

Article

Strengthening Finnish Wildfire Preparedness and Response Through Lessons from Sweden's 2018 Fires

Pekka Tiainen ¹, Zoltán Török ^{2,*} , Horațiu-Ioan Ștefănie ² , Ágoston Restás ³  and Alexandru Ozunu ² 

¹ Doctoral School of Environmental Science, Babeș-Bolyai University, 30 Fantanele St., 400294 Cluj-Napoca, Romania; tiainen.pekka@ubbcluj.ro

² Research Institute for Disaster Management Based on High Performance Computing, Faculty of Environmental Science and Engineering, Babeș-Bolyai University, 30 Fantanele St., 400294 Cluj-Napoca, Romania; horatiu.stefanie@ubbcluj.ro (H.-I.Ș.)

³ Institute of Disaster Management, Ludovika University of Public Service, Ludovika Tér 2, 1083 Budapest, Hungary; restas.agoston@uni-nke.hu

* Correspondence: zoltan.torok@ubbcluj.ro

Abstract

In recent years, devastating wildfires have occurred in less fire-prone areas, and an increase in boreal region wildfires is expected in the future. Using a qualitative comparative approach based on a literature review and policy document analysis, this study aims to examine the wildfire management systems and practices in Sweden and Finland, focusing on the remarkably different outcomes of the 2018 wildfire season. Despite experiencing similar climatic conditions, in Sweden a total of approximately 25,000 hectares of forest burned, compared to the 1200 hectares in Finland. The analysis examines thematic areas from general disaster management and wildfire-specific elements. The main differences in the organizational structures between the two countries are identified. Ecological aspects of boreal forests, fire suppression effectiveness, and response times are compared, and current and emerging technologies for fire detection and suppression, such as unmanned aerial vehicles, are presented. The role of volunteer fire brigades and their sustainability in rural areas, together with the effectiveness of host nation support arrangements and international cooperation mechanisms, are discussed. Based on this comparison of identified best practices and lessons learned, the authors provide recommendations for improving wildfire resilience both in Finland and Sweden, as well as in other boreal region countries.

Keywords: wildfire; fire management systems; Finland; Sweden; preparedness; response; lessons learned



Academic Editor: Grant Williamson

Received: 4 July 2025

Revised: 7 August 2025

Accepted: 11 August 2025

Published: 14 August 2025

Citation: Tiainen, P.; Török, Z.; Ștefănie, H.-I.; Restás, Á.; Ozunu, A. Strengthening Finnish Wildfire Preparedness and Response Through Lessons from Sweden's 2018 Fires. *Fire* **2025**, *8*, 325. <https://doi.org/10.3390/fire8080325>

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Wildfires have become a major topic of public concern due to climate change and more frequent extreme weather events. In recent years, devastating fires have occurred even in areas not typically considered fire-prone [1], and projections indicate an increase in wildfire frequency and intensity across Europe, not only in the south but also in boreal and temperate regions [2,3]. However, clear trends in burned areas or the number of large fires (over 30 hectares) remain elusive [4]. Analysis of data from the European Forest Fire Information System (EFFIS) between 2008 and 2018 suggests that relatively mild wildfire years are often followed by periods of extreme activity, complicating efforts to establish long-term trends [5]. These uncertainties, combined with the increasing pressure of climate change on forest ecosystems and their capacity to deliver essential services, underscore the

urgency of adopting adaptive forest management strategies. A recent survey showed that 73% of European forest owners acknowledge that climate change will impact their forests. However, only 36% have adapted their management practices accordingly [6], highlighting a gap between awareness and action that is reflected in uneven national responses.

At the European level, political and regulatory frameworks for wildfire and land management vary widely. Most countries impose legal restrictions on fire use, but policies remain fragmented. The European Commission is promoting wildfire risk prevention and the development of fire-smart territories (FSTs) through several initiatives and land management incentives [7]. Yet, experts recommend harmonizing and updating these fragmented measures into a more integrated and cohesive framework [8].

Recent studies have examined land management strategies to increase landscape heterogeneity and reduce fire risks [9]. In high-risk European regions, over 25% of land was found suitable for a combination of herbivory, mechanical fuel removal, and prescribed burning. Southern Europe showed a consistent suitability for prescribed burning, while northern regions like the Nordic countries favored herbivory.

Sweden and Finland have historically experienced low-intensity wildfires compared to the Mediterranean region or other boreal regions such as Siberia or Canada. During the summer of 2018, numerous large fires in Sweden burned a total of approximately 25,000 hectares of forest [10,11]. In Finland, the summer of 2018 was also extremely demanding for rescue services in terms of wildfires. Over the course of the year, more than 4000 wildfires broke out across the country. These fires burned approximately 1200 hectares of forest and nearly 400 hectares of other terrain. The largest individual fire destroyed around 80 hectares of forest in Pyhärinta, southwest Finland, causing property damage exceeding EUR 400,000 [12]. Despite experiencing similar climatic conditions in 2018, Sweden and Finland showed remarkably different outcomes in terms of fire severity and burned area. However, the average size of wildfires in Finland during the summer of 2018 remained under one hectare, and over 80% of all fires covered an area of less than half a hectare [12]. To understand these contrasting outcomes, a systematic comparison of the two countries' wildfire management approaches is required.

This study aims to examine and compare the wildfire management systems, policies, and practices in Sweden and Finland, focusing on the period following the severe wildfire season of 2018. The analysis identifies the main differences in the organizational structures between the two countries. Given the increasing frequency of severe wildfires, fire suppression effectiveness and response times are compared and current and emerging technologies for fire detection and suppression, such as unmanned aerial vehicles (UAVs) are presented. The role of volunteer fire brigades and their sustainability in rural areas, together with the effectiveness of host nation support (HNS) arrangements and international cooperation mechanisms are discussed. Based on this comparison of identified best practices and lessons learned, the authors provide recommendations for improving wildfire resilience in both countries as well as in other boreal region countries or countries with a sparse rural population.

2. Materials and Methods

This chapter outlines the methodological approach undertaken to conduct a comprehensive, qualitative comparison of the Finnish and Swedish wildfire management systems and identify key differences between these two countries. The study also focuses on understanding why similar fire weather conditions resulted in significantly different fire outcomes between the two countries. This qualitative comparative approach, developed by the authors, was deemed appropriate given the contextual nature and complexity of wildfire management systems.

The research relied on the review, analysis, and comparative interpretation of existing scientific literature, specific wildfire-related studies, institutional reports, and national policy documents and statistics (Finland, Sweden, European Union Commission). The review covered literature mostly from 2000 to 2024, with particular emphasis on publications after 2018 to describe recent developments and lessons learned.

The literature review has two main purposes: first, to identify existing wildfire-related studies in these two countries, highlighting the differences and similarities, and second, to identify best practices and lessons learned. Key differences and similarities between Finland and Sweden were identified through comparing thematic areas in (1) general disaster management aspects (legislation, HNS, volunteers, international assistance, climate change adaptation) and (2) wildfire management specific elements (ecological aspects, statistics, causes, fire suppression methods, response challenges, monitoring and detection, technologies).

The analytical process followed these steps: (1) Data collection: systematic review of relevant documents for each thematic area; (2) Data extraction: relevant information on wildfires and disaster management; (3) Comparative analysis: descriptive comparison of each element between the countries, considering functional elements of disaster management systems and their performance; analysis of differences, based on historical, geographical, and cultural context; and (4) Synthesis: identification of similarities, differences, and best practices.

The comparison framework integrates disaster management evaluation criteria with wildfire-specific indicators, drawing on the authors' professional experience in civil protection, disaster management and preparedness, and wildfire fighting. The framework examines three interconnected dimensions: (1) institutional arrangements—organizational structures, coordination mechanisms, and governance; (2) operational practices—response protocols, resource deployment, and technology utilization; and (3) outcomes—fire suppression effectiveness, burned area, and response times.

