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Wildland-urban interface fires in Norwegian coastal heathlands – Identifying risk reducing measures

Anna Marie Gjedrem [a,b], Maria Monika Metallinou [a,*]

[a] Fire Disaster Research Group, Western Norway University of Applied Sciences, 5528 Haugesund, Norway
[b] European University of Cyprus, 6 Diogenous Str. 2402 Engomi, Nikosia, Cyprus

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ABSTRACT

For five millennia, the coastal heathlands in Norway were managed with fire to improve grazing. The abandonment of this practice for the last ca. 70 years has resulted in biomass accumulation and increasing fire hazards. The present study analyses fire and rescue services' (FRS) risk perception ahead of the six most aggressive Norwegian wildland-urban interface (WUI) heathland fires in the period 2014–2021, tactical decisions during the responses and lessons learned for fire hazard mitigation. Guidebooks in fighting wildfires provided the framework for evaluating the adversity of the context and possible actions during responses. Based on interviews with FRS personnel, planned and/or implemented measures were categorized as reducing ignition frequency, reducing vulnerability, or improving community preparedness.

The results suggest that FRSs need locally adapted fire hazard warning tools as decision support, to implement a fire ban outside the official fire season. Challenging responses were followed by learning processes locally, but no sharing between FRSs was reported. Measures to improve preparedness were implemented in some municipalities, while all interviewees expressed an understanding of the importance of landscape management for fire-prone biomass reduction, to reduce vulnerability. One FRS who regularly performs prescribed burning (PB) exercises experienced large advantages when handling a potentially severe WUI fire. The authors suggest that PB be incorporated in the list of FRSs' yearly training sessions, if heathland is present in their jurisdiction. The PB suggestion may also be applicable elsewhere along the Atlantic coast, where coastal heathland historically existed, as well as in other areas with fire-adapted ecosystems.

1. Introduction

Human activities cause most of the world's wildfires (Syphard & Keeley, 2015). Ignitions occur in frontier rural landscapes, and fire frequency first rises with increased human activity, then declines due to urbanization (Cochrane & Bowman, 2021). Power lines, trains, commercial human activities in forests and recreation are some of the ignition causes. The amount and type of biomass, its continuity and proximity to settlements, as well as the weather conditions, define the potential severity of a fire event. Applicable response capabilities may vary, depending on the time of day, location and weather conditions. During an initial attack in rural areas, the number of responders, as well as their competence and experience, may be limited, before reinforcements arrive.

The well-known fire triangle is equally applicable in outdoor as in indoor fires. The presence of fuel, oxygen and heat (ignition source) is the prerequisite for flaming combustion (Drysdale, 1985). When addressing wildland fires, another triangle, combining fuel, topography and weather, is also used (Tolhurst, 2009). In many places, biomass accumulation has increased dramatically during recent years, due to altered landscape use and the abandonment of prescribed fire as a land management tool (Donovan & Brown, 2007; Log et al., 2017; Log et al., 2020). Additionally, the development of the wildland urban interface (WUI) has increased (Bento-Gonçalves and Vieira, 2019; Radeloff et al., 2018), caused by modern development in the fringes of metropolitan areas and by amenity migration in rural areas (Anton & Lawrence, 2016), thus, increasing the number of individuals and homes exposed to wildfire. The term 'WUI' is used in two different ways in the literature: a) as the fringe suburbs of metropolitan areas (Anton & Lawrence, 2016) and b) as areas where human developments meet or are intermingled with wildland (Bénichou et al., 2021). In the present study, the second definition is used.

* Corresponding author.
E-mail address: mm@hvl.no (M.M. Metallinou).

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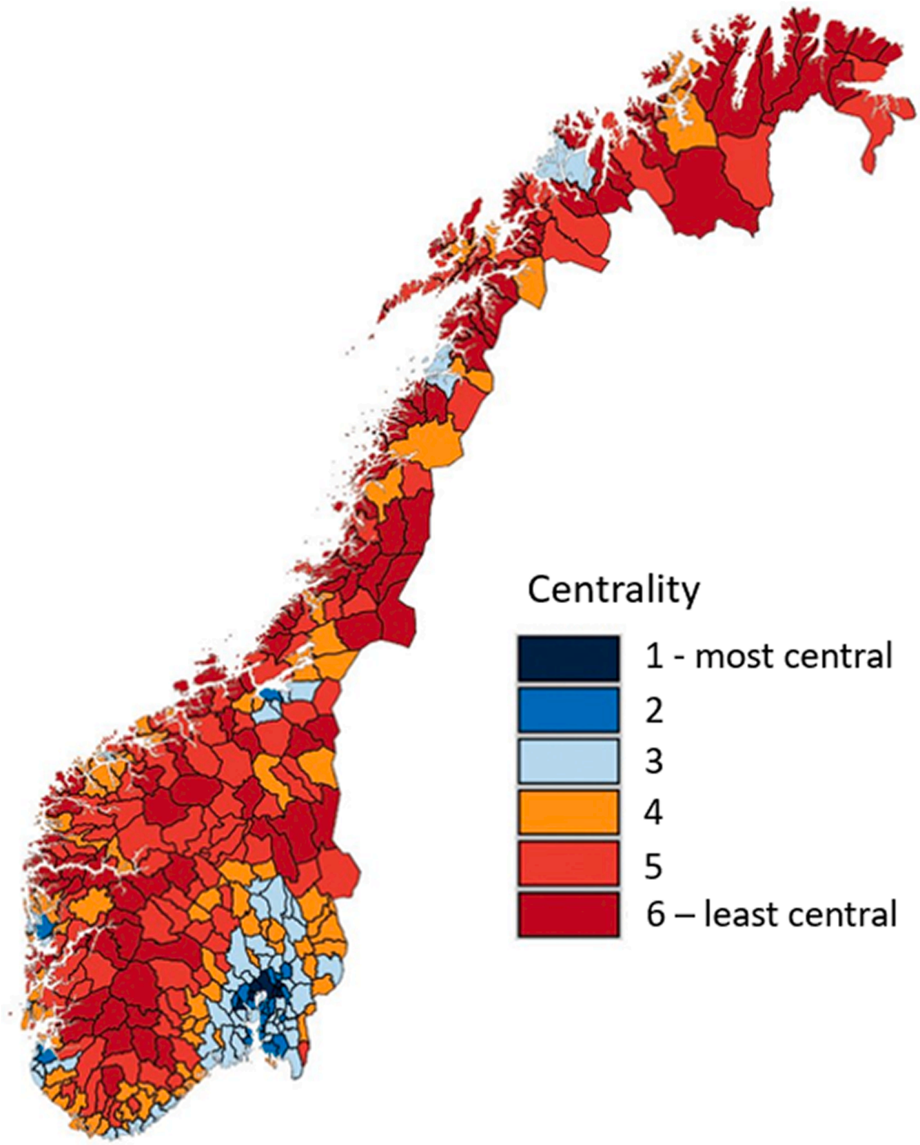

Fig. 1. Population data defining area centrality, from category 1 (most central) to category 6 (least central) (Meld. St. 5, 2019–2020).

Scientific studies describing the circumstances and extracting knowledge from severe WUI fire incidents are numerous. Incidents with a high toll on human lives are analysed to understand the causes and, thereby, to be better prepared and reduce the risk of future incidents. For example, the 2009 bushfires in Victoria, Australia, have been analysed in terms of the fire events, probable causes (Tolhurst, 2009; Miller et al., 2017), preparedness of the community before the incidents (Whittaker et al., 2013) and the development of risk mitigation projects in the aftermath (Hughes & Mercer, 2009). However, few sources address fire incidents involving only property destruction (Heath et al., 2011). In the Norwegian context the sub-zero temperature town fire of Lærdal 2014 has been investigated (Log, 2016; Andresen, 2017). Moreover, the Sotra WUI fire 2021 was investigated to suggest fire mitigation strategies (Log and Gjedrem, 2022). In the face of climate change, the Association for Fire Ecology (AFE) highlights in the San Diego declaration, (AFE, 2006) that continued treatment of fire-adapted ecosystems is essential for ecosystem health and vitality. Treatment of fire-adapted plants also reduces biomass, thus creating a safer environment for fire-sensitive ecosystems, where damage is incurred from severe fire incidents (AFE, 2006). Along the Atlantic coast of Norway, the *Calluna Vulgaris*-dominated heathlands have been treated with regular fire at 10- to 20-year intervals to improve grazing, for 5–6,000 years (Kaland, 1986). They are therefore fire-adapted ecosystems. However, this practice, which was common along the Atlantic coast of Europe, was interrupted about 70 years ago, because of intensive agriculture and industrialization. Today, only about 15 % of the original coverage of European heathlands is conserved (Davies et al., 2009). This is also the case in Norway, where the main threat to the nature type is vegetational encroachment (Kaland and Kvamme, 2013). Historically, grazing was the primary motivation for treating the heathlands, while fire safe landscapes and other ecosystem services were “bi-products”. After decades with abandonment, the society has realized that the secondary benefits were of importance and seeks ways of regaining those. Reducing accumulated fire-prone biomass, especially in the WUI, can be done with mechanical cutting, grazing, PB, or a combination thereof. Climate change has increased both the frequency and severity of WUI fire events, also in the Nordic countries (Log et al., 2017; DSB, 2018; Pinto et al., 2020). Several WUI fires have occurred in Norway, involving abandoned heathlands and settlements, over recent years (BRIS, brannstatistikk.no, 2021). Statistics Norway (SSB) recently published a cost-benefit analysis comparing the cost of treating the heathlands with that of the fire-fighting response. For the most optimal scenarios, the annual societal

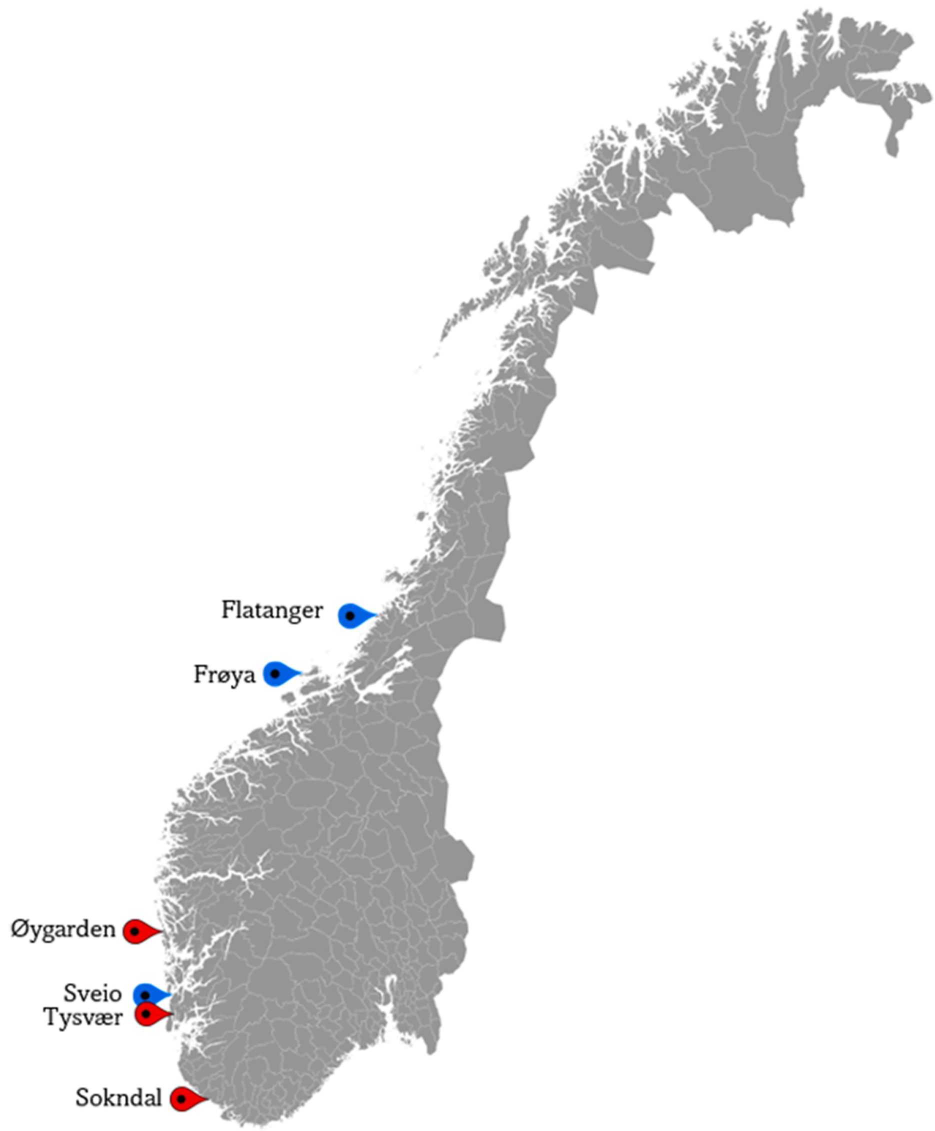

Fig. 2. Location of the studied fires. Blue marks indicate sub-zero temperature winter fires (all during 2014); red marks indicate two spring fires (2019) and one early summer fire (2021) (map from Wikimedia.org, 2021). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
The municipalities affected by the six abandoned heathland WUI fires analysed.

Municipality	Area (km^2)	Population	Population density (km^{-2})	FRS (responders)	Fire name
Flatanger [a]	460	1,120	2.4	Part-time	Flatanger
Frøya [b_1, b_2]	152	4,547	30.0	Part-time	Frøya
Sveio [c_1, c_2]	246	5,463	22.2	Part-time	Vandaskog
Tysvær [d_1, d_2]	425	11,044	26.0	Intermunicipal	Hetland
Sokndal [e_1, e_2]	295	3,300	11.2	Part-time	Sokndal
Øygarden [f_1, f_2]	314	38,664	123.1	Part-time	Sotra

(a: Data Flatanger 2014, b1: Data Frøya Area 2022, b 2: Data Frøya Population 2014, c 1: Data Sveio Area, c 2: Data Sveio Population 2014, d 1: Data Tysvær Area 2022, d 2: Data Tysvær population 2019, e 1: Data Sokndal Area 2022, e 2: Data Sokndal Population 2019, f 1: Data Øygarden Area 2022, f 2: Data Øygarden Population 2021

economic benefit was calculated to be about 200 + million NOK (i.e., 23.5 mill USD, or 20.3 mill Euro) (Halvorsen & Grimsrud, 2021, p. 54). Despite the clear societal and environmental benefit of treating the heathlands, challenges in assigning the treatment cost to the bodies who will save the cost of responses remain to be solved. This may delay beneficial decisions and actions.

The population distribution in Norway, as in other Nordic countries (Jokinen et al., 2020), consists of few urban centres and large areas with few inhabitants. Statistics Norway has classified Norwegian municipalities into six categories, from 1 (urban) to 6 (least central). The designation "rural" is used for areas classified as 5 or 6, representing 72 % of the area and 14 % of the inhabitants. Category 4, 5 and 6 areas cover 90 % of the area and include 30 % of the inhabitants (Meld. St. 5, 2019–2020), see Fig. 1.

In the present study, six WUI fires involving overgrown heathland in Western Norway have been analysed. Two of the studied fires occurred

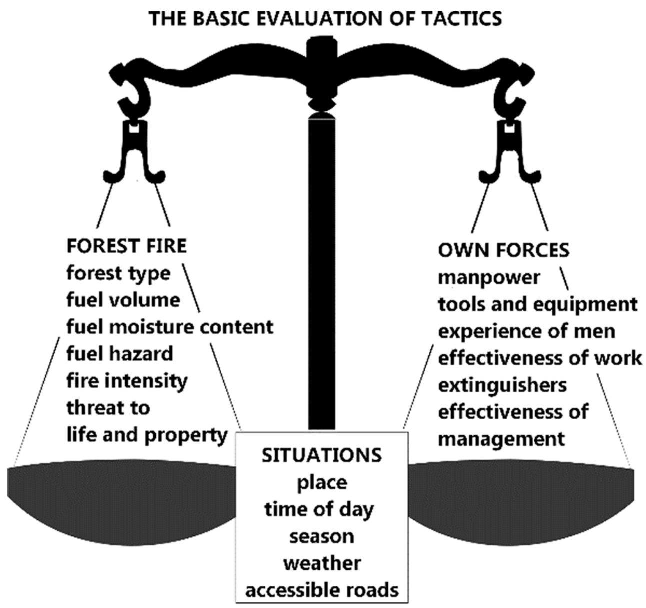

Fig. 3. Basic evaluation of response tactics (adapted from Heikkilä et al., 2007).

in rural communities (category 6), and four occurred in communities distant from metropolitan areas (category 4). The fires were selected because they occurred under adverse weather conditions, thus representing a severe fire risk to communities, to the extent that one of these fires resulted in the greatest loss of structures in a single fire in Norway since 1923.

