

Uncertainty in Forest Fire Management

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ABSTRACT

In forest fire management, uncertainties are inherent. One major challenge for forest fire managers is the uncertainty of whether a fire will start at all, where, when and with what effect. In particular, human negligence and arson are unforeseeable. This research focuses on these uncertainties affecting the preparatory practices of forest fire managers in Brandenburg, Germany, and how they are anticipated and dealt with. Qualitative content analysis of expert interviews and focus group discussions generate in-depth insights into the role of uncertainties in the prevention phase and during the control of the event. Findings shows that uncertainties pose barriers to preparatory action. Coping mechanisms rely on individual sensemaking that are in turn influenced by one's role, knowledge and experience as well as organizational habits and values. Analysis of German firefighters' perceptions of and coping with uncertainty shows that practices of imagination help to anticipate uncertain futures and to cope with dynamic, complex disasters.

Keywords

embodied uncertainty, forest fire, emergency management

INTRODUCTION

In the management of forest fires, uncertainties are inherent. One major challenge for emergency managers is the uncertainty of whether a fire will start at all, where, when and with what effect (McCaffrey et al., 2020). Forest fire events cannot be predicted with absolute precision, since they arise from a complex of causes consisting of physical and human factors, the actual cause of ignition and the predisposition of the affected areas (Süssner, 2020). Only the potential of the environment to spread the fire, e.g., soil condition, fuel potential and weather facilitating the burning, is used to calculate fire risk such as fire weather forecasts. Thus, uncertainties in fire management previously have mainly been examined in quantitative calculations and models (e.g. Barros-Daza et al., 2022; Diao et al., 2020; Doyle et al., 2019; Wibbenmeyer et al., 2013). These predictions have their limits, as they are subject to forecast uncertainty (Neisser & Kox, 2021; Owen et al., 2012). According to the German forest fire statistics, human action (negligent or intentional arson) is the main cause for forest fires (Bundesanstalt für Landwirtschaft und Ernährung, 2020). This makes the anticipation of such events very challenging. It is therefore important to consider how uncertainties affect the decision-making of forest fire managers and how they cope with these uncertainties (Taylor et al., 2013, p. 7).

Uncertainty is typically split into epistemic uncertainty, which arises from a lack of knowledge, and aleatory or variability uncertainty, which describes unpredictable variables (e.g. Aven, 2011; Kox et al., 2015; Sword-Daniels et al., 2018). Although many models assume that decision-making is predominantly analytic based on calculations and logic, the affective decision-making oftentimes overrules logic if both processes disagree. To enable a more representative concept of decision-making processes, the concept of embodied uncertainty considers the perception

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and handling of uncertainty form a multi-faceted perspective, including emotions and experience (Sword-Daniels et al., 2018). Embodied uncertainty aims to incorporate all aspects of uncertainty in the context of disaster management decision-making and calls for accepting uncertainty as an inherent part of the disaster management task (Sword-Daniels et al., 2018).

Using a qualitative approach, this paper dives deeper into constructions of social reality and thereby reveal underlying belief sets and processes of sensemaking that become relevant when dealing with uncertainty in forest fire management. By doing that, we investigate how uncertainty is embodied. The integration of socio-cultural factors into forest fire management models is still rare. It has previously been attempted by Patrão (2020), who calls for a more comprehensive conceptualization of forest fire management that includes socio-cultural realities and a multitude of stakeholders in all phases (e.g. not only firefighters but also the public, the government and agricultural professionals) and emphasizes the role of humans in forest fire management. Through a qualitative perspective this paper aims to explore uncertainties that forest fire managers perceive prior to and during the handling of a forest fire. Furthermore, it reveals how these practitioners contextualize and deal with these uncertainties and which strategies they use (or do not use) to handle the disaster.