The authors acknowledge limitations, such as gaps in publicly available data, and the challenges in comparing two national systems with different standards for reporting.

3. Results

3.1. General Disaster Management Systems

The most concrete wildfire prevention measure appeared in the Finnish legislation in the 559/1975 Fire and Rescue Act (the new version being The Rescue Act 379/2011 [13]), which for the first time established a legal obligation for the Finnish Meteorological Institute (FMI) to issue wildfire warnings. According to Chapter 4, 31§, "The Finnish Meteorological Institute shall issue a forest fire warning to an area where the risk of a forest fire is estimated to be obvious due to ground surface droughts and weather conditions. The Finnish Meteorological Institute shall ensure that forest fire warnings are communicated to the extent necessary" [13]. Conversely, in the Swedish legislation no specific legal wildfire warning obligations are applied.

One of the biggest differences between Finnish and Swedish rescue services is the volunteer fire brigade system, especially in rural areas. From the perspective of wildfire prevention and the fire suppression system, wildfire suppression in sparsely populated areas of Finland is largely the responsibility of local volunteer fire brigades [14,15]. As a result, fire brigades can often reach the fire site relatively quickly after an alarm is raised. However, both in Finland and Sweden, the migration of the population from rural areas to cities may pose significant operational challenges for volunteer fire brigades in the future [14]. In Sweden, the amount of the volunteer fire brigades has decreased, which affects the speed and resources available in sparsely populated areas. This is seen as one of the main reasons why wildfires in

Sweden have developed into severe incidents. Urbanization and the depopulation of rural areas have impacted the operational conditions of volunteer fire brigades.

The Swedish Civil Contingencies Agency (MSB) was the competent authority for requesting and receiving international assistance via the EU Civil Protection Mechanism (ERCC—Emergency Response Coordination Centre) and for providing HNS to incoming assets. During the 2018 wildfires, nine countries responded to Sweden's request for international assistance (Finland and Norway via the Nordred Agreement and Italy, France, Lithuania, Germany, Poland, Denmark, and Portugal via UCPM). Around 360 firefighters, seven aerial wildfire-fighting planes, and six helicopters cause massive challenges to the HNS arrangements [16]. All the international teams were supported by liaison officers in the field, and at the government level, huge effort was made to support the incoming foreign teams.

Finland has put a lot of effort into booting HNS arrangements, and new legislation has been in place since 2024, where the Helsinki Rescue Department has the responsibility to arrange HNS activities at the country level [17]. The Finnish HNS arrangement is based on UCPM guidelines [18].

However, HNS operations were seen to be better in Sweden than in Finland. During the 2018 megafires in Sweden, the collaboration of nine nations and the deployment of around 360 firefighters, along with extensive aerial support, not only highlighted the scale of the challenge, but also demonstrated the resilience and adaptability of Sweden's HNS arrangements. The concerted efforts, including the provision of liaison officers and comprehensive logistical support, ensured a coordinated and effective response that significantly mitigated the impact of this unprecedented natural disaster.

Despite the successful operations, some learned lessons were also identified. No national reception and departure center (RDC) was established. Instead, Sweden appointed liaison officers early and provided decentralized, on-site support. ERCC liaison officers initially based in Örebro (airport) were later moved to Stockholm for better effectiveness. For example, for the Polish Ground Forest Firefighting using Vehicles (GFFF-V) module, Sweden delivered a full HNS package from arrival to departure, including organized reception/check-in at Trelleborg port, continuous MSB and Swedish Armed Forces liaison, route planning and fuel stops from Trelleborg to Sveg and back, accommodation and meals en route, adapters to match hose couplings, RAKEL radios for interoperable communications, fuel supply for vehicles/equipment, 24/7 camp security by the armed forces, and ration packs for the return trip. While foreign teams generally rated Sweden's HNS very highly, both the inquiry and ERCC feedback point to improvement areas: clearer national reception arrangements, more consistent use of aerial operations expertise, and better dimensioning/timing of requests relative to evolving risk indices and needs [10].

It is also worth noting the observation mentioned in the Joint Research Centre's (JRC) technical report (2018) that Sweden's wildfire suppression operation and the related cooperation with international forces was one of the largest operations within the UCPM in Europe in 2018 [19].

3.2. Wildfire-Specific Management Elements

Finland and Sweden are both part of the boreal region [20], also known as the taiga, which is the world's largest biome characterized by vast coniferous forests, cold winters, and short and moist summers [20]. Thus, the vegetation is similar in Finland and Sweden. This region stretches across the northern parts of Europe, Asia, and North America. The forest is dominated by coniferous trees like spruce and pine along with some deciduous trees such as birch and aspen.

Up to 80% of the forests in Finland, Sweden, and Norway are actively harvested and thus fire suppression has been highly successful and effective [21,22]. Over the past

23 years, the average total burned area in Sweden has been approximately 3600 hectares per year. During the same period, the average number of wildfires has been just under 5000 per year, of which around 2500 have been wildfires [11]. Sweden's 2018 wildfire season was the worst on record. Of the burned area (21,605 hectares), 74 fires were assessed from satellite images to be larger than 30 hectares [19].

However in Finland, on average, between 1996 and 2020, 959 hectares burned annually. The largest single fire covered an area of 80 hectares of forest in Pyhärinta, southwest Finland, causing property damage [23]. In 2018's wildfire season, the number of fires in Finland was about double that of the normal average level. Statistical data retrieved from the rescue services' resource and accident statistics system, Pronto [24], shows that a total of 4252 wildfires occurred in 2018, with a total burned area of 1621 hectares. However, the summer of 2006 was the driest summer in Finland in over 100 years, making it a more severe wildfire season than 2018. In 2006, there were 6290 wildfires, and the total burned area was 2178 hectares [24].

Population declines in Sweden have reduced emergency response resources in sparsely populated areas, and thus the response time has increased, whereas Finland has managed to maintain their volunteer fire services in rural areas, and thus the response is shorter. Also, the dense forest harvesting road network and water sources create better conditions for firefighting in Finland, whereas in Sweden the forest harvesting road network is not that dense and Sweden has less lakes than Finland. When the FWI (forest fire weather index) is high enough, the Finnish national authority announces the open fire ban, whereas in Sweden it is the responsibility of the municipalities.

The largest fires (over 100 hectares) in Sweden, during the summer of 2018, were geographically concentrated mostly in sparsely populated areas in central and northern parts of the country and occurred primarily in July. Other characteristics of large fires (>100 hectares) included a first response time of 25–30 min [11] and high wildfire indices for several days after ignition. The causes of these fires were ignitions from lightning, forestry machinery, or re-ignition due to insufficient fire suppression clearance. These three causes accounted for 48% of fires exceeding 100 hectares [11]. However, the most common cause of all wildfires (including grass fires) is the burning of some material near residential areas, children playing with fire, and camping-related reasons (such as campfires and similar activities). Still, the cause of the fire has been found to remain unknown in about one-third of the cases [11].

From the perspective of wildfire suppression, it is crucial to detect ignited fires and reach the fire sites quickly. Decades of population decline in rural Sweden have likely reduced emergency response resources in sparsely populated areas, which in turn has weakened the chances of a successful initial fire suppression attack. This lack of resources is considered to be due to the state centralization of resources, such as rescue personnel [25] and other assets. The relationship between the average size of wildfires and response time from fire detection to the arrival of fire brigades has been studied, and it has been found that as response time increases, the average size of the fire grows almost exponentially [11].

Finland's distinct even-structured forestry system, with regular thinning and smaller forest compartments combined with a dense forest road network, is one reason why the annual burned forest area has significantly decreased in recent decades, and large-scale wildfires have been rare [26]. These forest roads, mostly built between the 1960s and 1980s, allow easier and faster access of rescue services to the fire site. The dense network of forest roads also provides numerous good firebreak lines for firefighters in the field.