Research questions of the study:

RQ1: *Did the fire and rescue services (FRSs) perceive the increased fire hazard in the days preceding the fires, and, if so, did they implement measures accordingly?*
RQ2: *How were the fires handled and why?*
RQ3: *Have fire hazard mitigation measures been implemented in the aftermath?*
RQ4: *Do different FRSs share knowledge after large outdoor fire events, and how can learning- sharing be improved?*

The present article focuses on the needs of the FRS regarding better risk awareness, their responses to WUI fires, as well as their possible role in long-term fire risk reduction. This focus on the FRS is unique in the literature, to our recent knowledge. Besides the tactical responses depending on the adversity of the context, the FRS' risk perception prior

Table 2
WUI-fire adversity table.

Adver-sity factor	Wind speed, m/s	Visibility	Accessibi-lity of fire-area	Vegetation type	Time to reinforce-ments	Distance from ignition point to threatened settlement	Natural barriers (e.g., lakes, marshes, or areas of low biomass)
5	Above 16	Dark (black sky)	No roads or dead-end roads	Coniferous forest	More than 90 min	Less than 2 km	None
4	13 – 16	–	–	Mixed forest conifers and deciduous or heavily juniper-encroached heathland	Between 61 and 90 min	2 – 3 km	Fire front much wider than barrier
3	9 – 12	Twilight	Terrain vehicles can be used	Degenerated heathland with low junipers	Between 31 and 60 min	3–4 km	Less than 5 years since last time burned
2	5 – 8	–	–	Old heathland (old Calluna plants)	Between 15 and 30 min	4 – 5 km	Areas burned during last 3 years
1	Below 5	Daylight	Good road network	Managed heathland or cultivated land	Less than 15 min	Above 5 km	Waterways in the direction of fire spread

Table 3
Summary of information about the fires.

Fire name	Started	Duration incl. re-ignitions	Size (km^2)	Cause	Property damage	Response cost (€)
Flatanger	27/1/2014	15 days	15	Power line	63 structures	300,000
Frøya	29/1/2014	2 days	10	Children	1 structure	150,000
Vandaskog	1/2/2014	3 h	0.4	Arson	1 structure	5,000
Hetland	13/4/2019	4 days	4	PB	1 electricity transformer	100,000
Sokndal	23/4/2019	3 days	5	PB (plausible)	None	200,000
Sotra	3/6/2021	10 days	6	Transparent rubber ball (plausible)	2 structures 1 fire truck	600,000

Fig. 4. Areas with increased fire hazard, due to drought and sub-zero temperatures in winter 2014, marked in yellow (modified). NRK, reproduced with permission (Helljesen, NRK-2014). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

to the incidents and planned/implemented measures in the aftermath were also investigated. These measures are categorized as reducing the frequency of severe WUI fires (i.e., reducing ignition probability), reducing vulnerability (i.e., creating the preconditions for manageable fire regimes) or improving community preparedness (i.e., improving response capabilities). Thus, both the fire tactical approach and the aspect of involving other stakeholders, such as municipal authorities and their technical services, as well as citizens, were analysed. The article contributes to the WUI fire safety literature, suggesting measures that can improve WUI fire safety in Norway and other areas with fire-adapted ecosystems.

2. Materials and methods

A qualitative research approach was chosen, and information was gathered from several sources. Purposive sampling was chosen for conducting interviews with involved fire incident commanders (IC) and the fire chiefs of the six FRSs. Following their suggestions, five sector leaders were also contacted and interviewed. This made a total of 17 interviews. The interviews were semi-structured (Gillham, 2005; Kvale, 2004), with a preliminary guide (presented in appendix G) and possibility for discussion during the session. Each interview lasted between 45 and 85 min. Most of the interviews were conducted by two researchers. Due to the COVID-19 restrictions and geographical distance, the interviews were performed digitally. Projecting maps on the shared screen created a common ground between the interviewee and the researchers. After the interviewee had signed an informed consent about participating in the research project, the sessions were recorded, transcribed, coded and analysed. The project was approved by the Norwegian Centre for Research Data. Media coverage on the investigated fires was studied ahead of the interviews, as well as reports (DSB, 2014; PwC, 2014) scientific publications (Alstad, 2016; Småsund, 2016; Log et al., 2017) and the logs and evaluation reports of the involved FRSs (Report Flatanger FRS, 2014; Report Frøya FRS, 2014; Report Log 110 Sveio, 2014; Report Haugaland FRS, 2019; Report Sokndal FRS, 2019; Report Øygarden FRS, 2021). Moreover, three field visits (Sveio, Hetland and Sotra) to affected areas were conducted for observations and conversations.

Each fire was allocated “a name” by the involved FRS and public media. These names were used in the research project. In some cases, the name of the municipality has been used, while in others the name points to the place the fire started. In the latter, the name of the municipality follows in parenthesis. The names used are: Flatanger fire, Frøya fire, Vandaskog fire (Sveio), Hetland fire (Tysvær), Sokndal fire and Sotra fire (Øygarden). The locations of the involved municipalities are shown in Fig. 2.

Three of the fires took place in late January / early February 2014, i.e., during wintertime and outside the official fire-ban season. Two occurred in the second half of April 2019, barely within the official fire-ban season, which starts on April 15th. The most recent among the studied fires started in early summer, June 3rd, 2021.

Data about the municipalities (area, population and how the FRS was organized at the time of the incident) are presented in Table 1. (Key information on organizing and dimensioning Norwegian FRSs can be found in section 3.).

The framework by Heikkilä et al. (2007) incorporating situational aspects, fire-related parameters and response capabilities, was consulted to evaluate the appropriateness of the different responses, under the given preconditions. This framework, illustrated in Fig. 3, incorporates the situational preconditions: place, time of day, season, weather and accessible roads. The parameters affecting fire characteristics are vegetation type, fuel volume, fuel moisture content, fuel hazard, fire intensity and threat to life and property. The parameters affecting response capabilities are manpower, tools and equipment, crew experience, effectiveness of work, extinguishers, and effectiveness of management. These proposed parameters agree with the Canada National Guide on WUI Fires (Bénichou et al., 2021).

Evaluating the efficiency (how fast) and effectiveness (how suitable) of responses is an increasing trend in society. The extensive criticism after the response to the Grenfell fire is among the most renown examples (The Guardian, 2019). To understand what is humanly possible (what we may reasonably expect from the emergency services), knowledge about the context of the incident is vital.

All six studied fires started outdoors and threatened settlements some distance away. The parameters from the framework of Heikkilä et al. (2007), used in the present study were wind speed, visibility (time of day), accessibility, vegetation type and place. The latter was interpreted as time to reinforcements, distance from ignition point to threatened settlement and the eventual presence of natural barriers in the direction of fire spread (Table 2), i.e., aspects relevant for responses to WUI-fires. There is no research on visibility issues due to time of the day, concerning wildfires. Literature on twilight is focused on pedestrians‘ and cyclists‘ traffic safety (Owens, 2003). Direct threat to people is not included in Table 2, as evacuation of settlements downwind of

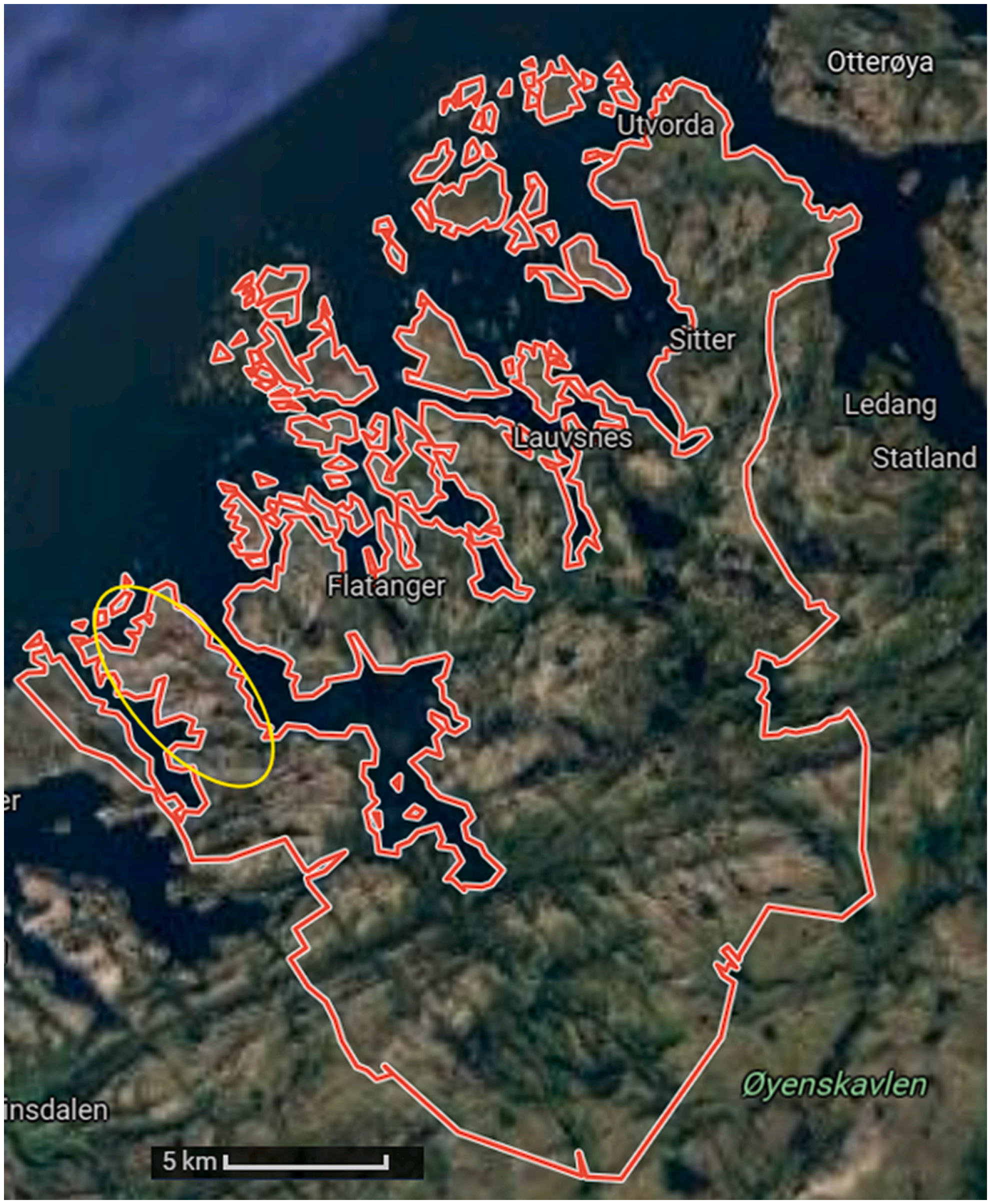

Fig. A1. The Flatanger municipality, red boundary, google maps. The affected peninsula is indicated by a yellow ellipse. Google maps.

aggressive fires is usually the first decision made by FRSs in Norway.

Additionally, we assigned grades to the adversity factors. The grades are on a "Likert scale" from 1 (favourable) to 5 (very adverse) and represent "rules of thumb" considerations from a fire dynamics perspective.

To estimate an overall adversity for each fire incident, the adversity factors were multiplied.

Multiplying the factors is not an attempt to produce a mathematical model to calculate expected adversity the FRS may experience in handling WUI-fires in coastal Norway. It may however be a convenient way to compare adversity of WUI fire incidents. In the literature we may find articles using the term "multiply" for example as to adverse health factors (Gutiérrez et al. 2015). The term is often used in the meaning "strengthen". The advantage by multiplication (compared to for example summing up) is that factor 1 does not contribute to adversity. Moreover, multiplication demonstrates that changing the value of one high factor to a low one has a great effect on the outcome. The product of the adversity factors may indicate the severity of the event and expected consequences.

The World Health Organization, WHO, emergency training programme (WHO, 2002) defines "Mitigation" as long-term disaster risk reduction. Reducing frequency and reducing vulnerability comprise "primary mitigation measures", while improving preparedness is defined as a "secondary mitigation measure". This framework was chosen to analyse the statements describing "lessons learned". The approach agrees well with our intention to identify measures for reducing the frequency of aggressive fires, reducing vulnerability and improving community preparedness.

3. The Norwegian fire and rescue services (FRSs)

The duties of the Norwegian FRSs are stated in the "Fire and Explosion Protection Act" (MoJ, 2002a, LOV-2002-06-14-20). Two regulations authorized in the Act, "Regulation on organising and dimensioning FRSs" (MoJ, 2002b, FOR-2002-06-26-729) and "Regulation on fire prevention" (MoJ, 2015, FOR-2015-12-17-1710), ensure a focus on both emergency preparedness and fire prevention. The FRSs may be regarded as a multi-unit organization (Hansen, 1999; Markides and Williamson, 1994) that reports to one common professional authority, i.e., the Directorate for Civil Protection (DSB), which also has

Fig. A2. The fire started in the hamlet of Uran (yellow banner) and affected the area within the yellow boundary line, ca. 15 km^2. Google maps.

Fig. A3. The fire was caused by sparks from an aluminium power line, with a detached upper cable striking the lower cables in strong wind. The sparks ignited cured grass. (Photo: NRK, reproduced with permission.).

Fig. A4. After a direct attack in Uran (ignition point, marked yellow), which saved the settlement, the fire spread to the hills. Red lines show the main directions of fire spread, while smaller twisted arrows indicate spread in different directions as the wind direction varied. Fire control lines established by the FRS are illustrated by blue lines. Flatanger FRS, reproduced with permission. (https://geoforum.no/wp-content/uploads/2014/12/Hva-skjedde-i-Flatanger.pdf).

the responsibility for educating fire responders at the National Fire Academy. Each FRS is owned by the municipality it serves, either alone or in cooperation with other municipalities, by formalized cooperation or intermunicipal companies. For acute pollution accidents, larger cooperation networks exist, in which many FRSs and other organizations participate, administered by the Norwegian Coastal Administration. These networks can also be activated in other capacity-demanding incidents, like wildfires. In 2011, the DSB introduced an incident handling system, (ELS) (DSB, 2011), inspired by the FEMA Incident Command System (ICS) (FEMA, 2017).

The FRSs shall address locally mapped risks, where practically possible (MoJ, 2002a; 2002b; 2015). Each FRS shall therefore be organized and trained according to the risk they may face, while the regulation presents the minimum requirements. Besides their generic competence, the expertise of FRSs may vary, according to the training undertaken in response to local risk and vulnerability analyses.

In the case of wildfires, the DSB has agreements with private companies providing year-round helicopter services (DSB, 2021), with a short response time during the official fire-ban season, April 15th to September 15th. The period is based on historical data, as well as the Canadian Fire Weather Index (CFWI) (Van Wagner, 1974; De Groot, 1998). However, research demonstrates that the index did not reveal a fire hazard at sub-zero temperatures (Log, 2016; Log et al., 2017) and gives better predictions in forested land than in heathlands. The DSB has organized a “leadership support system”, activated upon requisition of helicopter support but which can also be requested independently. The arrangement offers local FRS support from fire chiefs experienced in handling wildfires. The basic firefighter education includes, among other things, an outdoor firefighting module (Bjølseth, 2019), which offers insight into direct attack (when possible) and indirect attack. Defence fire (counter fire) is advised against as being too risky. Wildfire incidents extend over large areas. Sectorization will almost always be used during the response, distributing resources and responsibilities, and is practised in the module.

Available first response forces depend on the number of inhabitants in each settlement. A fire station may be manned 24/7 (in towns with 20,000 + inhabitants), operated during the daytime, with part-time responders during evening and night shifts (in towns of between 8,000 to 20,000 inhabitants), or organized completely part-time, with responders on-call in small settlements (MoJ, 2002b). The competence part-time responders possess may not be as “all-hazard-updated” as for full-time personnel, but their knowledge of the local conditions is invaluable (Småsund, 2016).