Operational decisions are never based on a single piece of information, especially when decision-making is done in the context of multiple factors of uncertainty (Roncoli et al., 2012). Anderson (2010) identifies three practices of anticipation: imagination, performance and calculation. Practices of calculation are limited in forest fire management. Important tools for calculating the hazard risk of forest fires are fire danger rating systems, which are numerical or qualitative indicators that reflect the fire potential (Goldammer, 1998; Neisser & Kox, 2021). These include, in particular, meteorological indices, which combine several influencing factors in one index. In Germany, the forest fire hazard index (WBI) is provided by the agro-meteorological department of the German Weather Service (DWD) indicating daily and weekly forest fire danger levels from 1 (very low danger) to 5 (very high danger) for each county based on air temperature, relative humidity, wind speed and precipitation. Performative practices of anticipation in disaster management are for example training exercises, imitating and therefore embodying possible futures. Regular firefighting drills are part of the training of firefighters, but the focus on specifics of forest firefighting is still rare. Imagination as anticipatory practice refers to envisioning certain futures through scenario planning, and exchanging visions and stories of past events (Anderson, 2010; Neisser & Kox, 2021).

Another concept investigating the perception and management of the unexpected is sensemaking (Weick & Sutcliffe, 2015). In general, sensemaking can be seen as a process of social construction that occurs when discrepant cues interrupt individuals' ongoing activities and involves the retrospective development of plausible meanings that rationalize people's actions (Weick, 1995, 2005). In particular in ambiguous and uncertain moments, sensemaking happens on the account of cues from the environment (Maitlis & Christianson, 2014). Sensemaking processes hence happen in the context of individual and organizational values, experience and knowledge (Barton et al., 2015, p. 81). Whiteman and Cooper (2011) further differentiate that sense-giving while in action plays an important role in managing sudden disasters, such as forest fires. However, unexpected events do not trigger sensemaking per se, but sensemaking occurs when the discrepancy between what is expected and what is experienced is large and important enough to cause individuals or groups to ask "what's going on" and what they should do next. Under growing pressure and prolonged operations sensemaking is deemed to become more challenging and hence, it has been found that under those conditions people rely on their previous understanding of their role and fall back into old habits (Weick & Sutcliffe, 2008).

The purpose of this study is to gain insight into perceptions of uncertainties and barriers to preparedness activities: What uncertainties do forest fire managers perceive in their work? What is their role in forest fire prevention?

MATERIALS AND METHODS

To gain insight into the perceptions of uncertainties and barriers to preparatory measures of forest fire management in Germany, a qualitative research approach was selected. This approach allows to not only shed light on underlying decision-making but also emotions and habits guiding sensemaking and more affective decision-making and reveals in how far uncertainties are embodied. After a systematic literature research, two focus group discussions with overall twelve participants and six in-depth, problem-centered expert interviews were conducted with forest fire protection and management practitioners in Brandenburg, Germany. Brandenburg is the federal state in Germany that is most vulnerable to forest fires, because of its dry soils, same-aged needle woods plantation and continental climate (Gnilke & Sanders, 2021; Thonicke & Cramer, 2006), making it a suitable case study area for assessing forest fire management strategies in Germany. The interviewees included representatives of the Brandenburg Forestry Administration's Forest Fire Monitoring Center and of the Brandenburg State Firefighters Association, employees of regional disaster control administration, as well as local fire chiefs and staff of the control and dispatch centers. The anonymized transcriptions of the interviews were analyzed using qualitative content analysis with

support of MaxQDA software. Qualitative content analysis is particularly useful for gaining detailed insight into the thought processes, meaning-making, and overarching narratives of individuals and groups, and is therefore an appropriate method for uncovering the uncertainties perceived by forest fire managers. Coding was done using a combination of inductive and deductive categories, guided by the relevant literature and taking into account, among other things, the theoretical foundations of organizational sensemaking, organizational culture and management under uncertainty.

RESULTS

The results show that dealing with uncertainty is an important part of the work of forest fire managers. Uncertainty is generally seen as a normal influencing factor of work, which one simply has to accept, since forest fire managers see little possibility to influence it. One can classify the mentioning of uncertainties into uncertainties prior to and during a forest fire event. After examining the general uncertainties that came up during the interviews, we describe coping strategies that have been mentioned or became clear indirectly. The focus lies on the use of forecasting and the role of organizational knowledge. As a final step, we put the results together in a visual overview, attempting to systematize the findings and relate them to the theory discussed above.

Uncertainties Identified Prior to and During the Forest Fire Event

Generally, forest fire managers acknowledge that uncertainties are inherent to forest fire events and mention several uncertainties affecting their work. Overall, they accept that in uncertainty is an invariable inherent component of their work. The uncertainties mentioned by the forest fire managers can be categorized into uncertainty perceived in the phases prior to and during the event (see Tab. 1). Prior to the event uncertainties revolve mainly around the occurrence of a fire and during the event they mostly concern fire behavior (see Fig. 1).