The statistical study "Hevonkuusessa palaa isosti" [12] extensively examined wildfire spread statistics in Finland, from the summer of 2018. The study concluded that a high wildfire index did not increase the proportion of large wildfires, but strong winds did.

Wind was also found to have increased the number of fires. Large fires were determined to have occurred in remote areas, leading to delays in detection and long emergency response times. Perhaps the most significant conclusion of the study was that if the open fire ban had been strictly followed during wildfire warnings, approximately one-third of all wildfires could have been prevented [12].

3.2.1. Ecological Aspects of Boreal Forests of Finland and Sweden

Boreal forests in Finland and Sweden are primarily composed of Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*), and birch species (*Betula pendula*, *B. pubescens*) [27]. While both countries share this species composition, Sweden's boreal forests are more fragmented by industrial forestry and clear-cuts, whereas Finland has more uniform forests with extensive peatlands and naturally regenerated stands [28].

Climate warming and drought are significantly altering fuel dynamics. Higher temperatures increase evapotranspiration and dry forest floors, particularly mosses, needles, and fine woody debris, which act as ignition sources [29]. Drought events, intensified by climate change, promote insect outbreaks and windthrows, increasing deadwood—especially in spruce forests—thereby elevating fire risk [30,31].

In Sweden, major fires in 2014 and 2018 were linked to these risk factors and to logging residues left in managed stands [32]. Species flammability and fire adaptation vary. Scots pine is the most fire-resilient, with thick bark and sparse crowns that allow surface fires to pass. Norway spruce, in contrast, is highly flammable and vulnerable due to thin bark, shallow roots, and dense canopy structure [33]. Birch species regenerate quickly post-fire, colonizing disturbed areas but are only moderately fire-tolerant [34].

The growing incidence of wildfires undermines conventional forest management strategies, especially in landscapes dominated by fire-prone spruce monocultures. Both countries must now reconsider forest planning by promoting pine and birch mixtures, reducing fuel loads, and enhancing prescribed burning [35].

3.2.2. Detection and Monitoring Systems

Both countries use systems based on the Canadian forest fire weather index (FWI) system [36], but there are some differences in implementation and usage. The FWI system is a numerical rating of fire danger that combines measurements of temperature, humidity, wind, and precipitation to estimate the potential fire intensity. In Finland the forest fire hazard is based on the forest fire index (FFI) [37], also called simply the wildfire index [38]. It is also calibrated for Swedish conditions, which are slightly drier, and sometimes integrates local drought effects. Further on in the paper, we will use the FWI acronym.

To calculate the FWI, a grid-based method is used [38]. This involves estimating the values of various weather parameters at regularly spaced points across a grid, covering the whole country, with uniform coordinate projection. Each grid point represents an area of a specific size, known as a lattice cell, surrounding that point, with a resolution of 10 km × 10 km. Meteorological data—including air temperature, wind speed, and relative humidity—obtained from local stations, together with precipitation data retrieved from a weather radar network, and solar radiation assessed by using a numerical weather prediction model, are used as inputs in the risk model. This comprehensive approach enables accurate and timely wildfire risk assessments across large geographical areas [38].

The MSR (monthly severity rating) and SSR (seasonal severity rating) are fire weather indices developed and used by the FMI to evaluate wildfire danger based on weather conditions and terrain factors. They are part of the broader FWI system, which helps predict the likelihood and potential severity of wildfires. These indices are used by emergency

services, forest authorities, and meteorological agencies to make decisions about issuing wildfire warnings.

In Finland, emergency calls made by citizens via mobile phones, an aerial surveillance system using aircraft on 22 routes flown 1–2 times daily, depending on the FWI [39], and supporting satellite monitoring have traditionally ensured that rescue services receive alarms on time and suppress wildfires before they spread into large-scale fires.

The Regional State Administrative Agency (AVI) for northern Finland oversees organizing effective aerial forest fire surveillance nationwide in Finland. Surveillance services are usually provided by a local aviation club or aviation industry company. In Sweden they have a decentralized model: each County Administrative Board (Länsstyrelsen) decides whether to run patrols and applies for state co-funding from the MSB (Swedish Civil Contingencies Agency). In Finland patrols run April–September on the 22 predefined routes. Flights are launch risk-based: a typical operational threshold is when the Finnish fire weather index exceeds level 4. In Sweden patrols are activated by counties during dry periods as stated in the MSB guidelines; local arrangements define exact frequency and daily numbers according to fire risk. In Finland flying routes are typically flown by local aero clubs or aviation firms under AVI contracts; patrol aircraft report smoke and can be tasked by rescue authorities to clarify uncertain smoke sightings. In Sweden flight routes are frequently flown by volunteer aviation organizations (e.g., Frivilliga Flygkåren, FFK; KSAK clubs) under county/MSB funding. Crews act as “eyes in the sky”, reporting directly to local rescue services (via SOS Alarm) as per county procedures. Finland has centralized funding (the Ministry of the Interior allocates funds to AVI), and the procurement covers flight hours over the national route network. In Sweden MSB grants are available to all counties which contract local providers. Finland is using light fixed-wing aircraft predominantly. Patrol flights can be also used for other reconnaissance (storm/flood/oil spills) and command-support orbits when requested by rescue services. Sweden also uses light fixed-wing patrol aircraft.

Finland’s single national organizer with fixed routes enables uniform coverage and clear national thresholds (e.g., index ≥ 4), which can translate to predictable patrol availability across regions. Sweden’s county-led approach allows flexible local scaling, but patrol intensity can vary by county budgets/choices; the MSB’s framework provides consistency; yet execution remains decentralized. Finland emphasizes systematic route coverage during the core season, which historically yields a steady stream of early detections. Sweden benefits from broad volunteer aviation networks that can surge flights when counties raise risk levels. Finland concentrates funding centrally and flies hundreds of sorties at moderate cost suggesting tight risk-based activation and cost discipline. Sweden spreads costs across counties with MSB co-funding. The readiness levels vary, but clubs commonly pre-contract daily sortie capacity by risk class, which strengthens availability during peak periods.

To summarize the experiences of the different systems and, due to the similar problems in the Nordic countries, to optimize the future possibilities of early fire detection, Finnish, Swedish, and Norwegian researchers launched a joint research project called FIREBAR—developing wildfire observation in the Barents region. The project’s results so far suggest that in the future, countries will develop closer cooperation for early fire detection, as a response to reducing the fire risks caused by climate change in northern areas. This could mean not only faster and wider sharing of available data and experience, but also joint cross-border aerial patrols [40].

Additionally, forest owners can improve the detection of wildfires with their continuous presence and local knowledge. Mutual trust between firefighter commanders and forest owners increases operational effectiveness [41].

3.2.3. Technological Innovations

Examining the possibilities of early fire detection is essential in order to increase the effectiveness of intervention. The effectiveness of suppressing wildfires clearly shows a close correlation with the quickness of the hot spot detection [42]. It is logical that faster detection means a smaller burnt area and a shorter front line, and vice versa, late fire detection means a larger burnt area and a longer front line.

There are several methods for early fire detection, such as ground patrols during high-risk periods or area monitoring by humans from suitable towers [43,44]. Fixed camera observation stations enable early fire detection at a central location using remote sensing [45]. Fire detection can be performed passively or actively; in the latter case, image processing algorithms that enable automatic fire detection can be run on the system. Networked systems can also provide the exact coordinates of the fire.