The municipalities of Flatanger, Frøya, Sveio and Sokndal had FRSs based on part-time on-call responders (Table 1), according to the regulation on organizing and dimensioning FRSs (MoJ, 2002b). Leaders had part-time duties in the FRSs but were 100 % employed in the respective municipalities, in combination with other duties. Tysvær joined an intermunicipal FRS in 2018. In Øygarden, though the municipality has 39,000 inhabitants, there are no large settlements. The FRS was therefore mainly based on part-time responders.

4. Description of the six selected WUI fires

This section briefly presents the WUI fires in Flatanger, Frøya and Vandaskog (Sveio) in January 2014; in Hetland (Tysvær) and Sokndal in April 2019; and Sotra (Øygarden) in June 2021, see Table 3. The locations of these fires are shown in Fig. 2.

The most severe of these fires, i.e., the fire in Flatanger in January 2014, resulted in 63 lost structures, which is the highest number in a

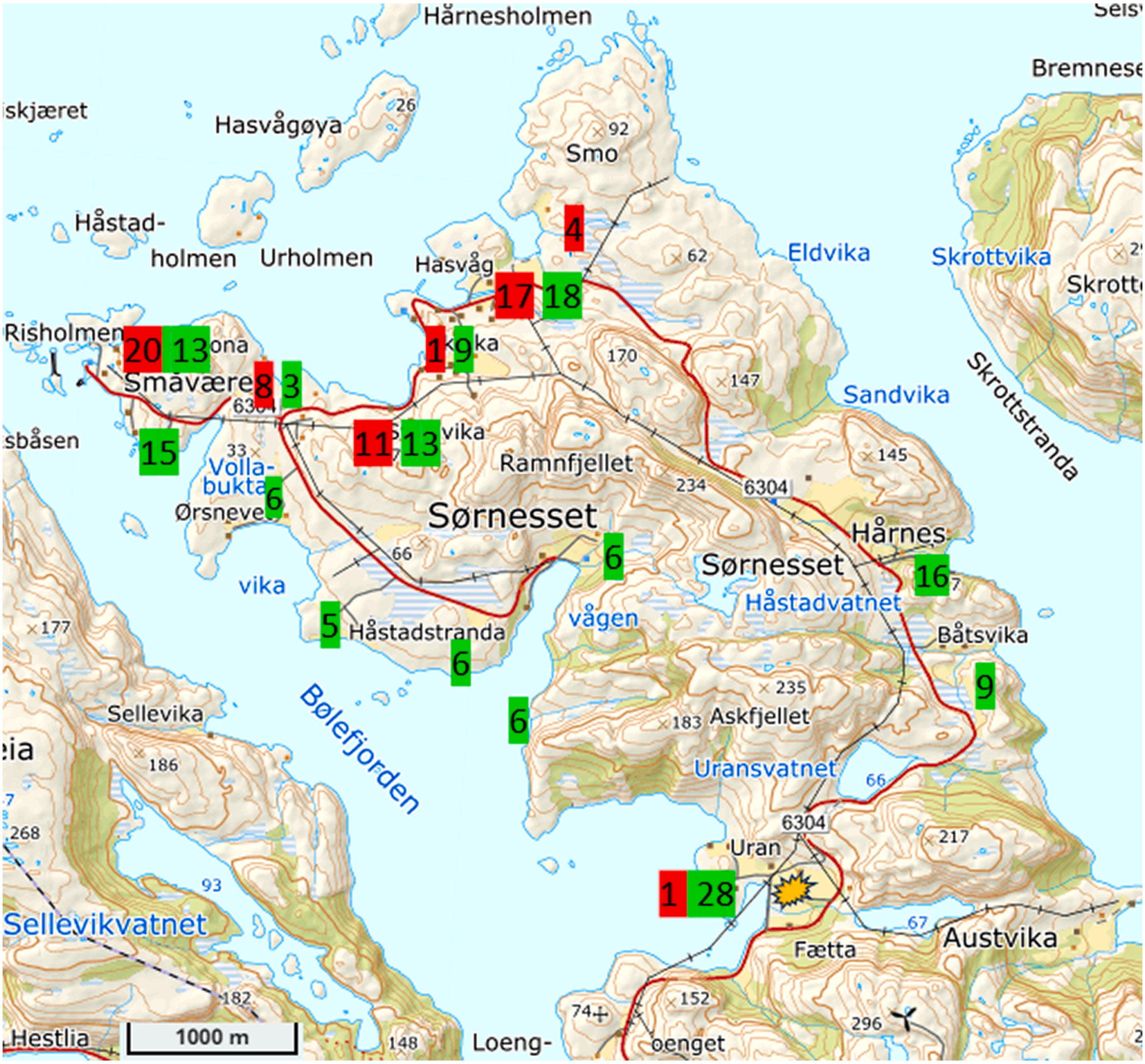

Fig. A5. Map with altitude quotas and road 6304, ending at Håstadvågen on the west side of the peninsula (www.kart.dsb.no). Ignition point marked with yellow banner. Number and location of burned / severely damaged and unburned / slightly damaged houses, respectively, in red and green backgrounds.

single fire in Norway since 1923 (Losnegård, 2013). Fortunately, none of the studied WUI fires resulted in fatalities. Detailed information about the FRSs' risk perception before the incident, the fire development and tactical response, as well as decisions, actions and reflections in the aftermath, are presented in Appendixes, A – F. A summary is presented in the following sections.

4.1. The three winter fires January/February 2014

The three 2014 winter WUI fires in Flatanger, Frøya and Vandaskog (Sveio), marked blue in Fig. 2, occurred within one week, from late January to February 1st, 2014, after a prolonged period of drought and sub-zero temperatures. The areas where these weather conditions prevailed are marked in yellow on the map shown in Fig. 4. Two weeks earlier, a town fire in Lærdal destroyed 40 structures (Log, 2016). It started in a single-family home and developed into a conflagration threatening the whole town. The fire also spread to the vegetation and burned up the steep valley sides, self-extinguishing when it reached snow-covered ground.

During the winter of 2014, the level of fire activity was high, with an unusually large number of incidents, which were generally successfully extinguished (DeRosa & Bach, Aftenposten-2014).

4.1.1. The Flatanger fire, January 27th, 2014

The fire in Flatanger (Fig. A.1) started in the hamlet of Uran (Fig. A.2) on January 27th, 2014, about two hours before midnight. An electrical power cable partly disassembled (Fig. A.3) in storm-strength easterly winds (20 m/s) and generated sparks (Hofstad, 2014; DSB, 2014; PwC, 2014). Cured grass was ignited (Tse & Fernandez-Pello, 1998), and, despite swift mobilization of the FRS, the fire escaped (Fig. A.4). The terrain was rugged, and the vegetation was degraded heathland and mixed forest in the lowland, with bushes at higher elevation. The threatened settlements were accessible only through a dead-end road. The inhabitants in the direction of the fire spread were safely evacuated early on. The combined challenges of stormy winds, darkness and a single (dead-end) road led the FRS to prioritize saving

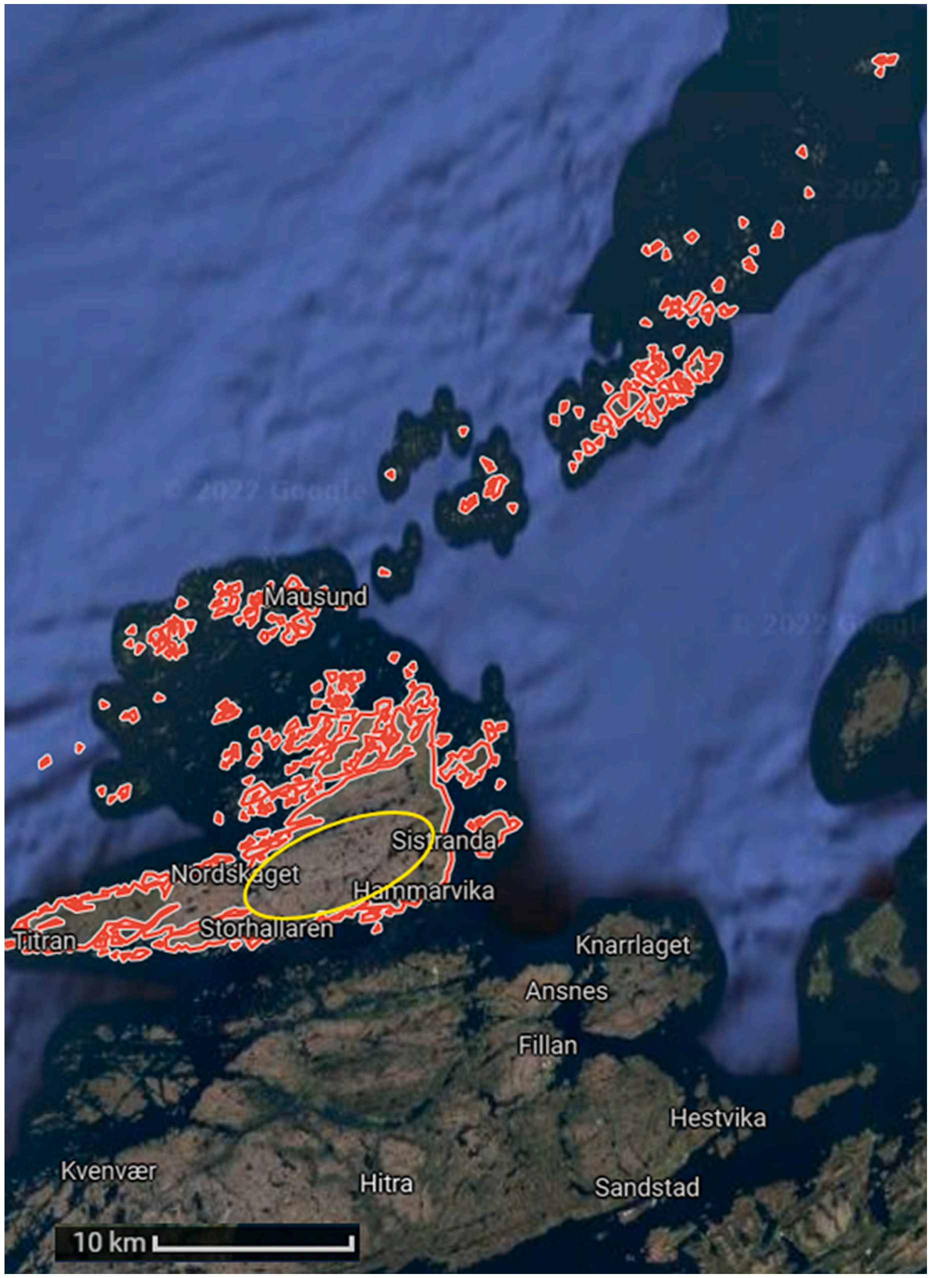

Fig. B1. The Frøya municipality, red boundary. Yellow ellipse indicates the affected part of the main Frøya island. Google maps.

lives, while saving property was unmanageable without a high risk to the responders (Report Flatanger FRS, 2014). No response was therefore undertaken in the direction north or west of Hårnes (Fig. A.5). towards the North Sea during the first night of the fire. During the early hours of January 28th, 63 structures in the hamlets of Hasvåg and Småværet, 5 km from Uran (fire start), were lost (Fig. A.5). Although strong winds also prevented aerial operations over the next two days, all secondary destruction was prevented by ground forces through indirect and direct attack. With re-ignitions and post-extinguishment, the fire incident lasted for two weeks.

4.1.2. The Frøya fire, January 29th, 2014

The Frøya fire started on the main island (Fig. B.1) at 11:00 a.m. on January 29th, 2014, while school children ice skated on the lake, Litlvatnet (just west of Frøya's most densely settled area, Sistranda) (Fig. B.2), and played with fire (DSB, 2014; PwC, 2014). A police helicopter was by chance flying above Frøya and contributed with reconnaissance (Alstad, 2016). As the air distance from Flatanger to Frøya is only 127 km, helicopters already in Flatanger were redirected to Frøya (video air force; video vgtv). East winds, 15 m/s, made aerial support possible. Settlements in the direction of fire spread (5 to 6 km northwest from the fire start) were evacuated (Fig. B.2). It was decided to use two frozen lakes (Figs. B.2 and B.3) as primary fire control lines for indirect attack (plan A). A corridor of land between the two lakes (about 200 m wide) was wetted and iced, as well as some areas in extension of the lakes. A secondary fire control line (plan B) was prepared in conjunction with a road (Fig. B.3), before the fire (eventually) could reach the settlements in the northwest part of the island (Report Frøya FRS, 2014). The primary fire control line was successfully defended. Since the terrain is rather flat and the lakes were frozen (15 cm ice), extensive use of All-terrain vehicles (ATVs) was possible. Thirty private and FRS-owned ATVs served firefighters with smoke-diving equipment and other supplies. A cabin was lost in the fire.

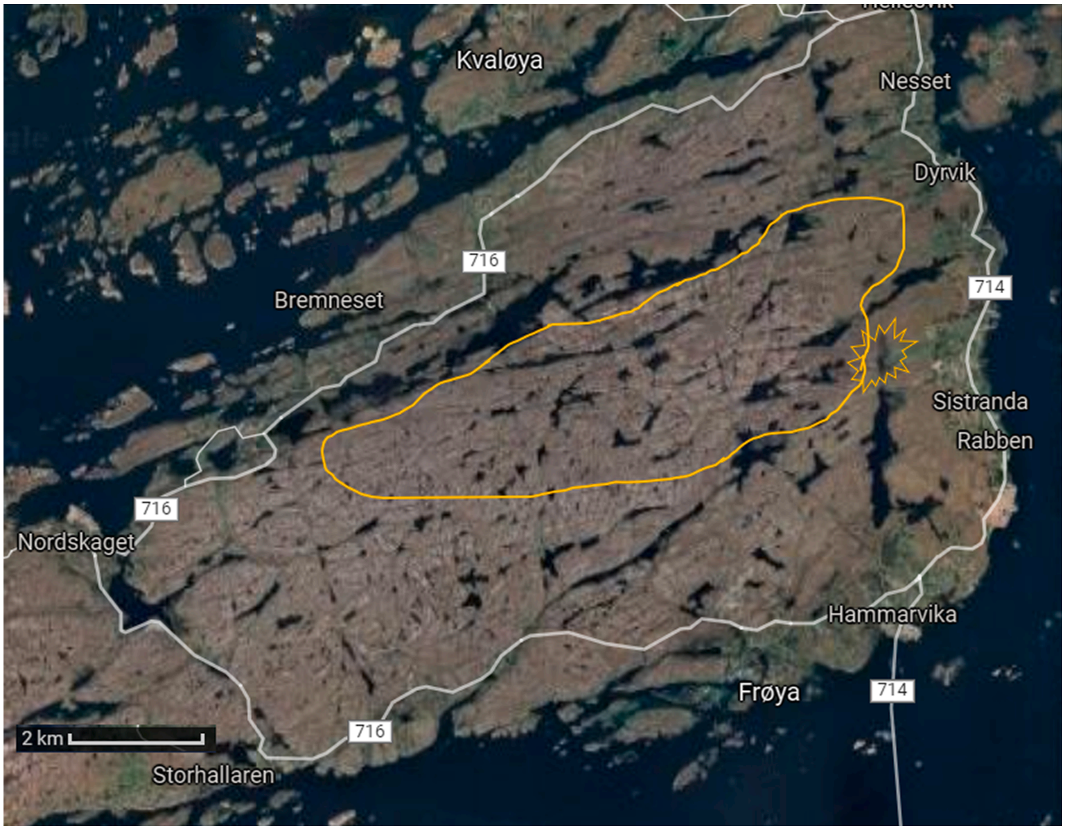

Fig. B2. The ignition point was by a small frozen lake (inside the yellow banner). The affected area, ca. 10 km^2, is indicated by the yellow boundary line. Google maps.

4.1.3. The Vandaskog fire, February 1st, 2014

The fire in Vandaskog (Sveio) (Fig. C.1) was started by arson during the night of February 1st in a public community house, previously used as a school (Fig. C.2). The area is desolate, and the emergency call centre received the first notification of smoke just before 06:00 in the morning, when the wind was 15 m/s (Report-Log, Sveio 110, 2014). Upon arrival, the responders could see that the building was essentially destroyed. Moreover, embers had ignited a wildfire on the west side of the road (Fig. C.2). Since the fire spread northwest, settlements in this direction (about 2 km from the fire start) were evacuated (Fig. C.3). Initially, the fire spread through a forest, without igniting crowns, and continued northwest into an area which had been treated by prescribed burning (PB) two years earlier. The limited biomass eased the response and made extinguishing possible with direct attack using fire swatters (plan A). The plan for indirect attack (plan B) involved a frozen lake where forces were already deployed (Fig. C.3). The fire was extinguished within three hours.