Table 1. Uncertainties prior to and during a forest fire event

Prior to the event	During the event
Weather condition & fuel potential	Availability of volunteer fire fighters
Cause (human ignition)	Development of weather conditions (& fire)
Time and place of the event	Duration of the event

In the anticipation of a possible forest fire, practitioners describe uncertainty mainly as the unpredictability of the time and place of forest fire events, especially since most forest fires in Brandenburg are started by people due to negligent or intentional arson.

Although there is generally an understanding that even weather forecasts cannot predict the upcoming weather conditions in their region with 100% accuracy, forest fire managers still wish for them to be as precise as possibility. Especially the spatial accuracy considering regional conditions and the visualization of meteorological values and their probability are important for practitioners. They state wind direction and speed, wind gusts potential, precipitation, heat, UV radiation and soil moisture as most important variables for them. The ambiguity of trust in weather forecasts becomes clear. On the one hand, the tendency to distrust weather forecasts is due to past deceptions and perceived errors in forecasting; on the other hand, forecasts represent at least one means of computational practice to predict an unexpected event. The actual forecasting of a forest fire event is perceived as highly uncertain and forest fire managers tend to check forecasts through their own observations or through information from people on site.

After the alarm to a forest fire, the biggest uncertainty lies in the structure inherent to the fire management system, namely its dependency on volunteer firefighters. Because of the sudden alarm, it is difficult to know exactly how many of the firefighters can arrive in time at the forest fire event. A major problem with this is that many volunteer firefighters today work in larger cities that are far from their home. This limits their ability to arrive at their assigned fire station or on site in the shortest time possible. Another unknown variable is the duration of the forest fire, as it depends heavily on the time of arrival of the first firefighters, weather conditions such as wind speed and direction, soil moisture and precipitation, and the local conditions of the affected area. In the region, there is also the problem that some forests are former military sites and therefore there are restrictions on entering the area to ensure the safety of firefighters.

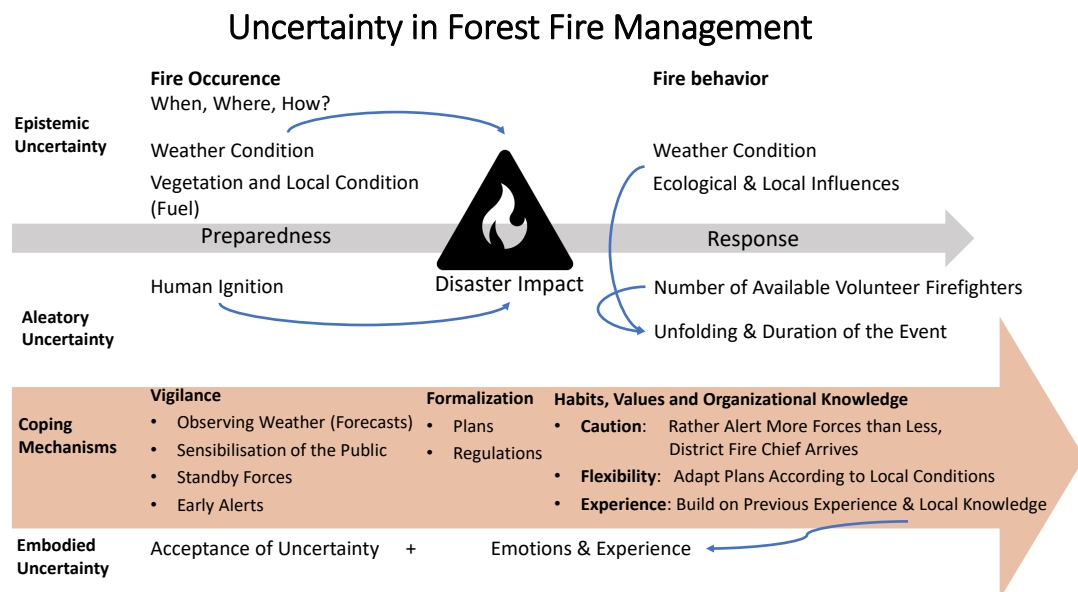


Figure 1. Uncertainty in forest fire management and coping mechanisms to deal with these uncertainties

Coping Mechanisms for Dealing with Uncertainties

The interviews revealed different strategies for coping with uncertainty. While tools and probabilistic calculations such as weather forecasts and formalized structures such as plans and established procedures minimize epistemic uncertainty, values and experiences as part of organizational culture seem to play an important role in managing aleatory uncertainty.