During periods of high wildfire risk, aerial patrols have been used for decades, and based on optimization analyses, some countries, for example Finland, still maintain them through voluntary flight associations, while others have discontinued them, citing high costs. During aerial patrols, a specialist on board an aircraft conducts continuous observation at a specific flight altitude, during which he can also provide precise characteristics of the fire upon detection. The system is flexible and effective from a professional perspective, but its costs limit its widespread use. One way to reduce costs is to use lighter aircraft with low operating costs. The question arises regarding whether UAVs, i.e., drones, could be suitable for replacing this task. The operating costs of drones are significantly lower than lighter aircraft [46]; so the possibility of reducing costs is clearly given. Two criteria must be met for drones to be as efficient as aircraft: comparable flight time and good-resolution onboard cameras. The first is a criterion that has already been solved by many drone manufacturers based on technical parameters, and the second criterion is also given, since there are many camera types to choose from on the market [47]. Due to the limited flight (hover) time of drones, the frequency of flights and the routes can be optimized based on the FWI.

Regardless of the method of aerial surveillance by using cameras, the patrol route can be divided into monitored and unmonitored sections at a given moment [48]. The efficiency of the aerial surveillance can be increased if the unobserved sections are smaller, or if a section is re-observed as soon as possible again [49]. In Finland the high coverage offered by 22 surveillance flight routes [39] makes it possible to detect fires efficiently across the country, reducing unobserved sections.

While the above suggestions are logical, the development of any system must be optimized for the characteristics of the given terrain and the level of the FWI. However, given Finland's expansive boreal forests and complex terrain, drones are now being trialed to either supplement these traditional aerial patrols or hover over high-risk zones identified via the FWI. Finnish rescue services, supported by their dense network of fire stations and aerial firefighting commanders trained to direct operations from the air, have recognized that UAVs boarding high-resolution cameras coupled with thermal imaging can provide real-time data, enabling quicker localization and assessment of wildfires, especially in remote or difficult-to-access areas [50,51].

In addition to quickly detecting a fire, drones can also assist responders during the intervention. The most basic practical experiences can be summarized as follows [52]:

To obtain the most important information about the fire during the reconnaissance, first responders must walk around the burning area, which is time-consuming. However, with the help of a drone, firefighters can see the entire area almost immediately after arriving at the front line and identify the most important parameters related to firefighting, thus facilitating the commander's decision making.

Following the reconnaissance phase, the drone operator can continue to gather critical information during the intervention stage through aerial surveillance. This includes data on fire intensity, the direction and rate of fire spread, and the type and condition of surrounding vegetation, as well as changes in these variables over time. Additionally, drones can assist in identifying areas at risk, wind direction and velocity, accessible routes, and potential locations of water sources. Ensuring the safety of response personnel is also a key concern, and drones contribute significantly by helping to identify escape routes, guiding ground-based firefighters, and preventing situations that may lead to entrapment.

Also, the post-extinguishment monitoring remains essential. Residual embers beneath layers of ash can be reignited by wind, posing a continued risk of fire. Drones equipped with thermal imaging cameras offer an effective means of detecting such hidden heat sources.

The experiences gained so far in both early fire detection and intervention will certainly be expanded with the results of future research. In both Finland and Sweden, ongoing research is underway on the use of drones in forest fires. Recent research in Finland focuses primarily on the use of drones in swarms [53], the potential application of thermal imaging cameras [54], and the support of fire prevention and firefighting activities with artificial intelligence [55], while the most recent feature of Swedish research is the collaboration in the development of a firefighting drone [56].

Nevertheless, the use of drones also has operational challenges. Legal regulations can hinder simple use, and in Europe, the Commission Delegated Regulations (EU) 2019/945 [57] and 2019/947 [58] provide a framework for this. This is not a problem for research, as these are pre-planned flights, but in practice it can be a hindrance for immediate applications. For example, in the case of the open operations category, the maximum flight altitude cannot exceed 120 m. Even if the aerial reconnaissance can be very helpful from this altitude, our own experience shows that we often need 2–3 times this height.

A technical obstacle may be the operating time of the batteries, which for a drone with average technical characteristics can mean a flight time of about 30 min. Fortunately, practice shows that much less flight time is sufficient for reconnaissance and information gathering; so this is usually not a problem during interventions. If a longer flight time is needed, the problem can be easily solved with a 3 min battery change.

Flights are also affected by weather conditions; in the case of drones, wind, visibility and precipitation can inflict flight limitations. Fortunately, we do not have to count on the latter two in the case of forest fires. The situation is also fundamentally favorable in terms of wind, as the drones can fly stably even in significant winds; so the assessment of the possibility of application is also favorable. Based on our analysis of meteorological data, the annual average proportion of periods with wind speeds exceeding 15 m/s in Finland and Sweden is below 5%. Notably, most contemporary drone platforms are capable of stable operation in wind conditions up to 20 m/s. Such elevated wind speeds are more commonly observed during winter and early spring, seasons during which forest fires are relatively uncommon. In terms of meteorological considerations, it is also important to note that drones are capable of operating at night under appropriate conditions. Nighttime operations often provide enhanced thermal contrast, allowing a more precise identification of certain fire characteristics compared to daytime.

A factor that complicates the use of drones may be their joint use with traditional aircraft. The joint use requires careful cooperation, although it is not certain that this is necessary. The primary task of drones, observation and information gathering, can be practically solved by using traditional aircraft, which makes joint use unnecessary. Experience shows that drones can unfortunately sometimes cause accidents, or a flight ban may be imposed to avoid this [59].

3.3. Case Study of the 2018 Wildfire Season in Sweden and Finland

During the summer of 2018, when Sweden was facing the megafires, burning down 25,000 hectares of forest, wildfires also became an important topic in public discussions in Finland [10,14]. The summer of 2018 was extremely demanding for rescue services in Finland from the perspective of wildfires. Over the course of the year, more than 4000 wildfires broke out across the country. These fires burned approximately 1200 hectares of forest and nearly 400 hectares of other terrain [12].

Despite experiencing similar climatic conditions in 2018, Sweden and Finland showed remarkably different outcomes in terms of fire severity and burned area. However, the average size of wildfires in Finland during the summer of 2018 remained under one hectare, and over 80% of all fires covered an area of less than half a hectare [12].

Figure 1 represents the monthly MSR indices from May to September 2018, as well as the estimated SSR for the entire May to September period [14,15]. The summer of 2018, in terms of weather conditions, was exceptionally warm and, in many areas, extremely dry [14,15].