4.2. The two spring fires, April 2019

The two WUI fires in Hetland (Tysvær) and Sokndal (see Fig. 1) occurred during the second half of April 2019, after a three-week period of drought and sunny weather. Though the vegetation was dry, the respective FRSs (in Tysvær and Sokndal municipalities) approved PB sessions before the official fire-ban season started, on April 15th. The Hetland fire started when the PB operation got out of control and caused a wildfire. No conclusive fire cause has been identified for the Sokndal fire, but PB operations ca. one week before the incident were identified as a plausible cause.

4.2.1. The Hetland fire, April 13th, 2019

The fire in Hetland (municipality of Tysvær, Fig. D.1) started around noon on April 13th, 2019, as a PB operation and developed into a wildfire (Fig. D.2). After struggling to regain control, the four PB practitioners called other members of the civic PB group, "Haugaland Heathland Burning Reserve (HHBR)", for reinforcements (Metallinou, 2020). The FRS was alerted ca. three hours later and arrived on scene at about 16:00 (Report Haugaland FRS, 2019). Subsequently, the FRS worked together with the HHBR reinforcements to prevent fire spread eastwards, driven by the sea breeze (Fig. D.3). A combination of direct and indirect attack was used, as well as techniques used by the HHBR involving counter fire controlled with leaf-blowers and fire swatters. The extinguishing continued the following day. Unfortunately, logs and branches under power lines sustained smouldering combustion and acted as a re-ignition source in 14-m/s wind two days later. The reignited fire destroyed power cables and a transformer and spread northwest (Fig. D.3). Mobile water pumps were transported by boats to create fire control lines to protect cabins. The fire eased and was extinguished as it reached an area that had been treated with PB three years earlier. It was stopped through indirect attack, by strengthening natural fire barriers such as lakes, marshes and stone fences. The versatile use of techniques and tools resulted in successful response without aerial support. The incident lasted for four days.

4.2.2. The Sokndal fire, April 23rd, 2019

The Sokndal fire (Fig. E.1) was reported to the emergency call centre in a dramatic manner, i.e., by two hikers at Hellershei (Fig. E.2), trapped by flames and smoke, at 14:00 on April 23rd, 2019. Rescue helicopters were mobilized, and the hikers were airlifted after 30 min. Though the cause of the fire has not been conclusively identified, it is believed that PB operations performed shortly before April 15th left smouldering patches underground, which one week later developed into flaming combustion in 14-m/s wind. In shifting wind directions, the fire burned "in a circle", moving first northwest, then south and finally to the

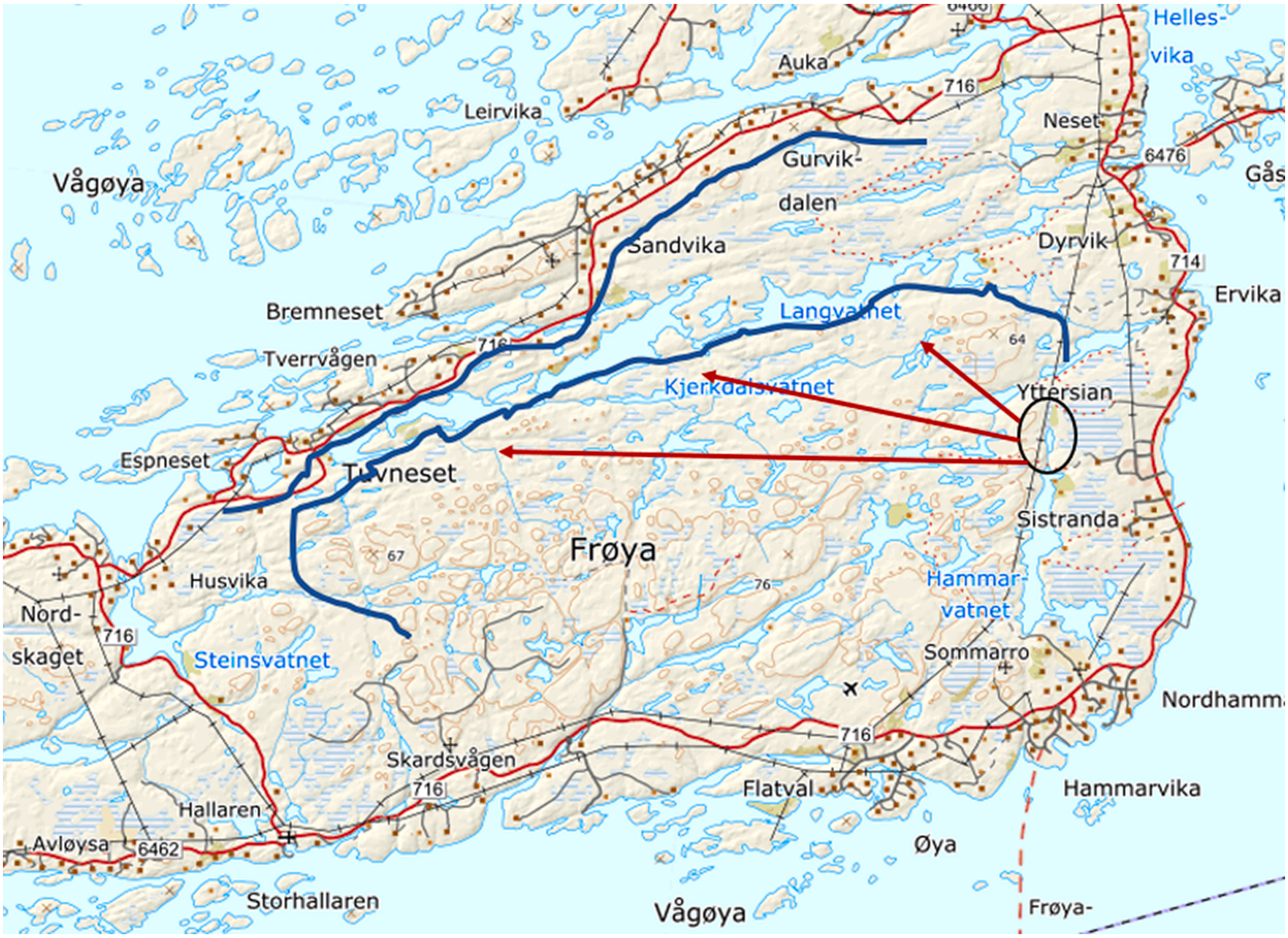

Fig. B3. Ignition point, Litlvannet, inside the black ellipse. Red arrows indicate fire spread direction, while blue lines indicate created fire lines, on the south side of the lakes, Langvatnet and Kjerkdalsvatnet, (plan A) and along road 716 (plan B), to save the settlements along the northwestern part of the island. kart.dsb.no.

northeast again (Fig. E.3) (Report Sokndal FRS, 2019). Aerial support was requested, as several settlements were threatened. The FRS described the response as "challenging their creativity", as various techniques were required. The intensity of this fire led the FRS to abandon direct attack in the terrain and utilize indirect attack some distance away in the direction of fire spread. Moreover, the forces were relocated incessantly in a hazardous environment between four different fires. The fire was finally extinguished on April 25th, without the loss of any valuable structures.

4.3. The fire in Sotra, June 2021

The Sotra fire (Øygarden) (Fig. F.1) was reported at 11:57 on June 3rd, 2021. The fire started along a road (Fig. F.2) and spread rapidly uphill. The cause of the fire has not been conclusively identified, but a 70-mm-diameter massive transparent rubber ball is a plausible fire cause (Harjo, 2019; Hafsaas, 2021). As the fire spread further into the terrain, direct attack was impossible, due to the fire's intensity. Indirect attack was the chosen tactic, since the fire spread towards settlements about 2 km to the west. About 500 people were evacuated. The distance was too short to prepare an indirect attack, with no other barriers than a road. Massive rescue resources were therefore necessary. The area is close to the city of Bergen, with many resources available to support the local FRS. Upon arrival of the first fire helicopter (after 90 min), the pilot, on their own initiative, requested more helicopters, due to the severity of the situation. Eight helicopters, one fire boat and 29 fire trucks were engaged. The chosen fire lines protected the settlement (Fig. F.3), but two structures (lying closely to, but before the road) were lost, despite the strategic direct attack (Report, Øygarden FRS, 2021). A belt of junipers lay uphill towards and close to the lost home, intensifying the fire (Log and Gjedrem, 2022). At another point, Sitka spruces' ignition resulted in fire spread 270 m across a fjord. This fire spread was extinguished by a helicopter and the firefighting (FiFi) boat. The fire was declared extinguished on June 4th but reignited on June 9th in 12-m/s wind. The reignited fire spread into an area burned in a wildfire in 2015. Because of the lower fire intensity there, the FRS could use traditional wildfire extinguishing tactics, supported by a single helicopter. The fire was finally terminated on June 13th.

5. Comparison of the studied fires

The main tactics used by each FRS in the studied incidents are summarized in Table 4. Whether the responders had experience with PB or cooperated with civic groups possessing such experience is also presented.

The responses to the fires were evaluated using the framework of situational aspects (Heikkilä et al., 2007), described in chapter 2. Adversity factors from Table 2 are used in Table 5, to compare the adversity of the different studied fires. For example, during the first night of the Flatanger fire, the wind speed was 28 m/s (above 16 m/s, i.e., factor 5), it was winter night (very dark in the night and few hours of weak daylight during day, visibility factor 5), the area had only one dead-end road in otherwise rugged terrain (accessibility: adversity factor 5), the vegetation was mixed forest (factor 4), it took long time to get

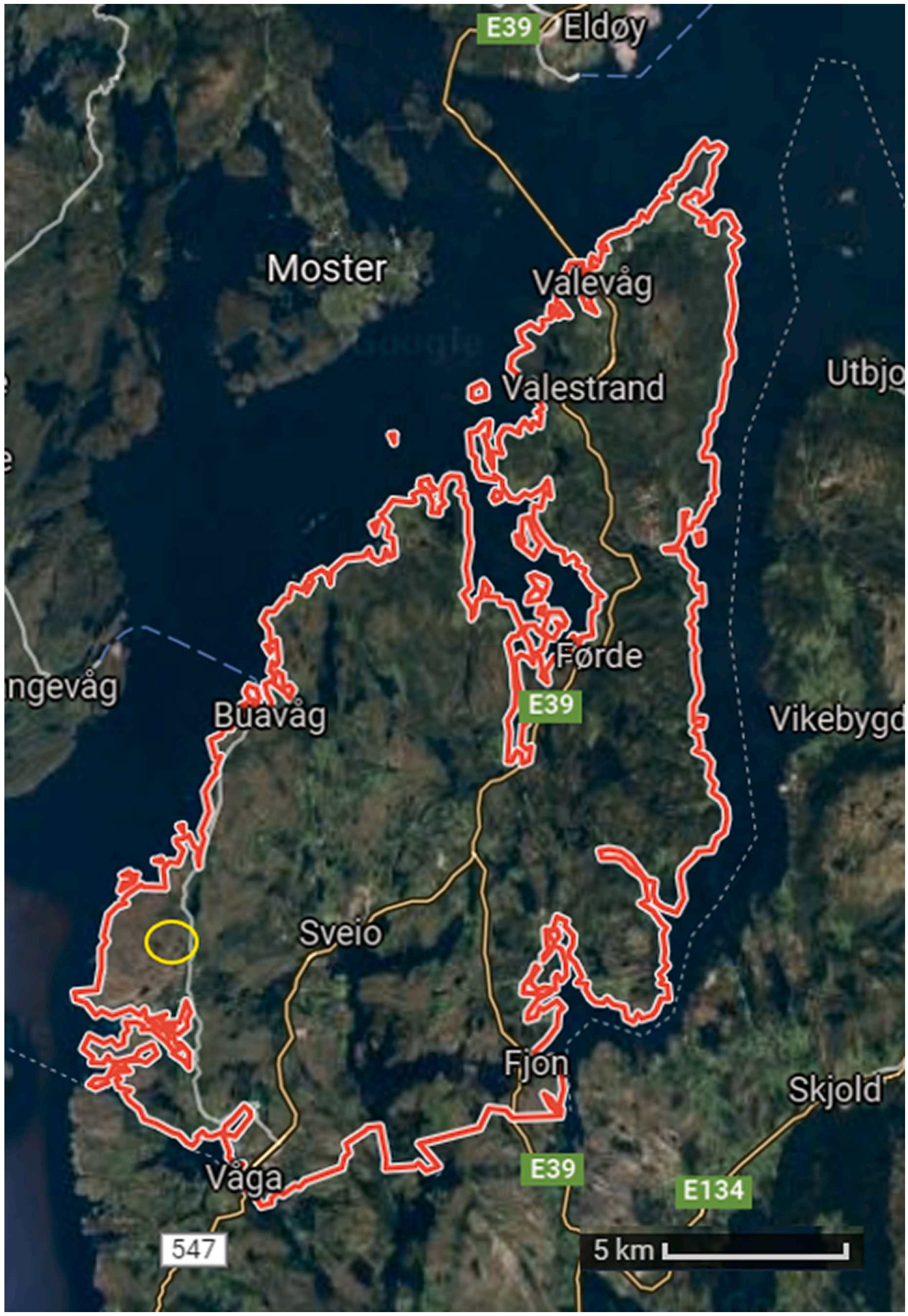

Fig. C1. The municipality of Sveio, red boundary. Yellow ellipse indicates the affected part. Google maps.

reinforcements (slightly less than 90 min, factor 4), the distance to the threatened settlements was 5.8 km (factor 1) and barriers were minimal, since the fire mainly followed a mountain range (factor 4).

Fuel moisture content (FMC) was not quantified in the actual spots during the fires but was estimated through atmospheric relative humidity, available through https://www.yr.no/ https://seklima.met.no/.

The table indicates that fires with similar adverse elements to those during the Flatanger fire 2014, may generate multiple losses, compared to improving one or two of the influencing factors. Since we cannot control the time of the day ignitions will occur or the weather conditions (and the probability of sustained ignition may increase when the fire weather is adverse and the FMC is low), we should concentrate on the other parameters. The fuel load and fuel type are probably the parameters most suitable for intervention in the fire hazard, as they develop slowly and allow for action during long periods prior to a potential wildfire. Therefore, aspects of fuel management were discussed in the interviews, as presented in the next chapter, "Results and discussion".

