accessed by the majority of our sample population on the Caldor fire, may be overrepresented in their usefulness to the public. By referring to Table 1, we see that social media, for example, while appearing as a major hub of information diffusion, received an average ranking of 3.13 (SD=0.92) on a 1-5 Likert scale assessing 'How well did this information source meet your needs?'. This demonstrates that while this hub was widely accessed by the public, it was not necessarily widely influential or important.

In contrast, the central hubs of information listed above fail to appear in the Mill sociograms, as the network depicts a less complex network with civilian participants primarily accessing a network of friends, family, and neighbors who were loosely connected to the broader network. The lack of central hubs or distributors of information on the Mill fire is likely a trait of the rapid onset and development of the fire. Several civilian nodes also have few or no connections to the broader network. These nodes represent civilians who had interacted with a few information sources during their evacuation process and were dangerously close to the origin of the Mill fire. Respondent C15 stands out to researchers as a nearly isolated node with only two ties to close social contacts such as friends, family, or neighbors. This individual, had they not had one of these two contacts, may have had no awareness of the unfolding disaster in their area until it was too late.

Researchers note that in the Caldor sociogram, many civilians were connected to friends, family, and neighbors, but the descriptive statistics indicate that these contacts may not have been sharing the most critical information, as they score an average ranking of 2.87 (SD 1.85) on the importance scale, neither important nor unimportant. Whereas on the Mill fire, friends, family, and neighbors received a slightly higher rating of importance at 3.19 (SD 1.90).

On both fires, researchers noted the ability for civilians to access and disseminate back-channel information through various means, which could only be examined through this network approach. On the Caldor fire, figure 10, scanners and civilian radio groups have been highlighted in red as well as their nearest neighbors in the sociogram. By doing so researchers observed how information from high-ranking members of the incident management team is made its way to the civilian level without the need for information mediators such as public information officers. A similar feature is observed on Figure 9 where when researchers highlight certain members of the incident command team we can see they have direct close social ties with members of the public, once again demonstrating how information has the ability to bypass typical channels of information dissemination. The observed process of information jumping from the top of the network to the bottom will be explored further in the discussion section.

6. Discussion

6.1 Information Gathering Dynamics

Firstly, we noted a significant difference between the amount of information taken in by our participants regarding the Mill and Caldor fires, with more information types and a broader depth of information utilized by Caldor participants prior to evacuation than by participants impacted by the Mill fire. Also observed were 16 instances of no-notice evacuations on the Mill fire, with 0 instances of no-notice evacuations on the Caldor fire. We believe these differences are at least partially driven by fire behavior, as the dangerously fast-moving Mill fire gave our public participants significantly less time to gather information than if they had been on the Caldor fire. Recorded incident radio traffic on the Mill fire and observations from AletWest cameras allowed us to estimate that from the start of the Mill fire to the first structures burning was a mere 7 minutes, which proved to be too fast for emergency managers to begin suppression efforts, notify the public, and deploy resources fast enough to stop further spread. This resulted in multiple instance of no-notice evacuations near the origin of the fire, and fewer further away. This time from incident start to impact was significantly shorter than on the Caldor fire, with multi-day lead up from ignition to structure threat. We believe this temporal difference is what resulted in our t-test finding that demonstrates a statistically significant difference between the average information intake before evacuation on the Caldor and Mill Fire. Further illustrating fire's influence on information gathering is our figure 3, which illustrates how on the Mill fire most of our participants were actively learning more about the fire while evacuating, which contrasts the Caldor fire where participants gathered most of their information before making the decision to evacuate. While we did not observe a significant difference in information intake between groupings of participants close to the fire's origin vs those further away, the data suggest that on the Caldor fire we see what appears to be a non-random reduction in the quantity of information gathered for participants on the East (closer to origin) than the West (further from origin), implying that the closer you are to the fires origin the less time you have to gather additional information. While this difference was, again, not statistically significant, this trend observed in the Caldor data suggests a fairly logical interplay between an individual's spatial location and how they are able to access information on a fire. Future studies of a similar nature may want to further examine this trend with an emphasis on increasing sample size and recording key evacuation trigger points that allow us to better understand the relationship between space and evacuation behavior in a fire. Through our study of the Caldor and Mill fires, we can readily observe how fast-moving fires significantly hinder the availability of information access for the public, a pattern that has shown up in major incidents such as the 2018 Camp fire. In our network analysis of the Mill fire, researchers noted the lack of central hubs of information dissemination and participants with very few ties to the broader network when compared to the Caldor fire. These findings again support our observation that fire behavior/rate of spread is correlated with information intake and information network development.