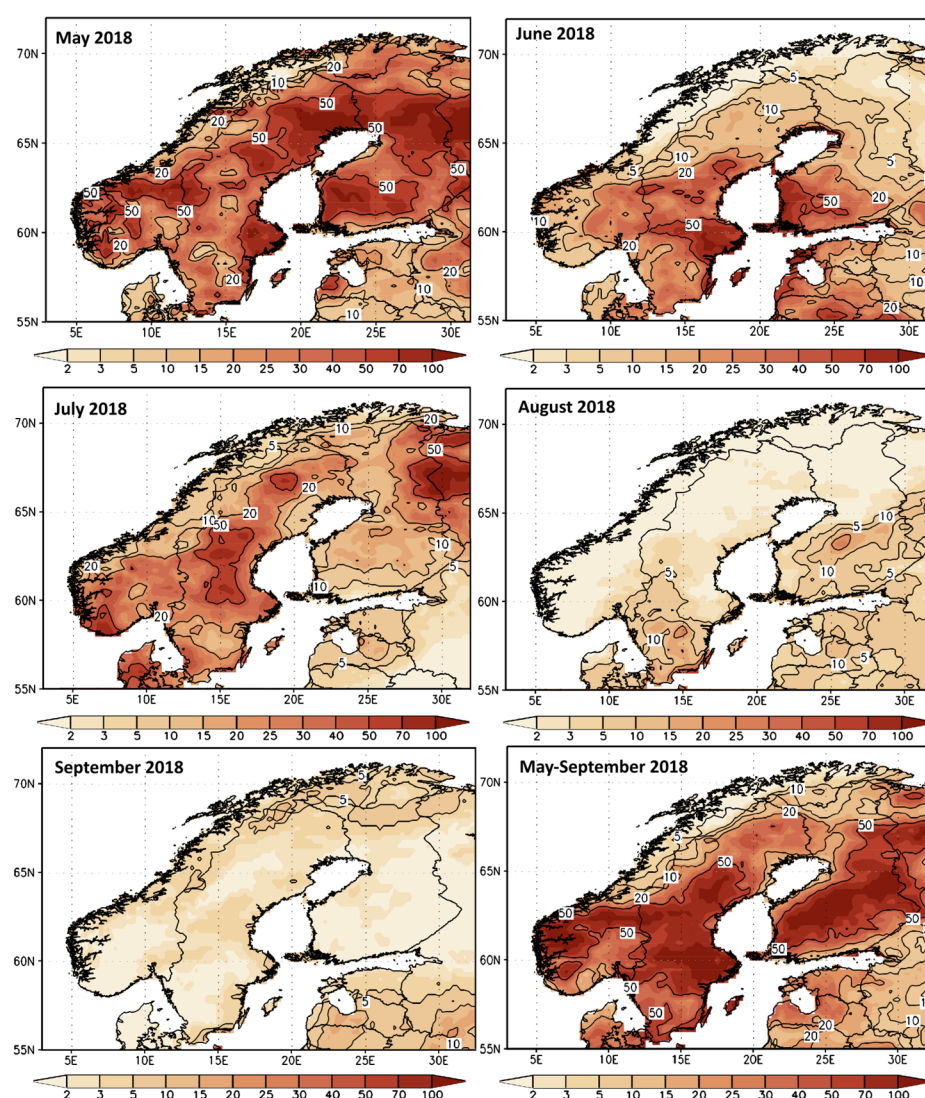


Figure 1. Fire weather conditions in Sweden and Finland—MSR (from May to September) and SSR (whole season) indices recurrence period (yearly) [14,15].

June 2018 was characterized by exceptionally high temperatures and low precipitation across Northern Europe, creating conditions conducive to wildfires. In Sweden, temperatures frequently exceeded 30 °C, even in northern regions near the Arctic Circle. For

instance, Kvikkjokk recorded temperatures above 32 °C. Similarly, in Finland, Helsinki experienced temperatures reaching 30 °C, significantly higher than average for that time of year. The prolonged heat wave led to severe drought conditions, with some areas in Sweden not receiving significant rainfall since 11 May 2018. This lack of precipitation resulted in extremely dry vegetation, providing ample fuel for wildfires [14,15].

The wildfires that happened in Sweden and Finland in the summer of 2018 were the result of a confluence of extreme weather conditions, including record-breaking temperatures and prolonged drought. The ERCC daily map from 19 July 2018 (Figure 2) provides a comprehensive overview of the wildfire situation in Northern Europe and underscores the severity and geographic spread of the wildfires. The FWI from that period highlights the elevated risk levels. These events serve as clear evidence of the increasing impact of climate change on wildfire frequency and intensity in Northern Europe. In Sweden, over 40 significant fires were burning, with at least 11 located within the Arctic Circle. The map also indicated elevated fire risks in Finland, although the situation, especially in terms of the size of the fires, was less severe compared to Sweden. Nevertheless, the prevailing weather conditions posed significant concerns for potential fire outbreaks in Finnish forests. It can be noted from Figure 2 that the forecast of the situation indicates rapid and dramatic change in the forest fire situation in the southern part of Finland, whereas the situation worsens in Sweden in only two days (20–21 July).

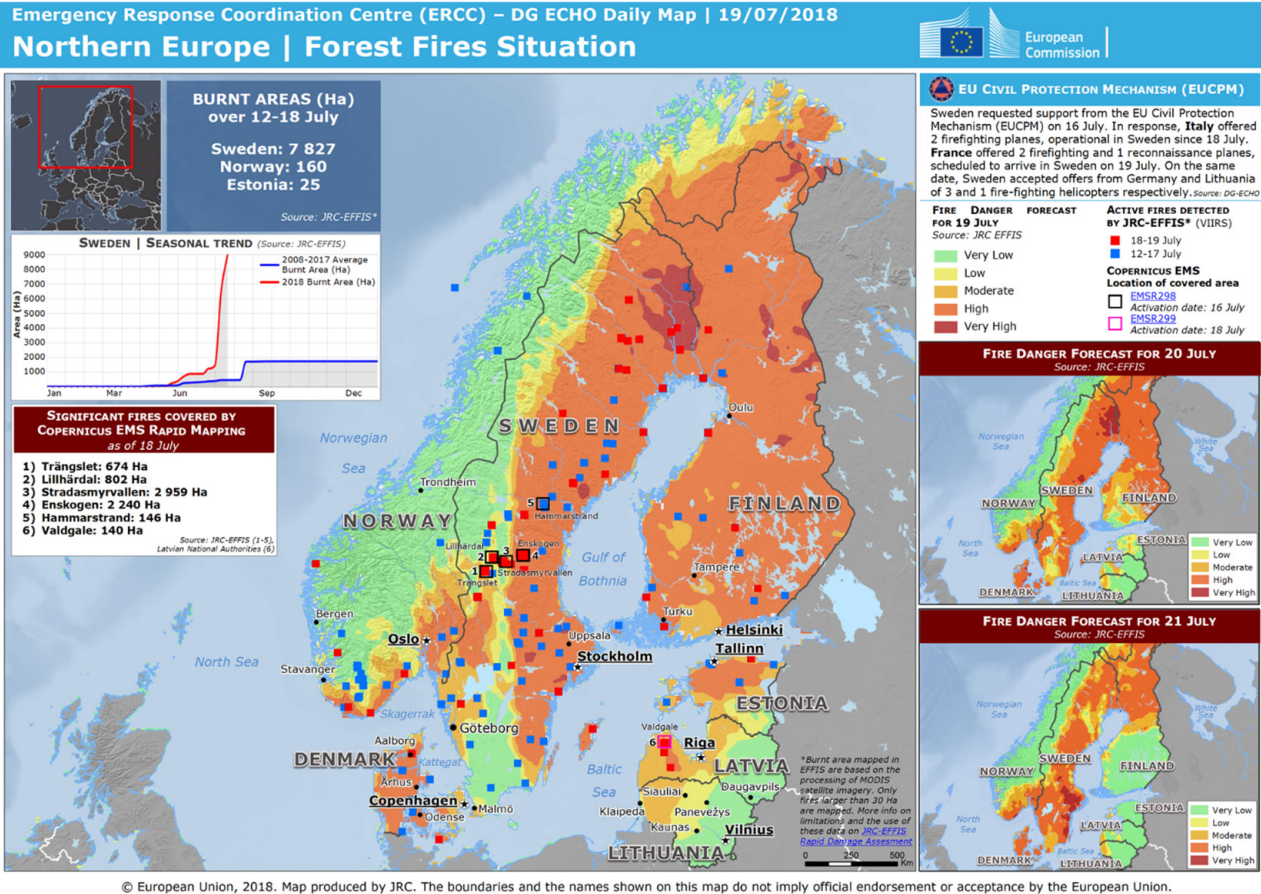


Figure 2. ERCC daily map 19.7.2018, Northern Europe forest fire situation [16].

Table 1 summarizes the similarities and differences of the forest fire situation of 2018 and the fire management arrangements in Sweden and Finland.

Table 1. Comparative analysis of disaster management and wildfire management systems in Sweden and Finland.