6. Results and discussion

6.1. Answers to the research questions

RQ1: *Did the FRSs perceive the increased fire hazard in the days preceding the fires, and, if so, did they implement immediate measures accordingly?*

Risk perception of the enhanced fire hazard was present in all six FRSs in the days prior to the studied WUI fires. Local knowledge about

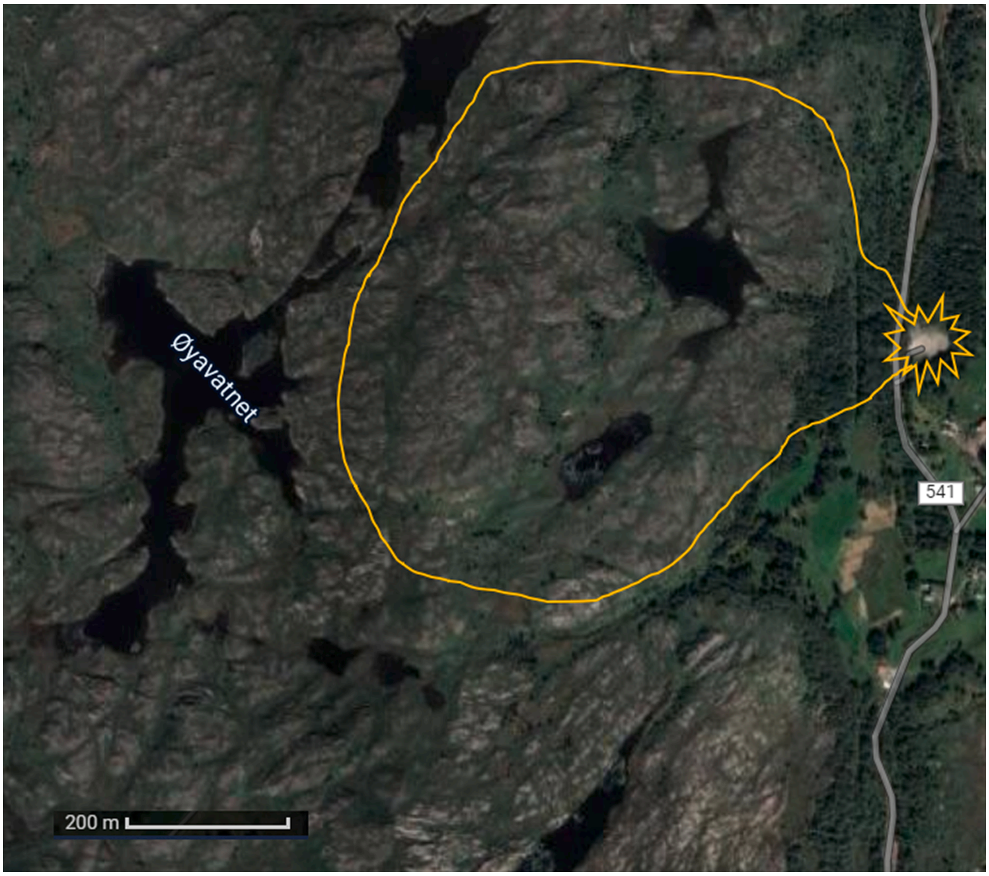

Fig. C2. Fire hearth marked with yellow banner. The affected area, ca. 0.4 km^2, is indicated by the yellow boundary line. Google maps.

weather conditions, observations of nature and numerous ignitions prior to the studied fires (in the precinct of four of the FRSs) provided a sense of alertness. However, their risk awareness did not result in fire preventive measures, e.g., a fire ban.

The lack of a reliable fire hazard index in cold weather, as well as a hazard index better adapted to coastal heathlands (Log, 2016; Log et al., 2017), led the FRSs to be reluctant to implement fire bans outside the official fire-ban season. The understanding of fire hazard in heathlands, where the soil layer may be thin on top of rocky terrain and dry out during a few days of good weather, thus depriving the biomass of water, can also be improved (Haugum et al., 2021; Log, 2020). Research demonstrates that the CFWI (which the Norwegian wildfire risk prediction is based on) is more suitable during summertime than at sub-zero temperatures and gives better predictions in forested land than in heathlands. When the Sotra fire occurred, the fire hazard index was "yellow level", which did not prompt a feeling of extraordinary emergency. A fire hazard index adapted to the heathland is required. The developed predictive model for dense wooden settlements (Stokkenes et al., 2021) may serve as an example. Research-based criteria, including both the condition and type of vegetational biomass, as well as the organic soil, must be developed for dynamic fire hazard warnings. These may inform the FRS about the probability of smouldering fires in the soil (for example, after PB) – which may represent ignition points - in combination with adverse fire weather during the ensuing days.

A locally adapted fire hazard warning system may provide opportunities for extra manning on risk peaks, initiatives to mobilize resources (e.g., fire trucks) in strategic locations, and the mobilization of wildfire extinguishing gear to part-time, on-call responders, to decrease the response time.

RQ2: *How were the fire incidents handled and why?*

Safekeeping of life was the first priority. Threatened households and barns were evacuated early. All FRSs attempted direct attacks at first. However, only one of the fires (Vandaskog – Sveio) was extinguished with that sole technique, due to previous biomass reduction by PB. All FRSs mentioned the importance of recognizing when to change tactics from direct to indirect attack, without insisting on the first technique for too long. Two of the fires were extinguished with indirect attack, combined with aerial support (Frøya and Sotra). In two other fires (Hetland and Sokndal), a combination of direct attack, indirect attack and counter fire was used, applying techniques and equipment often used in PB operations, which some of the crews had experience with. These techniques are more advanced than the general wildfire education provided by the fire academy. In the Sokndal fire, aerial support was also included. When the fires entered, or were guided to, areas with low biomass, direct attack was possible. Leadership support from fire chiefs experienced with wildfires was greatly appreciated. Overall, the FRSs expressed satisfaction with their own choices and performance during the responses. Besides improvement points, mainly on coordination and delegation, the FRSs experienced reassurance and deeper comprehension of several successfully used techniques (Sommer et al., 2013).

Based on the analysis, it appears that all six fires were handled properly, given the degree of adversity, as described in Table 5. The fire hazard awareness of the FRSs upon ignition resulted in resolute responses and early requisitioning of support.

RQ3: *Have fire hazard mitigation measures been implemented in the aftermath?*

We differentiated between primary and secondary mitigation measures (WHO, 2002) for reducing WUI fire hazard. Primary mitigation consists of measures to *reduce the frequency* of aggressive fire events and

Fig. C3. Fire hearth inside the black circle. Red arrows indicate direction of fire spread. Green line indicates where the fire was extinguished with a direct attack. kart.dsb.no.

measures to *reduce* the *vulnerability* of potentially affected areas. Secondary mitigation includes measures to *improve future responses (preparedness)*.

To *reduce the frequency* of aggressive fires, several of the studied FRSs subsequently increased their activity in raising awareness of the fire hazard amongst the public, through visual material. They also acquired subscriptions to advanced weather forecasts, to improve their own fire hazard awareness. However, a fire hazard warning tool adapted to coastal heathland was asked for but is currently not available.

Reducing vulnerability requires the societal trend of landscape management over the last 70 years to be reconsidered and is a task that must involve large parts of society at all levels. The studied FRSs reported that they do not perceive themselves as an important driver in such processes. Though cost-benefit analyses of reducing vulnerability through biomass reduction in the Norwegian heathlands (Halvorsen & Grimsrud, 2021) document savings, compared to costly responses, there is a resource bottleneck, partly due to a broadening of the FRS responsibility regarding overall societal safety. Having developed municipal plans for managing the wildland statistically reduced the costs to emergency responses. A similar finding was presented for fire protection of historical buildings in Norway (Kristoffersen and Log, 2022). It was highlighted by several interviewees that, without additional support in the future, the resource bottleneck may limit the FRS' capacity to implement WUI fire preventive measures. Major WUI fires have little statistical weight in Norway because they have not claimed lives, something building fires often do (DSB, 2010). This is also the

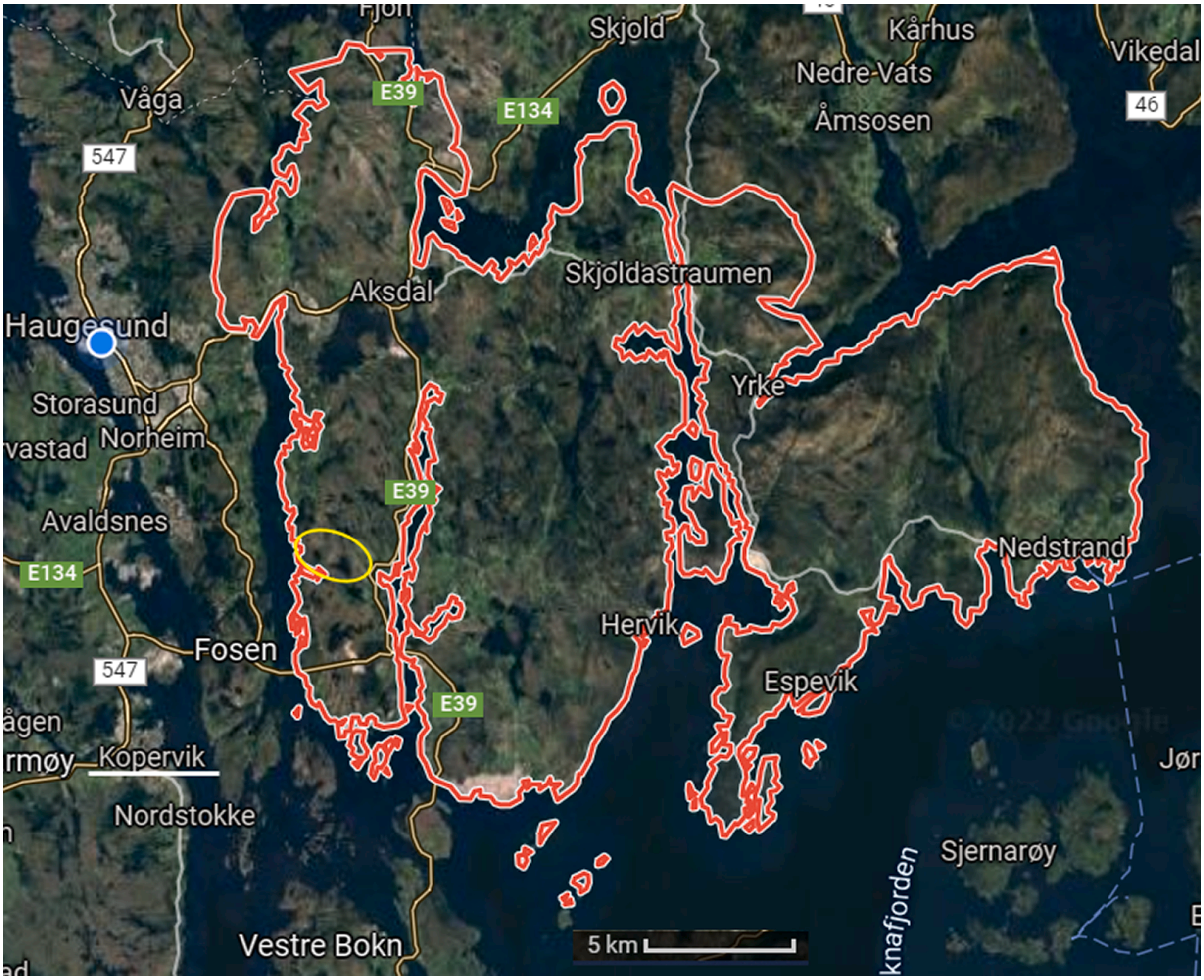

Fig. D1. The municipality of Tysvær, red boundary. Yellow ellipse indicates the affected area. Google maps.

reason that the FRS fire preventive work focuses on dwellings and indoor ignitions. Measures to reduce outdoor vulnerability appear immature, with only the placement of garbage bins away from combustible outer walls (primarily focused on public buildings, such as schools, etc.) being focused on.

However, the Sveio FRS has performed PB as an exercise for the last 20 years, to reduce fire hazards in their jurisdiction and restore an endangered heathland habitat. Additionally, the Sokndal FRSs has several employees who perform PB privately. Research shows that the combined identities of being a fire responder and a farmer are key for establishing effective PB civic groups (Metallinou, 2020). On the Frøya municipality main island, PB operations have been prohibited, due to the risk of uncontrolled fires, while, in smaller scattered islands, PB has been performed regularly. A PB course administrated from HHBR was held on Frøya in the winter of 2022, with the intention of paving the way for safe PB on the main island. It should be noted that invasive Sitka spruce have been partially removed from the main island for environmental reasons, thus also reducing vulnerability in the case of future ignitions.

On the question of how the FRS should be supported in the years to come, the 2014 Frøya fire chief responded: "*We are lucky to have a lot of sheep keeping the vegetation low. The vegetation, and especially old heather and dry grass, is challenging; we should manage the heathland [by PB and grazing]*". After the Sotra fire, the citizens advised the major to "hire 1000 municipal sheep" (Røhr-Staff, 2021). This indicates that the necessity of managing the landscape to reduce fire-prone biomass is becoming a concern outside a limited circle of fire ecologists and fire scientists.

When using PB as a management tool, responsible burning and liability issues will be raised when prescribed operations get out of control. Thoughts about the need for certification (similar to Florida's certificate of Prescribed Burn Managers and Prescribed Fire Burn Boss) were uttered by the County Governor's Environmental Office in Rogaland, Norway, after the unusual fire activity in April 2019. Reducing vulnerability is the most demanding and the best identified form of primary fire hazard mitigation (Halvorsen & Grimsrud, 2021).

During the window of opportunity after an incident that has caused a hazard experience (McGee et al., 2009), increased focus on secondary mitigation measures may be observed. Secondary mitigation, i.e., *improving response capabilities*, requires investments in the FRS and/or the society. Investments require political approval to raise the funding, and allocation decisions are easier to make after incidents. In Flatanger, a water tank truck was acquired after the 2014 fire, while in Frøya the municipal technical services installed hydrants on the outskirts of the settlements to secure water access for future responses. After the incident, a watch scheme was introduced for the summer and other vacation periods, as well as for weekends, i.e., an increase in preparedness. Training regimes with proper equipment for outdoor firefighting (e.g., leaf blowers) were also upscaled in several FRSs. However, research states that, without addressing the cause of increasing WUI fire potential, a management strategy focusing on improved response capabilities may be inadequate (Rego et al., 2018; Xanthopoulos et al., 2022). The interviewed FRSs also had full understanding of this argument.

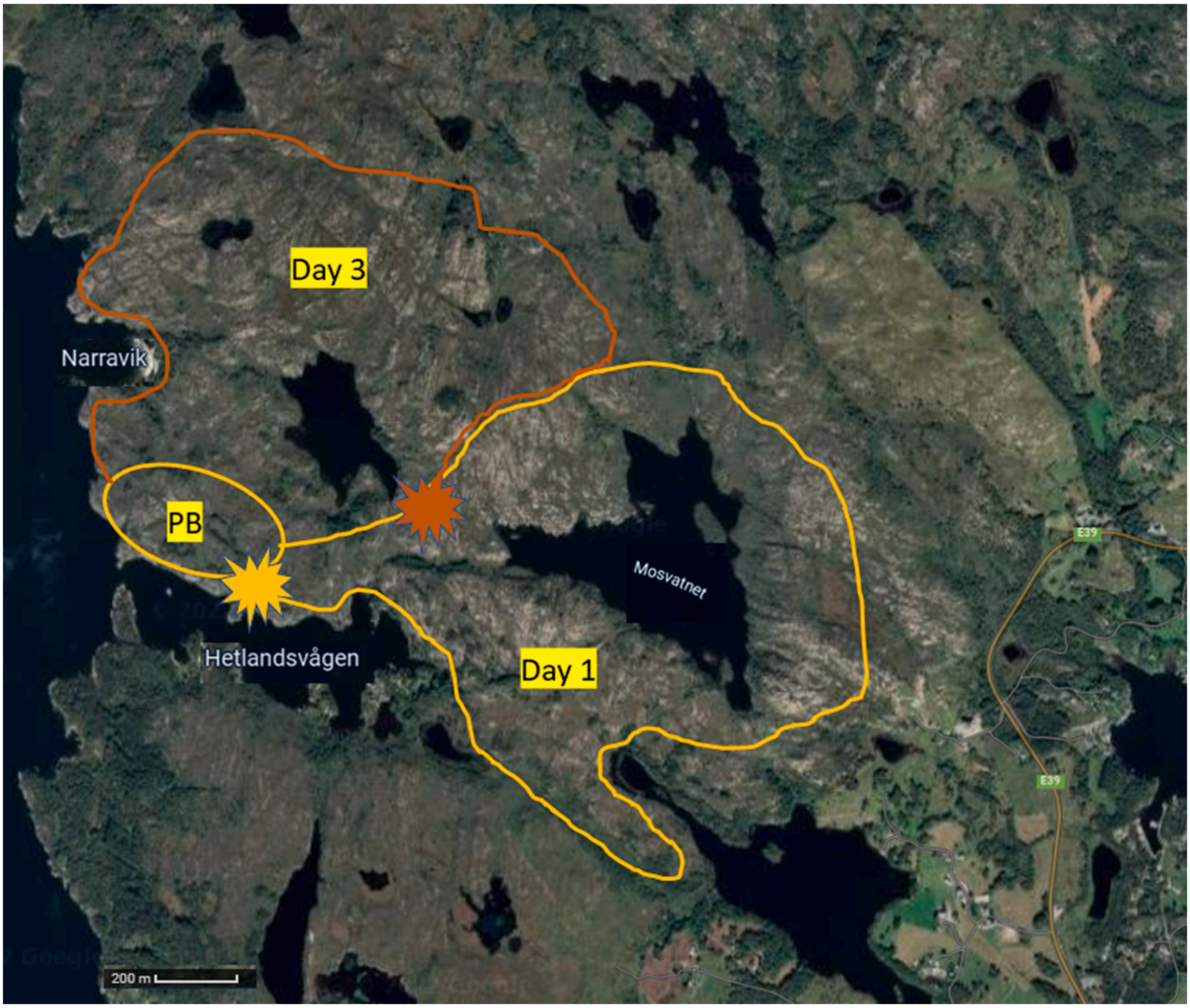

Fig. D2. Area treated with PB in the morning, marked in the yellow ellipse. The PB got out of control at the point indicated by the yellow banner. The fire-affected area during the first day of the wildfire is outlined by the yellow curve. Two days later, the fire reignited at the orange banner and burned the area within the orange marked curve. Google maps.