Vigilance

To minimize the impact of uncertainties on forest fire management, most forest fire managers seem to be increasingly vigilant towards cues for forest fire risks. Most importantly, weather forecasts and forest fire risk indices are a relevant tool to envision possible origins of forest fires and even more so the potential development of the forest fire behavior. Forest fire managers rely mostly on calculations such as meteorological weather information because regulations and legal liability hold them responsible for actions taken or not taken based on different forecasts or fire warning levels of the German forest fire risk index. Probabilistic forecasts are sometimes mentioned to help consider those uncertainties in an even more detailed way. Nevertheless, the aim to counter the uncertainties of weather forecasts by predicting possible impacts through impact-based forecasting is oftentimes considered irrelevant by the interviewees, who emphasize that experience and local knowledge are their most important guidance. However, forest fire managers see potential in providing such additional guidance to the public, who they believe are not as well informed. The interviewees deem that the public could be more inclined to seek protection and change their behavior when receiving additional information on possible weather impacts. This in turn would ease their job, as fewer operations would become necessary if people were more sensitized to the risk of fire weather and acted in accordance with the warnings. Another aspect of vigilance and increased alertness is to call standby forces to the fire station, if the fire risk is assessed to be high according to the weather forecast, the forest fire warning index, or personal feeling. However, as there are no formal regulations to allow this standby procedure and most German firefighters are volunteers, this is only possible on weekends or evenings, when the firefighters do not have to attend their regular job. Otherwise, firefighters rely on early alerts to get to the scene as quickly as possible.

Formalization

Another way to cope with uncertainties is to prepare for events through plans based on previous experiences and risk calculations. In Brandenburg, Germany, there is a defined organizational structure specifying who is in charge of making plans, revising and enacting these plans. These regulations and guidelines are distributed in the emergency vehicles, the command and dispatch center and at the fire stations. Commonly, plans are to be updated every three years or after extreme forest fires. There are also forestry regulations that allow forest managers to restrict public access to the forest when there is a high forest fire warning level of 4 or 5 out of 5. However, this is not commonly used by the practitioners, because the forest managers feel that these regulations cannot be enforced.

Habits, Values and Organizational Knowledge

To balance uncertainties, some general organizational and individual habits come into play. One of them is increased caution. According to the interviewed fire managers, the district (or county) fire chief (*Kreisbrandmeister*) always takes part in the first forest fire assessment onsite if the notifying command and dispatch center alerts a bigger forest fire with the code for larger forest fires (*Brand: Wald/groß*). The motto is to rather request more emergency personnel than necessary than have too few available. Since one of the greatest uncertainties is that the volunteer firefighters will actually show up in time. Because of that, some fire brigades even choose to call a stationary attendance if they suspect an event happening in the close future, although no formal plans to call such stand-by attendance exist. Another aspect of taking caution is to forward every warning received, even if it is a false alarm. Caution during the incident particularly involves keeping the firefighters safe, e.g. from threats arising from old munition, thunderstorm, heat and high UV or landslide risk. Especially during a bigger event some interviewees deem it relevant to stay calm. For example, one interviewee emphasizes that he learned from older colleagues to keep calm and wait, and manage the event with composure. Other practitioners emphasize that there is “no universal dogma” applicable to any situation and all fire stations as “no operation is the same as another”. This demonstrates that adaptivity and flexibility are relevant to coping with forest fires, their unexpected cause and their uncertain development. A positive attitude and motivation for their job support these habits and values. All practitioners agree that experience is more important than any predictive calculation, weather forecast, or forest fire risk index. As one fire brigade leader puts it, firefighting is always a “step by step” learning process, in which all firefighters evolve and enhance their skills. This implies that knowledge transfer within the organization is of high relevancy. However, knowledge transfer is rarely systematic. In some organizations, certain stories are told by senior colleagues, while in others it is emphasized that experience is best gained by being exposed to real firefighting operations, not just practical exercises or theoretical lessons. Talking to other members of the organization and learning from their experience is thought to be more helpful than learning by book. Some use a mentoring program that gradually gives younger, newer firefighters more responsibility in the field, but always offers the chance to draw on the experience of the mentor in case of difficulties. At the governance level, knowledge exchange also extends to international and scientific exchange. Successful firefighting is also based on mutual trust. Local fire brigade leaders create this trust by repeatedly making it clear that the safety of the firefighters is paramount, by promoting an open culture of error and being proud of their comrades.