Category	Sweden	Finland
Average Annual Wildfires	~5000 wildfires, ~3600 ha burned annually	~959 ha burned annually
Largest Wildfire (2018)	21,605 ha burned; 74 fires > 30 ha	Largest fire: 80 ha
Most Severe Year	2018, with record-breaking fires and extensive damage	2006, with driest summer in over 100 years; 2018 also challenging
Response Challenges	Long response times in remote areas, resource constraints, centralization issues	Quick response from local volunteer fire brigades, but rural depopulation poses challenges
Primary Wildfire Causes	Lightning, forestry machinery, insufficient clearance; also burning near residences, children, camping	High wind increased spread; ~ ¹ / ₃ of fires due to non-compliance with open fire bans
Fire Suppression Methods	Aerial firefighting assets, prepositioning of equipment	Dense forest road network and aerial surveillance; quick suppression by local volunteer fire brigades
Forest Management	Clear-felling of 70–80% of forested areas, but less compartmentalization	Even-structured forestry with dense forest road network, compartmentalized areas
Host Nation Support (HNS)	Good HNS arrangements, cooperation, and capacity (2018 operation largest in UCPM)	Good HNS arrangements but still developing; new legislation (2024) to enhance coordination
Volunteer Fire Brigades	Declining in rural areas, weakening suppression capabilities	Strong network, but future viability threatened by urbanization
Fire Weather Monitoring	Real-time, satellite-based wildfire detection system, high forest fire indices, but slow response in remote areas	FMI uses grid-based FWI system, MSR and SSR indices, plus aerial and satellite monitoring
Legislation	No specific legal wildfire warning obligations	Legal obligation (since 1975) for FMI to issue wildfire warnings
Emergency Response Culture	Firefighters stay back due to safety regulations	Firefighters engage directly in forest firefighting
Adaptation to Climate Change	Predicted higher fire risks in central/southern Sweden, longer fire seasons	Predicted higher fire risks in central/northern Finland; longer fire seasons
Technology and Innovations	Largest EU aerial firefighting operation in 2018, new aerial firefighting concept	Exploring UAVs, forestry machinery for suppression, artificial intelligence (AI) for fire prediction
International Assistance	Extensive in 2018 (UCPM, Nordred, bilateral)	Planning domestic HNS arrangements; aims for self-sufficiency with international backup

4. Discussion

The research supports previous information suggesting that forestry management practices have had a positive impact on wildfire prevention in Finland. The number of forest roads in Finland, compartmentalized forest management, cooperation between different parties, and monitoring help prevent the spread of fires. Successful fire prevention requires efficient information flow and the transfer of research knowledge into practice.

4.1. Climate Change Implications

Climate change is affecting environmental and socio-political landscapes globally and Northern Europe is no exception. In future, Finland and Sweden will be increasingly vulnerable to climate-driven wildfires. Warming climate and thus warmer temperatures have extended the wildfire season. Both countries experience more extreme weather phenomena like earlier snowmelt, prolonged heat waves, and heavy thunderstorms, which increase fire risk in countries.

The subtle but significant climate and terrain differences between Finland and Sweden result in different wildfire suppression strategies. Finland's slightly wetter climate, characterized by higher humidity, abundant wetlands, and peat-dominated soils, tends to limit fire spread and allows suppression through early local intervention, especially by volunteer fire brigades. Fires are often smaller and slower-growing, and suppression strategies rely on natural landscape features such as lakes and swamps to compartmentalize fire movement [28]. However, the presence of deep organic peat layers means that, once ignited under drought, these fires require prolonged and specialized suppression efforts, including soil saturation with water [31]. By contrast, Sweden's boreal forests, particularly in central and southern regions, experience more frequent summer droughts and lower relative humidity, contributing to rapid fire escalation, especially in pine-dominated stands and clear-cut areas [32]. In response, Sweden has prioritized the development of national aerial suppression assets, including AT-802 Fire Boss scoopers and helicopter capacity, which are rapidly deployed to contain fast-moving fires in terrain with limited natural barriers (MSB, 2021). Furthermore, Sweden's suppression strategy includes mechanical fire line construction, pre-planned access routes, and portable water supply systems, which are less commonly employed in Finland due to its moister soil conditions and relatively shorter suppression distances. As both countries face increasing fire risk driven by warming, drought, and changes in land use, integrating terrain-based risk analysis, climatic modeling, and operational best practices will be essential. Sweden's airborne suppression model, for instance, may offer insights for Finland as fire seasons lengthen. Conversely, Finland's risk-based patrol and early suppression efficiency provides a valuable model for rural firefighting effectiveness in fragmented territories.

Climate models suggest that Northern Europe, where both Sweden and Finland are located, is on a path toward higher wildfire risk over the coming decades. Estimates from the Intergovernmental Panel on Climate Change (IPCC) indicate that Northern Europe is expected to become a high-risk zone by 2040 [60]. Based on different model simulations [61,62], a lengthening of the fire season, with earlier starts and later ends, and an increase in the number of fires and the burnt area is expected until the end of the century. Also, increased fire danger due to drier—and thus more flammable—fuels is expected.

Areas in central and northern Finland, historically too cold and wet for significant fires, may face increased risk due to permafrost melting and disappearance and vegetation changes. While Finland is more extensively affected by permafrost-related landscapes, such as swamps and peat plateaus, emerging wildfire risks linked to permafrost melt are relevant for both Finland and Sweden. In Finland, degrading permafrost in northern peatlands may increase surface dryness and fuel availability, creating conditions for deep-burning,

long-duration fires that are difficult to suppress. In Sweden, although permafrost is more limited to alpine areas, similar risks arise in organic soils and upland peat zones that are experiencing earlier snowmelt, reduced soil moisture, and vegetation shifts toward more flammable species [63]. Climate projections for both countries indicate increased fire danger in central and northern inland regions by mid-century, particularly under prolonged drought and warming scenarios [29]. Adaptive strategies must include enhanced monitoring of peat-rich areas, early detection and remote sensing, and improved integration of permafrost and hydrological data into fire risk modeling.

4.2. Response Operations and Challenges

In the exceptionally hot and dry summer of 2018, both Finland and Sweden faced severe wildfire challenges, though the scale and operational demands differed greatly. Finland's wildfires were mostly due to high temperatures and occasional rainfall, while its mosaic of lakes, wetlands, and effective early fire detection systems, including aerial surveillance, helped contain outbreaks. Rural firefighting relied on volunteer brigades, local water sources, and forest harvesting roads for access.

Sweden, however, experienced catastrophic conditions, with around 25,000 hectares burned in numerous large-scale fires driven by prolonged drought and record temperatures. The continuity of flammable pine and spruce forests, combined with limited early detection and forest road infrastructure, compounded the crisis.

Moreover, the culture of wildfire fighting is different; in Finland, firefighters go into the forest to extinguish the fire, whereas in Sweden, they stay farther away due to the occupational safety regulations.

During the summer wildfires, Sweden's national response capacity was exceeded, prompting the activation of the EU Civil Protection Mechanism as a preventive measure and initiating contact with the ERCC. The response effort encountered significant logistical and HNS challenges. According to feedback from the ERCC, the organizational structure of the MSB during the crisis appeared somewhat fragmented, particularly with respect to the division of operational leadership between Stockholm and Karlstad [10]. A more centralized command structure—ideally located in a single operational hub—could have enhanced situational awareness and improved the efficiency of information management and decision-making processes.

Furthermore, Sweden lacked a formal reception center for incoming international assistance, although liaison officers were appointed directly and the international support received was reported to be both effective and well-received. Another critical issue was the high staff turnover within the MSB throughout the crisis, which posed a significant risk to information continuity and institutional memory. On the other hand, Finland managed its wildfires within national resources.

These contrasting experiences underscored the crucial role of early detection, rural firefighting capacity, and forest road networks in wildfire resilience.

4.3. Best Practices and Lessons Learned

There is a lack of wildfire suppression experience and specialization, and lessons learnt from other countries, such as Portugal, Spain, France, etc., should be a continuous process. For example, study trips and exchange of experts are good ways to learn from other countries' experiences.