RQ4: *Do different FRSs share knowledge after large outdoor fire events, and how can learning- sharing be improved?*

Norwegian FRSs seldom have demanding WUI fire incidents. This could imply that shared learning from each other's experiences would be important. The FRSs evaluated their own responses to identify learning points after the incidents and disseminated presentations of their experiences in seminars in which other FRSs participated. However, this was not a systematic process. Most FRSs get information about incidents other FRSs have handled through media coverage. The knowledge about tools, e.g., back-carried water pumps, ATVs equipped with a water tank or leaf blowers for fire control, may occasionally be shared in informal forums, such as seminars, personal communications, and in closed groups on Facebook. However, to achieve learning, the information must be processed by the recipient and adapted to the local risk picture. This may not be prioritized in a busy working situation. An interviewee commented that the FRS follow routines in the way they mitigate the risk, prepare for, and respond to major events. Learning may be fruitful, therefore, if it aims to provide routines that can be locally implemented for dynamic risk management. Research suggests that a centrally organized knowledge-sharing mechanism may alleviate the situation, as the material would be better arranged to facilitate learning (Metallinou, 2019).

The regulation on organizing Norwegian FRSs has been revised, and the version valid from March 2022 (MoJ, 2021), dedicates one paragraph (§26) to evaluation and learning after incidents. The formulation "*The FRS shall have a system for evaluating incidents, and for sharing and receiving evaluations from others, for the purpose of identifying relevant learning points. … The fire and rescue service shall document how learning points are implemented in fire and the rescue service to ensure that learning takes place in the organization*" indicates progress in this important matter. The US Wildland Fire Lessons Learned Center (2022) may be a way to develop such a sharing system, as required by the new regulation. Additionally, due to COVID-19, the digital competence in the population and at the FRSs has increased, allowing sharing formats that would not have been considered prior to the pandemic.

6.2. Final remarks

Mitigating fire hazards through physical work in the terrain, e.g., the maintenance of roads, cutting (and removing) vegetation surrounding the electrical grid, the construction of fire hydrants, and fuel management, requires the involvement of the municipality and its citizens (Xanthopoulos et al., 2022). Involving citizens in biomass reduction may involve PB, as well as cutting, cultivating and grazing. After the Sotra fire, the funding for performing PB operations in Vestland County was increased. Realizing the effect animals have on maintaining the landscape, farmers increasingly utilize a digital system (Nofence) approved

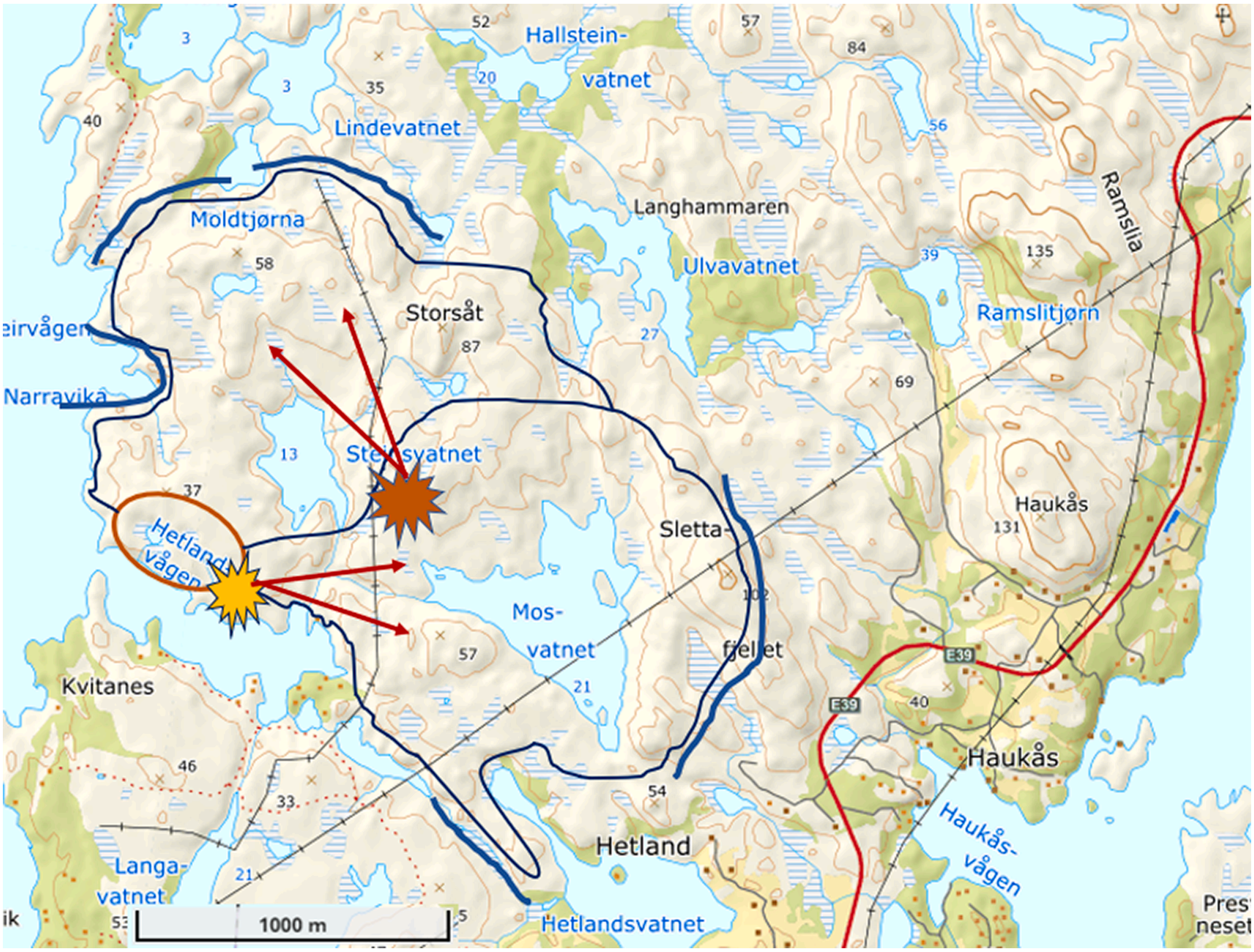

Fig. D3. Ignition point on the first day indicated by the yellow banner and reignition on the third day by the orange banner. Red arrows indicate directions of fire spread. Dark blue line indicates affected area. kart.dsb.no.

in Norway and several other countries for fenceless goats, sheep and cattle grazing, to contribute to wildfire hazard reduction (Brunberg et al., 2013). In the WUI, citizens may engage in cutting, if motivated appropriately. Haugesund municipality has undertaken a pilot project exploring the potential of the activity. Practical research projects, identifying proper tools for the different types of plants, may be useful to provide guidance, increasing the effectiveness and efficiency of citizens' efforts. The FRS may play a catalyst role in initiating and maintaining a focus on the issue, to secure momentum and speed up political processes. Developing national guidelines to support local FRS in adapting integrated fire management, including PB practices, may improve preparedness, and simultaneously reduce vulnerability.

The present study concentrated on six FRSs, which is a low number. By 2015, the number of municipalities with coastal heathland was 117 (Halvorsen & Grimsrud, 2021, page 11), out of 428 Norwegian municipalities. Every fourth Norwegian municipality must address issues with this nature type. Through merging, there are now 345 municipalities and 275 FRSs, of which, 75 FRSs have heathlands in their jurisdiction and the possibility to perform PB exercises locally. We chose to study the FRSs which had experienced fires in WUI-coastal heathland during adverse fire weather conditions. Many similarities in the way the interviewees perceived fire hazard and measures for hazard mitigation among different FRSs were expressed, thus strengthening the results. Despite expressing similar concerns, systematic sharing of experiences to learn from each other's incidents was not revealed (Metallinou, 2019). It will be interesting for future research to investigate whether and how the updated regulation (MoJ, 2021), valid from March 2022, may contribute to promote learning sharing among FRSs. Information published in the aftermath of large outdoor WUI fires with or without loss of life, mainly from California (Velez et al., 2017; Steelman & McCaffrey, 2013) and Australia (Hughes & Mercer, 2009; Heath et al., 2011; Whittaker et al., 2013), focuses mostly on residents' perception of and preparation for the events. In Norway, the threat to individuals is currently low, and therefore the present study investigated fire hazard perception and mitigation at an organizational level, through the FRSs. Moreover, the FRSs have a key role in fire hazard risk reduction.

Research published in 2022 (Drobyshev et al., 2022) correlates drought conditions in Scandinavia during the spring and summer to the ice cover in Baffin Bay and the Labrador Sea, promoting persistent high-pressure systems over the Scandinavian boreal zone. As large quantities of Greenlandic ice and cold water are released into Baffin Bay and the Labrador Sea, the amount of cold fresh surface water in the Western North Atlantic increases (before being diluted further south), especially during spring and summer, inducing dry, easterly winds over Scandinavia. This climatically induced change in Scandinavia's summer fire regimes may increase the focus on landscape management in Norway, to avoid responses to wildfires under adverse conditions. Managing the heathlands can have a key function in reducing WUI fire hazard (Pinto et al., 2020) in Norway and is especially important in the face of climate change.

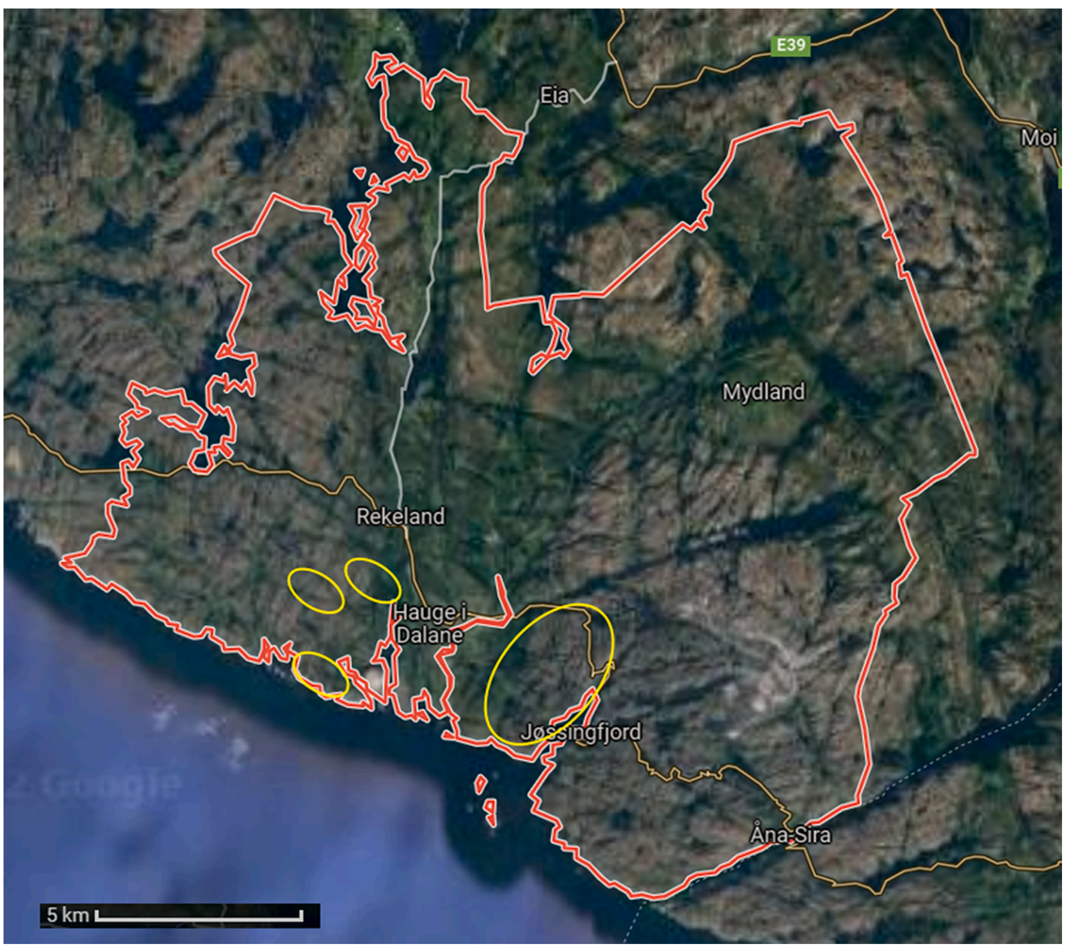

Fig. E1. The municipality of Sokndal, red boundary. Yellow ellipses indicate fires. The Sokndal fire is in the largest ellipse. Google maps.

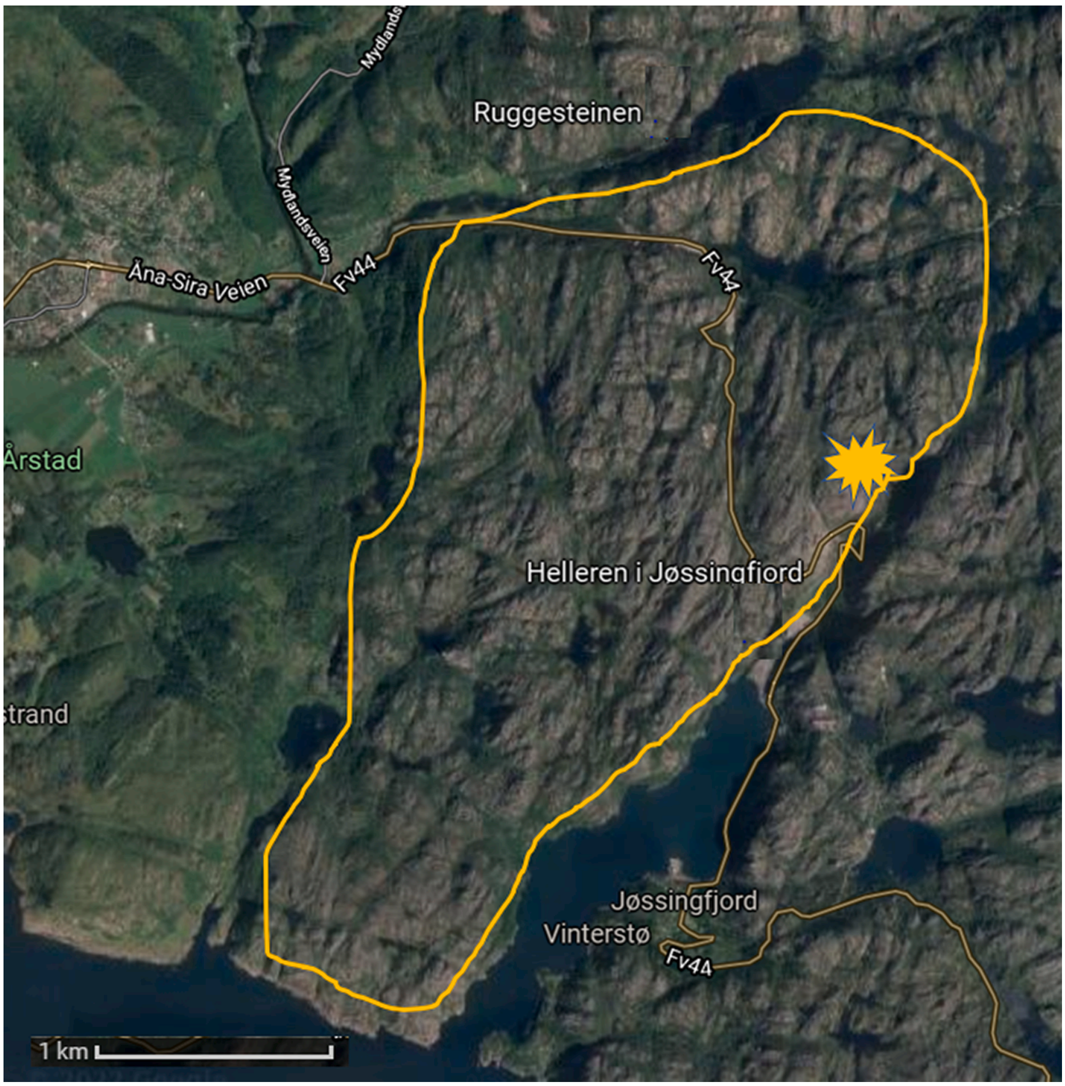

Fig. E2. Probable ignition point indicated by yellow banner. Affected area, ca. 5 km^2, indicated by yellow curve. Google maps.