Ultimately, these findings indicate that information gathering processes are reactionary and largely dependent on how the fire itself is behaving. This concept is supported by Suttons 2019 work, which builds upon existing evacuation decision-making literature. In this paper, Sutton outlines a pattern of information gathering that we found in our work, wherein so long as an individual does not feel protective action is necessary they will continue seeking out information that is timely, relevant, and aids in their risk assessment process. The Mill fire highlights how when fire progression is so rapid and threats are immediately imminent that gathering addition information is forgone for the sake of imposing necessary protective action. Where as the Caldor fire shows us the depth of information that the public will seek out in order to be kept informed on a large fire.

6.2 Friends, Family, Neighbors

We found that residents on both fires accessed some common resource types that are echoed in the larger wildfire literature, including friends, family, and neighbors; social media, CodeRed, and emergency managers Similar to Steelman et al. 2015 and Sutton et al. 2019. Similar to previous studies of disaster communications, we find that friends, family, and neighbors carry with them temporally relevant information, spatially relevant information, unique back-channel information sources, and or specialized backgrounds that allows greater insight into a fires development (Burger et al. , 2013, Steelman et al., 2015, Sutton et al, 2008).

In our data, we found the critical role that neighbors played in informing those around them of the rapidly developing Mill fire. Participants in Lincoln Heights were effectively able to run door to door as the fire was developing to alert their neighbors. This proved to be an effective strategy in this development, as housing lots are small and close to one another. We also believe this was one of the only ways to effectively notify the area of Lincoln Heights at this time. The area was not under any preemptive hazard warnings such as a red flag warning, and there was no way to rapidly alert the area, such as through the use of sirens. Official evacuation orders (CodeRed notifications and door knocking) would not begin to arrive until after impacts to structures had already begun. The Mill fire, in many ways, was yet another warning call for managers that our traditional notification systems are being stressed in new ways in this era of faster-moving fires that they cannot necessarily handle. As seen by the need for residents to alert each other of imminent danger as no official warnings were arriving. Furthermore, for some residents the traditional alert and warning system may have proven insufficient as they were hard of hearing, visually impaired, or otherwise unable to receive an alert to their phones. As such, they were dependent on neighbors who were aware of their need for assistance to force entry into their home in order to safely be evacuated. Since the Mill fire, several other fast-moving fires have challenged traditional alert and warning systems, such as the 2025 Los Angeles fires and the 2023 Hawaii fires.

In more rural spaces of the Caldor fire, the dynamic of neighbors keeping each other informed was achieved using a variety of tools, such as phone calls, group emails, or neighborhood radio watch groups. These radio watch groups are comprised of individuals on General Mobile Radio Service (GMRS) frequencies, which require a license to transmit on. During an active fire, these individuals will form an organizational structure similar to the ICS system with a lead radio network controller directing other radio network members to listen to specific incident radio frequencies, such as air attack or dispatch, and report their observations back to the net controller. Listening to radio watch group transmissions could be done by anyone regardless of GMRS license status, which effectively allows radio watch members to keep both themselves and the broader community informed, so long as radio infrastructure such as repeaters remains operational. These groups allow for individuals separated by great distances or a lack of other communication services, such as cell signal, to form a larger nexus of information sharing. From a social network perspective, researchers note how these radio groups effectively allow for the capture and transfer of rich back-channel incident information to the public. The information these radio watch members gather may relate to key operational details, such as additional firefighting resource orders, if a containment line is failing, or where new spot fires are. To further support these unique methods and redundancies in communications, researchers identified the opportunity to inject funding for radio infrastructure (battery/generator backups, new repeater sites, equipment repair and restoration programs) and training exchange programs. Multiple community radio watch groups exist around the country already, and providing opportunities for these organizations to swap knowledge and expertise could prove to be highly productive for increasing overall adaptive capacity. Furthermore, finding opportunities to engage with a younger audience will be critical in enhancing this communication method. Our participants who reported being active in their local radio watch group or Community Emergency Radio Association (CERA) were primarily recent retirees or soon-to-be retired. Engaging and training a younger population to pick up many of the roles of an aging population will be critical for keeping this method of communication operating.