The potential for firefighter fatigue during suppression activities was also seen as a risk, and the methods, tactics, personal protective equipment, and firefighting equipment need to be enhanced.

The national coordination of resources was seen as a problem in large overlapping situations affecting several regions. Resource allocation according to the situational picture to the right places in the country is something that needs adequate situational awareness. New command and coordination arrangements in Finland will be one of the solutions for that.

5. Conclusions

The future of volunteer fire brigades is important for better wildfire management, as they were seen to be at risk in sparsely populated areas, with rural Finland experiencing an accelerating population decline. Ensuring the functioning of volunteer fire brigades also supports continuity management, meaning the continued operational and material capability in long-term and large-scale tasks, thereby improving Finland's resilience.

The large wildfires that raged in Sweden in 2014 and several simultaneous large fires in 2018 are also possible in Finland. Due to climate change, the likelihood of conditions favorable for wildfires has increased. Attention must be given to weather forecasting and the assessment of fire weather conditions. It is also important to invest in the effective suppression of wildfires in the early stages, to prevent them from developing into large-scale fires.

The use of new technologies, such as UAV detection and operations, as well as alternative firefighting methods, such as using forestry harvesting machinery designed for firefighting, should be actively and widely adopted. Research into the effectiveness of these methods should also be increased.

The command centers' operational, situational, and analytical capacity play a significant role in large-scale wildfires. Learning from international examples, such as Spain's Forest Fires Advisory and Assessment Team (FAST) [64], could also be beneficial. Moreover, using artificial intelligence (AI) to predict and analyze the spread of wildfires would add value for the fire service leadership.

National coordination, including aerial firefighting operations, needs to be further developed in Finland. Domestic HNS arrangements should be planned, and uniform operational procedures should be established across the country.

If the volunteer fire brigade model cannot be maintained in sparsely populated areas, alternative models and tactics should be considered. The Portuguese model of aerial wildfire fighting teams as part of the initial response is one tactic worth exploring, and the early use of aerial firefighting equipment, even in smaller wildfire situations, especially in sparsely populated areas, is something to consider.

Wildfire situations can be long-lasting, as the 2018 situation in Sweden demonstrated. In wildfires, which last days or even weeks, continuity of management functions becomes particularly important. Wildfire management continuity plans should include both functional (personnel) and material (equipment and supplies) aspects, and they should also apply to all levels of the organization, from national leadership to firefighting operations in the field.

The comparison between two similar boreal countries, such as Sweden and Finland, provides valuable insights into forest fire management in sparsely populated and heavily forested regions. Many predominantly rural countries around the world are currently experiencing rapid urbanization and rural depopulation, conditions that mirror the demographic and land use patterns found in parts of Sweden and Finland. The strategies these countries have developed to manage forest fire risks under such conditions or adapting governance to low-density contexts could enhance fire prevention and mitigation efforts in other rural regions globally, including in Eastern Europe, parts of South America, or Central Asia.

Author Contributions: Conceptualization, P.T. and Z.T.; methodology, Z.T.; formal analysis, P.T. and H.-I.S.; investigation, P.T., Z.T., H.-I.S., and Á.R.; writing—P.T., Z.T., H.-I.S., and Á.R.; writing—review and editing, P.T., Z.T., and A.O.; visualization, Z.T.; supervision, A.O.; project administration, A.O.

and Z.T.; funding acquisition A.O. and Z.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

AI	Artificial Intelligence
AVI	Regional State Administrative Agency
EFFIS	European Forest Fire Information System
ERCC	Emergency Response Coordination Centre
FAST	Forest Fires Advisory and Assessment Team
FFI	Forest Fire Index
FMI	Finnish Meteorological Institute
FTS	Fire-smart territories
FWI	Forest Fire Weather Index
GFFF-V	Ground Forest Firefighting using Vehicles
HNS	Host Nation Support
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
MSB	Swedish Civil Contingencies Agency
MSR	Monthly Severity Rating
SSR	Seasonal Severity Rating
UAV	Unmanned Aerial Vehicle
UCPM	Union Civil Protection Mechanism

References

1. United Nations Environment Programme. *Spreading Like Wildfire: The Rising Threat of Extraordinary Landscape Fires*; A UNEP Rapid Response Assessment; United Nations Environment Programme: Nairobi, Kenya, 2022; p. 26. Available online: <https://www.unep.org/resources/report/spreading-wildfire-rising-threat-extraordinary-landscape-fires> (accessed on 3 July 2025).
2. Fernandez-Anez, N.; Krasovskiy, A.; Müller, M.; Vacik, H.; Baetens, J.; Hukić, E.; Solomun, M.K.; Atanassova, I.; Glushkova, M.; Bogunović, I.; et al. Current wildland fire patterns and challenges in Europe: A synthesis of national perspectives. *Air Soil Water Res.* **2021**, *14*, 1–19. [\[CrossRef\]](#)
3. El Garroussi, S.; Di Giuseppe, F.; Barnard, C.; Wetterhall, F. Europe faces up to tenfold increase in extreme fires in a warming climate. *npj Clim. Atmos. Sci.* **2024**, *7*, 30. [\[CrossRef\]](#)
4. Jacome Felix Oom, D.; De Rigo, D.; Pfeiffer, H.; Branco, A.; Ferrari, D.; Grecchi, R.; Artes Vivancos, T.; Durrant, T.; Boca, R.; Maianti, P.; et al. *Pan-European Wildfire Risk Assessment*; EUR 31160 EN; JRC130136; Publications Office of the European Union: Luxembourg, 2022; ISBN 978-92-76-55137-9. [\[CrossRef\]](#)
5. European Forest Fire Information System (EFFIS). Available online: <https://forest-fire.emergency.copernicus.eu/applications/data-and-services> (accessed on 3 July 2025).
6. Sousa-Silva, R.; Verbist, B.; Lomba, Â.; Valent, P.; Suškevičs, M.; Picard, O.; Hoogstra-Klein, M.A.; Cosofret, V.-C.; Bouriaud, L.; Ponette, Q.; et al. Adapting forest management to climate change in Europe: Linking perceptions to adaptive responses. *For. Policy Econ.* **2018**, *90*, 22–30. [\[CrossRef\]](#)
7. Ascoli, D.; Plana, E.; Oggioni, S.D.; Tomao, A.; Colonico, M.; Corona, P.; Giannino, F.; Moreno, M.; Xanthopoulos, G.; Kaoukis, K.; et al. Fire-smart solutions for sustainable wildfire risk prevention: Bottom-up initiatives meet top-down policies under EU green deal. *Int. J. Disaster Risk Reduct.* **2023**, *92*, 103715. [\[CrossRef\]](#)
8. Kalapodis, N.; Sakkas, G. Integrated Fire Management and Closer to Nature Forest Management at the Landscape Scale as a Holistic Approach to Foster Forest Resilience to Wildfires. *Open Res. Eur.* **2025**, *4*, 131. [\[CrossRef\]](#)
9. Neidermeier, A.N.; Zagaria, C.; Pampanoni, V.; West, T.A.P.; Verburg, P.H. Mapping opportunities for the use of land management strategies to address fire risk in Europe. *J. Environ. Manag.* **2023**, *346*, 118941. [\[CrossRef\]](#)