Fig. E3. Probable ignition point indicated by yellow banner, fire lines by blue lines. Wind directions throughout the response indicated by red arrows. kart.dsb.no.

Fig. F1. The municipality of Øygarden, red boundary. The area affected by the Sotra fire is indicated by a yellow ellipse. Google maps.

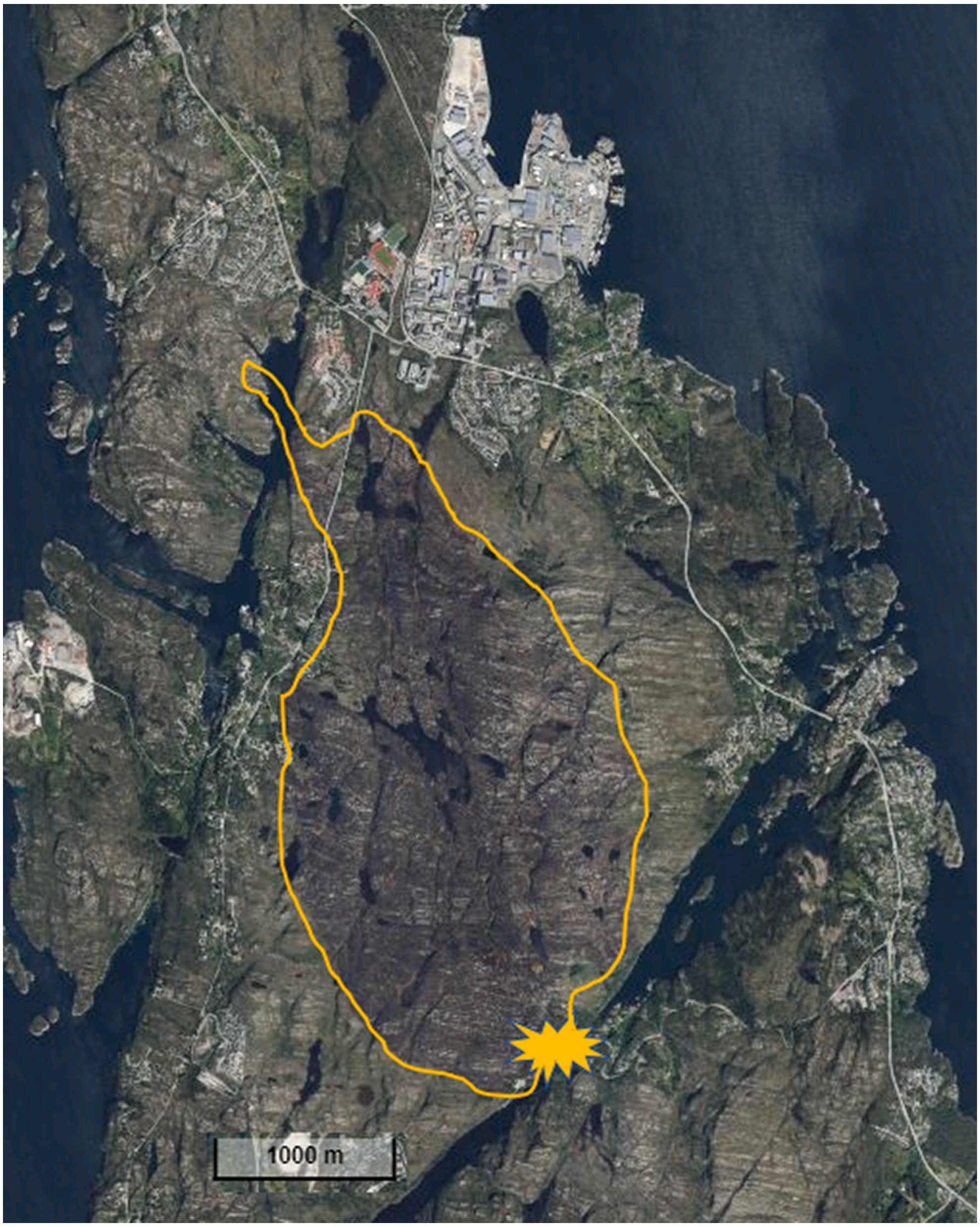

Fig. F2. The ignition point is marked by a yellow banner; the affected area is within the yellow contour. The picture (norgeskart.no) was taken a short time after the fire, and the burned area is visible.

7. Conclusions

Under the given preconditions and context, all six analysed responses to the challenging WUI fires analysed (involving abandoned heathland in coastal Norway: three during winter 2014, two during spring 2019 and one in early summer 2021) were conducted properly. However, the FRSs had been reluctant to implement local fire bans when fire-hazardous conditions developed outside the official fire season. The necessity for an adapted decision support tool may enable FRSs to implement a fire ban and thereby prevent ignitions under adverse conditions. Each FRS gained knowledge from their own outdoor fires but not from other FRSs. They expressed a need for educational material to be developed to help conceptualize their own conclusions and facilitate learning sharing.

Measures improving preparedness were implemented in two of the municipalities, while all interviewees expressed an understanding in their organizations of the usefulness of landscape management for fire-prone biomass reduction. The FRS which regularly performed PB of coastal heathland as an exercise experienced large advantages while handling the 2014 fire in their jurisdiction. The authors suggest that PB in coastal heathlands be incorporated in the list of yearly training sessions of relevant Norwegian FRSs. As drought periods in Scandinavia seem to be on the rise, and the heathland encroachment continues, the importance of reducing the fire-hazard vulnerability of the WUI increases.

CRediT authorship contribution statement

Anna Marie Gjedrem: Data Curation, Formal Analysis, Investigation, Validation, Writing-Original draft, Writing - review & editing. **Maria Monika Metallinou:** Conceptualization, Funding acquisition, Methodology, Investigation, Project administration, Supervision, Visualization, Writing - review & editing.

Fig. F3. Ignition point indicated by yellow banner. Wind direction indicated by red arrows. Blue curve indicates fire control line. kart.dsb.no.

Table 4
Main points about the tactical responses.

Fire name	Aerial support	Ground techniques	PB experience
Flatanger	Impossible	Unmanageable during first blaze	None
Frøya	Yes	Indirect attack	None
Vandaskog	No	Direct attack	Large (performed PB as exercises)
Hetland	No	Mixed (direct, indirect, counter fire)	Some Cooperated with PB group
Sokndal	Yes	Mixed (direct, indirect, counter fire)	Some
Sotra	Yes	Indirect attack	None

Table 5
Comparing the degree of adversity between the studied fires. *In the Vandaskog fire, embers crossed a road and entered a mixed forest area (4), where only ground vegetation (not crowns) was ignited. Then the fire entered a low biomass area (1).

Fire	Wind speed, m/s	Visibility	Accessibility of fire-area	Vegetation type	Time to reinforce-ments	Distance to threatened settlement	Natural barriers present	Estimated adversity
Flatanger	5	5	5	4	4	1	4	8,000
Frøya	4	1	2	3	1	1	1	24
Vandaskog	3	3	2	(4)1*	1	4	2	(576)144
Hetland	4	1	5	3	1	3	3	540
Sokndal	4	1	5	4	2	5	3	2400
Sotra	4	1	3	4	1	5	5	1200

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. The Flatanger fire, January 2014

The affected area

Flatanger, see Fig. A.1, is a 460-km^2 municipality in Trøndelag County, at 64.32° N, 10.45° E, with 1,120 inhabitants (Data Flatanger, 2014). The fire-affected peninsula is indicated with a yellow ellipse.

Flatanger experienced drought and sub-zero temperatures for about three weeks prior to the fire on January 27th, 2014. The terrain on the affected peninsula is rugged, with seven hills between 150 and 250 m above sea level (ASL) in a limited area (Figs. A2 and A5). At low elevation, deciduous trees and conifers were present, while shrubs (junipers and overgrown *Calluna*) dominated the elevated, rocky terrain.

The FRS was aware of the fire hazard, as they had responded to a fire earlier on the same day (to assist a neighbouring municipality), as well as the day before on Aspøy island. They also gained risk awareness from the town fire in Lærdal, 10 days earlier, which developed into a conflagration destroying 40 structures and threatened the whole town.

Fire spread and response

Evacuation of the peninsula north of Uran was organized shortly after fire outbreak, at 22:00 on January 27th, when the fire front escaped towards Askfjellet, 235 m ASL. Taking into consideration the adverse elements of darkness, sub-zero temperatures, storm-strength winds (easterly, 20 m/s gusting 28 m/s), the rugged terrain (seven peaks higher than 100 m ASL) and the dead-end road number 6304, the FRS decided not to perform any response north and west of Sandvika (Figs. A.4 and A.5). Fire control lines, i.e., ca. 100 m of watered and iced vegetation, in conjunction with road 6304, east side, were established. Jumping fire, by embers and firebrands that threatened buildings on the east side of road 6304, was extinguished.

After reaching Askfjellet mountain summit, the fire descended to its north side. It took a couple of hours to climb down Askfjellet and burn around Håstadvatnet, in the middle of the peninsula (Fig. A.5). Then, it accelerated again, towards Ramnfjellet (Report Flatanger fire, 2014). The researchers suggest that this fire behaviour may be explained by the strong southeasterly wind on the Askfjellet summit, likely creating an eddy at the northern steep slope. Thus, the fire moving north down the slope possibly met an upwind caused by the eddy, resulting in a slow downward fire spread. During the early morning hours, the fire reached Hasvåg and Småværet, see Figure A.5, 5.4 km from the ignition point, between 04:00 and 06:00, and destroyed 63 structures, i.e., the greatest number of structures lost in a single fire in Norway since 1923 (Losnegård, 2013).

Due to ground efforts by the FRS, secondary losses were prevented. Helicopter support was first possible on the third day of the fire, i.e., January 29th, when the wind abated. Nevertheless, the air support only lasted for a few hours, since the helicopters were redirected to support the extinguishing of the Frøya fire. During the following days, the dry weather continued and reignitions followed, making the fire incident last for about two weeks.

Without witnesses to the first fire blaze (inhabitants were evacuated, and no response was performed during the first night west of road 6304), there is no knowledge of the fire spread within the settlements that could explain why some properties were heavily affected and others not, see

Fig. A.5.

In Flatanger, 250 firefighters from 13 different FRSs participated in the response, and the Civil Defence contributed 170 persons and equipment. The total work has been estimated at three man-years (Report Flatanger fire, 2014).

The mayor of Flatanger municipality was interviewed by an MSc student about six months after the Flatanger and Frøya fires. Post-incident reflections are translated from the Norwegian (Småsund, 2016): "*On October 7th, 2011, regulations on municipal emergency preparedness were enforced* (MoJ, 2011, FOR-2011–08-22–894)*, so the municipalities have some responsibility to assess the risk. Maybe this is where we fell asleep …[failed]. The emergency preparedness was not increased, regardless of [extreme] drought,* i.e.*, people were out doing construction work, with minimal restraints regarding the terrain catching fire […]. We must think about safety and maybe restrict some activities in such weather. If it starts to burn under such conditions, there is no chance of extinguishing it […]*.

Appendix B. The Frøya fire, January 2014

The affected area

Frøya, see Fig. B.1, is a 152-km^2 island municipality in Trøndelag County (63.73° N, 8.80° E), with 4,547 inhabitants (Data Frøya, 2014). The affected part of the main island (also named Frøya) is indicated with a yellow ellipse. Frøya island is connected to the mainland by two tunnels, via the neighbouring Hitra island.

Frøya experienced drought and sub-zero temperatures for about three weeks prior to the fire on January 29th, 2014. The island is rather flat, large parts of it having an altitude of about 70 m ASL. The vegetation inside the affected area (yellow ellipse, Fig. B.1) was mostly degraded *Calluna* heathland (Fig. B.2). The FRS was aware of the fire hazard; during last five days before the ignition in Frøya, they had responded to five minor wildfires in the heathlands (some of them on the smaller islands), which were easily extinguished. It was known that the ongoing Flatanger fire, 127 km NE of Frøya, had destroyed 63 structures. The town fire in Lærdal, 12 days earlier, destroying 41 structures, was also important for the FRS's risk awareness.

The fire started ca. one hour before noon, when schoolchildren from the Sistranda settlement (east on the map, Fig. B.2) were on an ice-skating excursion. The cause of the fire was children playing with a perfume bottle and a lighter.

Fire spread and response

A moderate gale from the east, 15 m/s, gusting 23 m/s, allowed helicopter operations. A police helicopter, coincidently observing the fire in the early phase, offered FRS personnel a flight, to obtain an overview, shortly after ignition. This was important for the immediate tactical response plan. Settlements on the east side of the island, i.e., upwind, were not threatened, while inhabitants on the northwest side were evacuated, see Fig. B.3. It was decided to let the fire proceed northwest and use the two frozen lakes, Kjerkdalsvatnet and Langvatnet, at a 60-70° angle to the fire spread direction (Fig. B.3), as fire control lines. This involved wetting a 200-m land corridor between the two lakes and some area in the extension of the lakes. The wetted areas were soon ice-covered. The fire control line involving the lakes was the FRS's plan A.

The FRS's Plan B involved preparing a fire control line by wetting/icing vegetation to protect the north side of the lakes, in conjunction with road 716 (Fig. B.3). Moreover, ATVs were utilized for field transportation, as they could also drive over the frozen lakes to bring necessary supplies to the responders. The Frøya fire was under control the next day, i.e., January 30th, at about 14:00. Plan A proved effective, and the fire never crossed the lakes shown in Figs. B.2 and B.3.

Aerial support from four helicopters, 100 firefighters from eight different municipalities and a total of 165 persons from the Civil Defence, Red Cross and industry firefighters contributed to the response (Report Frøya fire, 2014).

Regarding the response, when interviewed, the 2014 fire chief noted that "*An important learning point [from the fire in 2014] is that we must look well ahead in time. I think it would have been a lot more difficult had we stayed behind the fire [*i.e.*, direct attack on the flanks]. We had to get in front of the fire [*i.e.*, indirect attack]. Although it might have seemed idiotic to the population that we soaked with water areas that were not burning, we had to make them wet before the fire eventually got there.*".

Appendix C. The Vandaskog fire (Sveio), February 2014

The affected area

The 246-km^2 municipality of Sveio, at 59.32° N and 5.35° E (Fig. C.1), had 5,463 inhabitants in 2014 (Data Sveio, 2014). It is named after the Norse word *Sviða,* meaning place cleared by burning.

Sveio experienced drought and sub-zero temperatures for about three weeks prior to the fire of February 1st, 2014. The affected area, see Fig. C.2, is hilly, with two small lakes and one hill of 50 m ASL east of the lake, Øyavatnet. The vegetation consisted of a narrow forest belt and well-managed heathland.

The fire was started by arson at a public community house (former public school) at the (now) gravel-covered area inside the yellow banner marked in Fig. C.2. The FRS was alerted at around 06:00 AM (Report / Incident Log, 2014 Vandaskog fire). Upon arrival, they realized that the building was lost, and that the fire had spread east of road 541 (Fig. C.2).

Fire spread and response

Due to the ongoing fire in Flatanger and the newly extinguished fire on Frøya, as well as the town fire in Lærdal two weeks earlier, the FRS quickly evacuated the settlement at Rødmyr and Lyngholmen, *N*-NW, Fig. C.3. Although the FRS proactively requested helicopter support, atmospheric turbulence hindered aerial operations.

Wind of 8–10 m/s, from the SE, spread the fire NW. Flying embers from the burning building ignited the vegetation west of road 541, and a ground fire propagated NW, without igniting the tree crowns. Then the fire entered an area of low biomass, where the FRS had practised PB two years before while simultaneously restoring the heathland. This gave the FRS a double advantage, i.e., local knowledge of the terrain and reduced biomass, leading to a successful direct attack with fire swatters from the flanks and behind in the winter darkness. Extra manning was deployed at a natural firebreak, i.e., the lake, Øyavannet, in case the direct attack was inadequate. No wetting of biomass was conducted. The red curve on Fig. C.3 indicates approximately where the fire was finally extinguished.