Integrative Framework of Uncertainty Perceptions and Coping Mechanisms

Fig. 1 visualizes which types of uncertainties forest fire managers perceive, how they can be theoretically categorized and which organizational coping strategies are employed to encounter them. The uncertainties and their coping strategies are organized along their stage of appearance in the disaster cycle. Interactions and dependencies are presented as blue arrows. For example, the uncertainties of the fire occurrence also affect the disaster impact. Furthermore, uncertainties about the fire behavior that we categorized as epistemic such as the weather condition predicted by forecasts, but also aleatory uncertainties such as the number of volunteer firefighters actually showing up, influence another factor of uncertainty: the unfolding and duration of the event. The coping mechanisms primarily applied in the different phases can be categorized into the anticipatory practices, which help deal with the different types of uncertainties and at different disaster stages (see 1). At different stages of the disaster cycle different practices of anticipations have varying relevancy to anticipate uncertainties and cope with the uncertainties. Furthermore, the type of uncertainty seems to influence the type of anticipation and coping strategy.

DISCUSSION

In the literature on forest fire management, it has been widely acknowledged that weather is an important factor in the development and modification of forest fire events (Boyчук et al., 2020). This study goes further and assesses the perception of weather forecast uncertainty in context with further uncertainties affecting forest fire management decision-making. Weather forecasts and warnings are important for practitioners, especially because of the related legal regulations. For the actual firefighting, however, they are combined with personal experience, own observations and local knowledge in order to make optimal adapted decisions. Hence, when distinguishing between intrinsic and contextual factors of operational decision-making (Roncoli et al., 2012), particularly the contextual factors of decision-making seem to be of relevance in forest fire management, as the situation is very dynamic and decisions have to be assessed and adapted accordingly.

When uncertainties prevail, the decision environment in which predictions are used matters. The results of our research show that apart from formalized structures in forest fire management, such as the organizational structure, information flows, or human factors especially values, previous experiences and local and organizational knowledge affect decision-making processes under uncertainty in forest fire management. To respond to the uncertainty

inherent to their job, organizations tend to follow habits, plans, goals or rituals that are intended to create more certainty and control over the situation, well-knowing that they can never be sure of the success of these aims (Turner, 1976, p. 378). The relevancy of values, experience and knowledge in sensemaking processes has also been demonstrated to be crucial by former studies (Barton et al., 2015, p. 81). In our case study, especially experience and local knowledge were significant factors to cope with uncertainties in forest fire management. This finding agrees with Weick and Sutcliffe's 2008 analysis of forest fire managers' sensemaking practices, who state that under growing pressure sensemaking becomes more challenging and hence people rely on their previous experiences and understanding of their role.

The analysis shows that values such as flexibility and adaptivity and a calm mindset are deemed crucial to cope with uncertainties in forest fire management. This finding can be used to develop these skills in forest fire exercises. Especially the aspect of flexibility and openness to adapt the current organizational structures and decision-making to the dynamic situation has been considered beneficial for emergency management by previous scholars and has been highlighted especially for firefighting (Weick & Sutcliffe, 2008).

Another mechanism that German forest fire practitioners emphasized for coping with uncertainty is increased vigilance and caution. Practitioners remain attentive to indications that the situation may change and not unnecessarily jeopardizing the safety of responders. Firefighters in Germany deem it impossible to completely hinder the occurrence of an event, but they always aim to get ahead of the threat and change the situation (Kox & Lüder, 2021). The forest fire managers tendency to rather warn and alert too often than too little has for instance also been observed in a study on hurricane prevention management, calling this practice the "worst-cased approach" (Bostrom, A., 2016), or in firefighters' response to weather warnings, calling it a "zero-risk strategy, in which even the lowest probability of occurrence is too much of a risk and thus has to be avoided" (Kox et al., 2018, p. 126). The safety of responders is a key priority in managing the event and previous studies have recognized the influence of self-protection decisions on fire suppression strategies (e.g. Patrão, 2020). The interviewees in this study also mentioned the aim to reach out to the public as part of their preparatory measures trying to prevent forest fires from happening. It seems that practitioners in fact already include socio-cultural factors in their management strategies and acknowledge the value of incorporating local communities into forest fire management (Patrão, 2020; Paveglio et al., 2019).