6.3 New information age, social media and back-channel information

The theme of the public keeping each other informed despite spatial differences was also seen through the use of social media. On both fires, we found the public to be using extra-local social media sources such as community Facebook groups. In some instances, these Facebook groups are how a participant would find out about the developing fire. Especially on the Caldor fire, where videos of the fire's origin and ignition were shared widely on Facebook. Throughout the Caldor and Mill fire, multiple local-specific Facebook pages were active, posting content that ranged from back-channel information details to rumors. For this reason, social media received one of the lowest trust scores from our participants with a high standard deviation. Still, our network analysis shows that on the Caldor fire, social media played a major role in distributing information to many of our participants through either direct ties to the hub or from having close social ties that fed them information from social media. The widespread adoption and use of social media by the public as a tool to stay informed during a fire has generated several nuanced impacts. Such as the spread of misinformation, rumors, and false reporting on the fires' condition, origins, or firefighting operations. At the same time as misinformation is spreading, we also found a number of actors who aim to challenge misinformation such as local public information officers posting in their capacity as representative of their fire suppression organization, independent wildfire analysts such as Zeke Lunder of The Lookout, and independent journalists who all post to various social media platforms and were accessed by our Caldor participants. The variety of information accessible to the public online is clearly outlined above as both problematic and greatly insightful, which is why we believe there to be such a large variance in how the public perceived social media as a tool of wildfire information dissemination.

Our social network-based approach to analyzing participant information intake allowed us to observe unique interactions with social media and the public. For instance, one participant reported how their sister's husband in Idaho learned of the developing Mill fire through social media and informed the sister, who then informed the participant, who had otherwise not heard of the new fire in their area. Social media and these niche groups that post fire-specific information on an extra-local level have effectively allowed friends who are not physically near the hazard area to keep an eye on those who are.

Some of the additional categories (online situational awareness tools and scanners) of information utilized on the Caldor fire demonstrate an interesting adaptation of those in wildfire-prone areas to seek out niche pieces of back-channel information that allow greater insights into firefighting operations. The category researchers designated as "online situational awareness tools" houses a wide array of information tools and platforms, including Flightradar24, AlertCA (now AlertWest), remote sensing products, weather forecasts, and live-streamed radio scanners. These somewhat obscure tools had appeared readily in the hands of our public participants and played a key role in shaping the incident narrative for the public. These back-channel information sources allowed the public to access, with some tools, near real-time updates on the fire, a feature that is often lacking from official sources that need to be verified through bureaucratic processes, such as twice-a-day incident briefings. Briefings, while critical for keeping the public informed about broad incident updates, at times will lack the spatial or temporal relevance that the public is looking for throughout the day. The frequency of updates was noted by our participants as being an important factor in how they chose to rank the importance of information sources. The sources that could provide the most real-time and the presumably accurate information were often seen as the most important for our participants. By the very nature of being back-channel sources, these types of information platforms are not necessarily under the control of incident managers. The public is free to tune their radio scanners into incident command radio channels or track planes to effectively construct their own incident narrative outside of the control of incident managers and public information officers. This skill is especially important in instances where no such official information is available in a timely manner. While these sources proved to be critical in keeping the public informed on the Caldor fire, they are incredibly susceptible to power or internet failures. Every source listed above, other than hand-held radios/scanners, requires both active data and power connections. As soon as either of those connections is lost, as is common during a wildfire, the tools are effectively inaccessible.

These online back-channel information sources, which were uniquely utilized on the Caldor fire and not Mill, required a participant to have either known about the platform before the fire or know someone who knew how to both access and utilize the tool, as many tools required a certain level of interpretation by the user. Participants noted how many of the sources they accessed they had learned about from their experience on previous wildfire seasons. We believe that the combination of tech worker migration into the South Lake Tahoe basin, along with a history of land management and high employment by land management agencies, promoted the adoption of unique back-channel tools that otherwise may have been difficult to access/unfamiliar to the public. During the Caldor fire, in our network findings, we observed how participants would collect and share back-channel information with each other, seen in figure 10. This network observation highlights how who you know during an incident may dictate what you know. For example, having a volunteer firefighter as your neighbor may allow you a great deal of access into back-channel sources.

At the same time as many of these new back-channel information sources and social media platforms have entered center stage, we noticed an information connection failure for some older participants. Several participants had no access to a personal computer or cell phone capable of accessing online briefings, back-channel sources, or social media pages. These participants noted frustration with trying to find relevant news on local radio stations, broadcast TV, or through incident hotlines. For both participants on the Mill and Caldor fire, neither region was covered in great depth by local broadcasters who were often located in the state capitol or out of Reno for the Caldor fire and Medford for Mill. Even if a broadcaster did mention the fire, it would often be a short, ineffective blurb about how many acres the fire has burned and what percentage of containment is. For the individuals who relied on mass media for their primary incident updates, they often had to turn to neighbors or family out of the region to get more accurate updates. This detail was again only able to be obtained through our network analysis.

This finding supports a claim made earlier in this paper that our alert and warning systems require an overhaul that is more inclusive, redundant, and fast to act to ensure that all populations threatened by a fire can stay informed promptly.

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