PB as exercise in Sveio FRS

A 5-km^2 wildfire at Hopsfjellet, in June 1992, resulted in an increased focus on forest and heathland fires in the Sveio municipality. In the aftermath of that fire, the FRS started arranging annual PB training sessions, to create a "fire safe" landscape and become familiar with landscape fires. Sveio FRS has actively contributed to knowledge sharing about PB, through seminars in collaboration with PB practitioners, ecologists, academics, etc. A firefighter who lectured at these seminars noted that: "*My goal is first and foremost to give FRSs a wake-up-call that this [PB operations] is a good way to practise [fire management].*" He elaborated the vicious cycle of PB exclusion: "*If landowners are not allowed to burn, the vegetation grows, and the increasingly combustible natural biomass may restrict future PB operations*." Additionally, the environmental goal of preserving the coastal heathlands, a semi-natural habitat hosting a variety of now red-listed birds, has increased the motivation for restorative burning. In 2014, the Sveio FRS was the only FRS in Norway with hands-on PB experience. This experience was very valuable regarding biomass control and risk understanding, prior to the Vandaskog fire.

Appendix D. The Hetland fire (Tysvær), April 2019

The affected area

The 425-km^2 Tysvær municipality, at 59.38° N, 5.44° E (Fig. D.1), had 11,044 inhabitants in 2019 (Data Tysvær area and Data Tysvær population, 2019). Five months before the Hetland fire, Tysvær FRS joined the intermunicipal company "Haugaland FRS", consisting of nine municipal FRSs. PB had gained sporadic interest in Tysvær since early 2000, when restorative burning was reintroduced by individual farmers. The practice was gradually upscaled, and the civic group, Haugaland Heathland Burning Reserve (HHBR), was established in the winter of 2019. Some of the members were also part-time fire responders.

The weather had been sunny for about three weeks before April 13th, when a planned PB operation was permitted by the FRS. The burning was conducted judiciously, in the area within the yellow ellipse in Fig. D.2. With wind from the SE, the burning against the wind should safely have been terminated in the south, at the Hetlandsvågen bay. However, almost at termination, embers falling down the 37-m-high rock towards the sea ignited leaves in a shelf about 20 m ASL. A crack in the rock, containing accumulated dry leaves, acted as a fuse, leading the flames up to the top again but beyond the previously constructed firebreak. Meanwhile, a strong sea breeze set in, and the wind direction changed to NW, spreading the fire southeast (Fig. D.2).

The terrain is hilly, with the highest peak in the affected area at 102 m ASL. The vegetation was mostly abandoned heathland, partly encroached by juniper, pine and spruce.

Fire spread and response

The four PB practitioners who had lost control called other HHBR members for assistance but had to alert the FRS three hours later. After reconnaissance, the FRS decided to transport mobile pumps to the inner parts of the Hetlandsvågen bay from the fire station in Kopervik (Fig. D.1). Power lines (66 kV and 400 kV), settlements (S, E and N), scattered cabins along the fjord and infrastructure such as the main road (E39) were at risk. In the fire area, there was generally good access to water from small lakes but no access roads. Boats and hiking paths were therefore used to transport responders and equipment during the response. The wind strength varied from 3 to 8 m/s throughout the fire period, with wind shifts. During the day, the temperature rose to 10 °C with 30 % Relative Humidity.

Mixed firefighting techniques were used, with direct attack when possible (using HHBR members with leaf blowers), indirect attack by wetting areas ahead of the fire, as well as counter fire. Unfortunately, biomass consisting of logs and branches, following logging to protect power lines several years previously but left in place, sustained hidden glowing or smouldering combustion. Two days later, a reignition occurred, see Figs. D.2 and D.3. As a result of accumulated dead biomass, the reignited fire destroyed a power line section and an electricity transformer. Besides that, the versatile use of techniques and tools resulted in a successful response without aerial support (Report Hetland fire, 2019). The fire lasted for four days and affected 4 km^2.

The extinguishing efforts were explained by the incident commander (IC): "*We used the topography; we did not work hard when the fire spread uphill, but we rather extinguished the fire as it spread downhill. We directed our efforts and used the natural barriers in the terrain. For example, we used pasture fields to stop the fire when it spread downhill [from mountains into marshes]*".

Consideration of PB as a fire cause

In the aftermath, the FRS recognized that permitting PB on April 13th, 2019, was a regrettable decision. Drought had made the vegetation fire-prone, and the forecasted fire-adverse weather in the following days increased the chances of reignition. However, balancing the positive long-term effect of PB for societal fire safety (expressed by the permission to conduct the session) against the short-term fire risk is challenging.

In the evaluation report prepared by the FRS, the cooperation between the FRS and the PB group was highlighted as effective [31 d]. The IC stressed the PB practitioners' invaluable expertise with fire development in heathlands: "*They [The PB practitioners] have developed much experience,* e.g.*, with leaf blowers. It was efficient [to use leaf blowers for fire extinguishing]*". Nevertheless, the PB group's expertise should not restrict them from asking for support early – if in trouble. He elaborated "*When in doubt about asking for support, there is no doubt that you must do so*", which is a core principle of proactive emergency management.

In early 2021, Haugaland FRS initiated official collaboration with the HHBR, stating that the PB practitioners would assist the FRS in extinguishing wildfires in the region. The agreement was utilized during a summer wildfire a few months later.

Appendix E. The Sokndal fire, April 2019

The affected area

The 295-km^2 municipality of Sokndal, at 58.32° N, 6.34° E (Fig. E.1), had 3,300 inhabitants in 2019 (Data Sokndal, 2019). Sokndal has a municipal part-time FRS, which cooperates with the neighbouring Flekkefjord FRS. PB activities have been performed in parts of Sokndal for millennia and are still ongoing. Several of the fire responders are active PB practitioners (privately). The studied fire-affected area is indicated by the largest yellow ellipse in Fig. E.1, while three smaller yellow ellipses indicate fires developing in parallel with the Sokndal fire.

The fire was reported to the emergency call centre at 14:00 on 23rd April, by two hikers trapped by flames and smoke on the Hellershei hill (Figs. E.2 and E.3). The endangered hikers were airlifted ca. 14:30 by an ambulance helicopter. Ignition point and fire cause have not been conclusively identified. However, the description by the hikers and the development of the fire point towards an ignition point in the valley below Hellershei, Hellersdalen, ca. 70 m ASL (Fig. E.3). The vegetation was overgrown coastal heathland and cured grass, with junipers and shrubs in rocky parts, and mixed forest with deciduous trees and conifers at a lower elevation. The weather prior to the fire had been dry, with moderate easterly winds.

PB operations conducted in the area before April 15th are a plausible cause of the fire. Possible smouldering fires in the ground may have erupted into flaming combustion in 14-m/s east winds (Report Sokndal fire, 2019). This theory is strengthened by the fact that the FRS had responded to nine fires between April 13th and 23rd, some of which were identified as reignitions after PB operations approved by the FRS.

The topography within the affected area is rugged, with Hellershei as the highest hill (314 m ASL), eight peaks between 200 and 300 m ASL and eight peaks between 100 and 200 m ASL. However, there are also small lakes and creeks, as well as roads, intended to be used as firebreaks. The ca. 5-km^2 affected area is indicated by a red boundary in Fig. E.2.

Fire spread and response

Throughout the response, which lasted until April 25th, the FRS and supporting emergency services were distributed between four different fires in the area, as seen in Fig. E.1. The most severe of these fires, i.e., the Sokndal fire, is analysed in the present study, while the smaller ones are mentioned because of the stress they posed for the FRS. Wind shifts and topography made the Sokndal fire move “in a circle”, first north, then west, then south and finally northeast, ending up again in the heritage settlement of Helleren (Fig. E.3), this time from the south. The fire at Helleren was described by eyewitnesses to be “*like a waterfall of sparkling rain down the mountain sides*”. The shifting fire-spread directions (due to wind shifts and topography) created challenging situations, with frequent relocations of forces, as different settlements were threatened, and 138 persons were evacuated. The Sokndal fire affected 5 km^2 and destroyed one cabin and a boathouse (Report Sokndal fire, 2019). Two threatened farms (not defended) did not burn down, as the fire self-extinguished upon entering farmland.

The FRS facilitated fire lines using back-carried water pumps, supplied by lakes and creeks, to protect settlements. One of the fire responders noted that the FRS was forced to think in new ways regarding fire response; he further elaborated:

> *We had to use the topography effectively; the fire was so intense that we had to think about our own safety at all times. Therefore, we had to let the fire come to us [indirect attack], as opposed to running after the fire [direct attack]. [During response] we utilized creeks, roads, local winds around hills at places where we had a strategic advantage. Moreover, we placed fire trucks and ATVs with water tanks and back-carried water pumps [where required].*

In total, 145 people from different emergency services and volunteers participated in the emergency response (Report Sokndal fire, 2019).

The Sokndal fire was a demanding incident that may indicate an altered fire signature on the west coast of Norway. One of the interviewees stated that:

> *For my part and that of my colleagues [in the FRS], the Sokndal fire was an “eye opener” far beyond what we actually envisioned possible regarding fire intensity and speed. [Surprisingly] the fire spread into places that had burned previously in the same spring [in areas perceived as safe black]. The fire jumped over roads, normally considered boundary lines. So, yes, for my part, I had to experience it [the novel fire signature] before I could imagine how intense it [a fire in previous Calluna-dominated heathland] can be.*

Consideration of PB as a fire cause

The high probability of smouldering patches after PB operations was mentioned by the FRS as a topic requiring further investigation. Smouldering fires in the soil are highly undesirable, regarding environmental, health and safety concerns. More focus is required on the (fuel) moisture content of plants and soil before final permission is granted for PB operations. The weather forecast for the days after the planned burning must also be consulted. “Best-practice” PB performance involves heavy rain in the days after the PB operation.

Appendix F. The Sotra fire (Øygarden), June 2021

The affected area

Øygarden is a 314-km^2 island municipality, at 60.35° N 5.02° E (Fig. F.1), with 38,664 inhabitants in 2021 (Data Øygarden, 2021). Despite the large number of inhabitants compared to other Norwegian islands, Øygarden has a part-time FRS because no settlement has more than 8,000 inhabitants. The terrain is rugged (Figs. F.2 and F.3), with three peaks between 100 and 200 m ASL, five peaks between 50 and 100 m ASL and interrupted by lakes, sounds and fjords. The vegetation in the affected area was typical for abandoned heathland, i.e., degrading *Calluna* encroached by juniper, some pine and patches of Sitka spruce.

The weather was sunny for about three weeks prior to the ignition, with low RH (below 40 %). The Sotra fire was reported at 11:57 on June 3rd, 2021. Moderate wind speed from the SE (6 m/s, gusting 10 m/s) dominated during the first day of the fire. The ignition point was at the roadside, in Fjæreide (Fig. F.3). A 7-cm-diameter transparent plastic ball, acting as a lens concentrating sunlight, was identified as the most likely source of the fire. The distance between the ignition point, at Fjæreide, and the settlements on the NW side of the island is only 2 km. Resolute mobilization of rescue resources was therefore necessary to protect the evacuated settlement.

Fire spread and response

Direct attack, to protect threatened infrastructure (a water treatment plant) and a farm in the vicinity of the ignition point in Fjæreide, and direct/indirect attack before road 5242 (Fig. F.3) were prepared. Helicopter support was requested within 20 min. However, it took 90 min before the first helicopter arrived from eastern Norway. Upon arrival, the pilot promptly called for seven additional helicopters to alleviate the situation. The pilots had only previously observed such a fire signature in Norway, including fire tornadoes and pyrocumulus clouds, during the 30-km^2 Froland forest fire of 2008. The helicopter pilots reported fire spread rates of up to 4–5 m/s in dense juniper fields. The fire jumped 270 m across a fjord, where it was extinguished by a FiFi boat and a helicopter.

During the evening of June 3rd, the wind abated, and the fire was extinguished. By noon on June 4th, the ca. 500 evacuees were allowed to return home. The FRS focused on impeding reignition. Nevertheless, six days later, on June 9th, in 14-m/s wind, the fire reignited at Spjeld mountain (Fig. F.3), and 200 inhabitants had to be evacuated. The fire then spread into a low biomass area, affected by a wildfire in 2015, and was managed by ground personnel using fire swatters and supported by one helicopter. On June 13th, 28 mm of precipitation extinguished the fire.

In total, eight helicopters, 29 fire trucks and one fire boat participated. About 100 firefighters and 40 persons from the civil defence participated. The monetary cost of the operation was about 6 million NOK, ca. 600,000 Euro (Report Sotra fire, 2021). One house and one fire truck (attempting to defend the house) were lost in the fire east of road 5242, while another house was partly damaged. One hut was also lost. Seven firefighters were hospitalized due to smoke inhalation and exhaustion. No civilians were injured.

Appendix G. Interview guide

Structure of Teams interview

- Shortly explain the research project and the purpose of the interview
- Proceed with the interview:
- Share screen and show a digital map (Norgeskart.no) of the fire investigated for the interviewee to use it as a tool while sharing his/her experience from the fire.

Questions

Initiating questions:

- What was your role (position in the FRS) when the fire occurred and what is your role (position) today?
- Years of experience in the Fire Service
- Experience of forest fires and WUI fires during the career.

Response:

- Please, tell us about your experience of the respective fire. (Map on shared screen.)
- How and where did the FRS respond to the fire?

Strategy, how did it come to be? What was the strategy?
What was most challenging?
What worked well?
How did you make decisions? New ideas or previous experience (or both)?
What could have been done differently?

- What was your responsibility area during the response?
- What previous experiences enabled the FRS to handle the incident the way you did?
- How did you acquire knowledge about large fires prior to this fire?
- When you became aware of the fire, what similar incidents could you draw on (from personal experiences and/or mentioned events)?
- Did the incident develop the way you supposed it would, upon making the incident response plan? What developed differently than planned for?
- Use of technology and techniques in the field. ATVs, water pumps, leaf blowers etc. and fuel barriers.
- Cooperation: Management support, DSB, crisis team, volunteers.
- Local knowledge: local conditions, people, and previous accidents

Risk understanding:

- How did you perceive the risk in the days before the fire? (What did you observe and how did you judge the fire risk.)
- How could the FRS prepare differently if an official fire hazard index indicated high values in the period prior to the fire?
- Which specific risks were you aware of? Did you convey your thoughts to others?

Learning points:

- What were the major experiences during the response that triggered learning?
- What did you learn from the fire that is relevant for future major fire incidents?
- How have these lessons been integrated in the fire service today?
- What has changed in the emergency preparedness today versus before the fire?
- How have you/the FRS helped spread this knowledge further? How and to whom?
- How could knowledge sharing be stimulated between FRSs after major incidents?
- What opportunities do you see for sharing knowledge in relation to large and rare fires?
- How (and who) should support the fire service to prevent major fire accidents?
- How are high-risk periods communicated today compared to before the fire incident?
- What has changed (in the FRS / municipality) after the fire? Preparedness/prevention.

Prescribed Burning (PB):

- Attitude to PB as a land management tool?

- Is PB seen as a measure for fire risk reduction in your area?
- Has the attitude to PB changed after the fire? If YES, how?
- Experience from PB? (Does the FRS participate/support in PB operations? Individuals in the FRS performing PB privately?)
- Do you know of any farmers / others who practice prescribed burning in the local area?
- Has there been any local focus on the preventive work farmers do to maintain the cultural landscape?

Mitigation of future fire risk:

- What suggestions do you have for possible measures for fire risk reduction?
- Which considerations has the fire service regarding future fire safety in the WUI?

More or different focus on major fires?

- Exchange of lessons between fire stations (within one large FRS) and across FRSs.
- What advice would you give to other FRSs / municipalities about fire prevention?
- Future training compared to current? What opportunities do you see? How can they be implemented?
- How could a fire risk warning system be best adapted to the FRS needs?
- How do/could the authorities or other actors support the FRS before/during/after a fire?
- Changes: training, manual, equipment, cooperation, strategy, and prevention.

End of the interview

- Is there anything more you want to add? Do you have any questions?
- Thank the interviewee for taking time to participate.

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