Barton et al. (2015, p. 81) find as an additional factor to manage uncertainty that leadership behavior influences effective disaster response. This aspect has not come up much with the interviewees in this context. One reason why this was only rarely mentioned could be that all interviewed persons were in a leadership position, and hence did not reflect the importance of their position and influence. Another reason could be that organizational structures and culture, and experience just matter more for forest fire managers than leadership behavior. However, the research shows that knowledge transfer is another important factor for managing uncertain complex fire events and the effectiveness of organizational knowledge transfer probably relies on leadership. The unclarity of the role of leadership in this research opens room for further research that should investigate on the links of knowledge transfer as part of leadership behavior, and leadership's potential to minimize uncertainties. Previous research has already discussed the impact of leadership on firefighters well-being but not focused on perceptions of uncertainty (Marques-Quinteiro et al., 2022).

Overall, our research has shown that to cope with uncertainties, practices of imagination, such as knowledge transfer, experience of senior colleagues told through stories or organizational values shaping individual sensemaking are highly relevant. These habits and values are shaped by a general acceptance of uncertainty. This finding agrees with previous research that asserts professional weather forecast users relatively good knowledge of forecast uncertainty (Kox et al., 2015). This embodied uncertainty helps to face the emerging threats with composure and to remain calm and flexible even in extreme situations. Accordingly, the interviewees stressed the relevancy of personal experiences, mindsets and emotions. As this is an exploratory case study, the research is limited to providing deep insights into the expert group in question; it cannot be expected that practitioners in other fields or other cultural contexts will necessarily hold the same views. Moreover, qualitative research is never completely free of subjectivity. Employing Lincoln and Guba's Standards for qualitative research in respect to transparency, credibility, dependability and confirmability was a measure to overcome this challenge (Shenton, 2004). Our results represent the viewpoints of the interviewees, which may be affected by social desirability and the general interview setting but are contextualized in the discussion and interpreted in the light of previous studies and findings of scholars exploring the management of the unexpected.

In contrast to previous quantitative studies, our research sheds deep insights into perceptions of uncertainties in forest fire management from the perspective of practitioners and analyses these in the context of the current state of organizational and disaster management research approaches. The findings serve to reveal underlying reasonings that influence decision-making under uncertainty in forest fire management as well as coping strategies. The

study thereby confirms findings of previous studies by analyzing first-hand experiences and conceptualizations of emergency service personnel in the forest fire sector. Moreover, we showed performance practices such as exercises to be less relevant to the group and highlighted aspects such as the role of local knowledge and knowledge transfer, that so far have received less attention by disaster scientists in Western countries. Presenting these findings will not only help advance research on management strategies in disaster management but also aid practitioners to contextualize and adapt their strategies. Our work adds to the growing literature on anticipatory wildfire governance a qualitative perspectives on use and perception of uncertainties (Miller et al., 2022). Future studies should take these findings and compare them in a wider, more international scope to find differences and similarities. This will enrich future strategies for managing and accepting the unexpected and integrating embodied uncertainty into forest fire management approaches.

CONCLUSIONS

Our study demonstrated perceptions of uncertainty in forest fire management prior to and during the event. The sensemaking approach was a valuable approach to classify these perceptions and how to deal with them. We show how German firefighters consciously and unconsciously employ certain strategies to deal with uncertainty, e.g., adaptive informal awareness mechanisms or formalization such as making plans based on past events. In general, a wait-and-see caution and constant vigilance are evident. In particularly extreme events, where aleatory uncertainties dominate, computational and performance practices are less relevant to anticipating the future development of a fire, while practices of imagination are essential. Experience, caution, composure, and flexibility are values that have been shown to be relevant to forest fire management in the face of uncertainty. In addition, the role of local knowledge and knowledge transfer in managing unexpected extreme fire events was emphasized and should be further explored in future studies.

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