10. Statens Offentliga Utredningar, Skogsbränderna Sommaren 2018—Betänkande av 2018 års Skogsbrandsutredning; SOU 2019:7; (In English: The Forest Fires of Summer 2018—Report of the 2018 Forest Fire Inquiry). Available online: <https://www.regeringen.se/contentassets/8a43cbc3286c4eb39be8b347ce78da16/skogsbranderna-sommaren-2018-sou-2019-7.pdf> (accessed on 3 July 2025).
11. Sjöström, J.; Granström, A. Human activity and demographics drive the fire regime in a highly developed European boreal region. *Fire Saf. J.* **2023**, *136*, 103743. [CrossRef]
12. Ketola, J. Hevonkuusessa Palaa Isosti—Tilastollinen Selvitys Kesän 2018 Metsäpalojen Leviämisestä. (In English: A Big Fire in the Middle of Nowhere—Statistical Report on the Spread of Forest Fires in the Summer of 2018). Pelastusopisto: Kuopio, Finland, 2018; ISBN 978-952-7217-16-0. Available online: http://info.smedu.fi/kirjasto/Sarja_D/D6_2018.pdf (accessed on 3 July 2025).
13. Finlex. The Rescue Act 379/2011. *Statute Book of Finland*; Finlex: Finland, 2011. Available online: https://finlex.fi/en/legislation/collection/2011/379?language=fin#OT2_OT8 (accessed on 3 July 2025).
14. Lehtonen, I.; Venäläinen, A. Metsäpaloakesä 2018 Muuttuvassa Ilmastossa—Poikkeuksellinen Vuosi Vai Uusi Normaali? (In English: Forest fire season 2018 in a changing climate—An exceptional year or new normal?). In *Finnish Meteorological Institute Reports*; STAKES: Helsinki, Finland, 2020; Volume 2, ISBN 978-952-336-108-9. [CrossRef]
15. Lehtonen, I.; Venäläinen, A. The exceptional Nordic forest fire season 2018 in the context of climate change. *FMI's Clim. Bull. Res. Lett.* **2021**, *1*, 8–10. [CrossRef]
16. Emergency Response Coordination Centre—ERCC. Available online: <https://erccportal.jrc.ec.europa.eu/ECHO-Products/Maps#> (accessed on 3 July 2025).
17. Finnish Government Decree 1110/2023—Valtioneuvoston Asetus Pelastustoimen Kansainvälisen Avun Vastaanottamisen Eriyisvalmiuden Kokoamisesta (In English: Government Decree on the Compilation of Special Preparedness for the Reception of International Assistance of Rescue Services). Available online: <https://finlex.fi/fi/lainsaadanto/2023/1110> (accessed on 3 July 2025).
18. European Commission. Commission Recommendation on EU Host Nation Support Guidelines 2024. Available online: <https://civil-protection-knowledge-network.europa.eu/media/commission-recommendation-eu-host-nation-support-guidelines-29112024> (accessed on 3 July 2025).
19. Joint Research Centre. JRC Technical Report—Forest Fires in Europe, Middle East and North Africa 2018. Available online: <https://publications.jrc.ec.europa.eu/repository/handle/JRC117883> (accessed on 3 July 2025).
20. Thiffault, E. Chapter 5—Boreal forests and soils. In *Developments in Soil Science*; Busse, M., Giardina, C.P., Morris, D.M., Page-Dumroese, D.S., Eds.; Elsevier: Amsterdam, The Netherlands, 2019; Volume 36, pp. 59–82, ISBN 9780444639981. [CrossRef]
21. Högberg, P.; Ceder, L.A.; Astrup, R.; Binkley, D.; Dalsgaard, L.; Egnell, G.; Filipchuk, A.; Genet, H.; Ilintsev, A.; Kurz, W.A.; et al. *Sustainable Boreal Forest Management Challenges and Opportunities for Climate Change Mitigation*; Swedish Forest Agency Report; Springer: Berlin/Heidelberg, Germany, 2021. Available online: <https://pure.iiasa.ac.at/id/eprint/17778/> (accessed on 3 July 2025).
22. Tijerín-Triviño, J.; Moreno-Fernández, D.; Zavala, M.A.; Astigarraga, J.; García, M. Identifying Forest Structural Types along an Aridity Gradient in Peninsular Spain: Integrating Low-Density LiDAR, Forest Inventory, and Aridity Index. *Remote Sens.* **2022**, *14*, 235. [CrossRef]
23. Ruuska, R. Suomen Maasto-ja Metsäpalojen Torjuntajärjestelmän Kehittäminen: Case Vertailu Suomen ja Ruotsin Järjestelmistä (In English: Development of Finland's Terrain and Forest Fire Prevention System: Case Comparison of Finnish and Swedish Systems). Master's Thesis, Lappeenranta University of Technology, Lapuanla, Finland, 2020. Available online: <https://lutpub.lut.fi/handle/10024/161949?show=full> (accessed on 3 July 2025).
24. Pronto—Rescue Services' Resource and Accident Statistics System. Finland. Available online: <https://prontonet.fi/> (accessed on 3 July 2025).
25. Kvarnlöf, L.; Eriksson, K. Filling the void: Rural disaster volunteerism during the Swedish wildfires of 2018. *Int. J. Disaster Risk Reduct.* **2024**, *105*, 104393. [CrossRef]
26. Lindberg, H. Fire Scars, Ground Vegetation Fuels, and Prescribed Burning: Towards Better Fire Management in Fennoscandia; Dissertationes Forestales. Ph.D. Thesis, University of Helsinki, Faculty of Agriculture and Forestry, Department of Forest Sciences, Helsinki, Finland, 2021. [CrossRef]
27. Aakala, T.; Storaunet, K.O.; Jonsson, B.G.; Korhonen, K.T. Drivers of snag fall rates in Fennoscandian boreal forests. *J. Appl. Ecol.* **2024**, *61*, 2392–2404. [CrossRef]
28. Lehtonen, I.; Aalto, J.; Peltonen-Sainio, P. *Climate Change in Finland—Recent Trends and Future Projections*; Publications of the Finnish Meteorological Institute: Helsinki, Finland, 2020; Volume 2020, p. 2.
29. Kilpeläinen, A.; Kellomäki, S.; Strandman, H.; Venäläinen, A. Climate change impacts on forest fire potential in boreal conditions in Finland. *Clim. Change* **2010**, *103*, 383–398. [CrossRef]
30. Fernandes, P.M. Fire-smart management of forest landscapes in the Mediterranean basin under global change. *Landsc. Urban Plan.* **2013**, *110*, 175–182. [CrossRef]
31. de Groot, W.J.; Cantin, A.S.; Flannigan, M.D.; Soja, A.J.; Gowman, L.M.; Newbery, A. A comparison of Canadian and Russian boreal forest fire regimes. *For. Ecol. Manag.* **2013**, *294*, 23–34. [CrossRef]

32. Sjöström, J.; Granström, A. Large fires in Swedish forests: Patterns and risks. In *Fire and Climate Change in the Boreal Zone*; Springer: Berlin/Heidelberg, Germany, 2020; pp. 17–34.
33. Granström, A.; Schimmel, J. Heat effects on seed germination of two conifers and some boreal forest floor species. *Can. J. For. Res.* **1993**, *23*, 919–926.
34. Zackrisson, O. Influence of forest fires on the north Swedish boreal forest. *Oikos* **1977**, *29*, 22–32. [[CrossRef](#)]
35. Niklasson, M.; Granström, A. Numbers and sizes of fires: Long-term spatially explicit fire history in a Swedish boreal landscape. *Ecology* **2000**, *81*, 1484–1499. [[CrossRef](#)]
36. Government of Canada, Natural Resources Canada. Canadian Forest Fire Weather Index (FWI) System. Available online: <https://cwfis.cfs.nrcan.gc.ca/background/summary/fwi> (accessed on 3 July 2025).
37. Vajda, A.; Venäläinen, A.; Suomi, I.; Junila, P.; Mäkelä, H. Assessment of forest fire danger in a boreal forest environment: Description and evaluation of the operational system applied in Finland. *Meteorol. Appl.* **2014**, *21*, 879–887. [[CrossRef](#)]
38. Finnish Meteorological Institute, FMI. The Wildfire Index. Available online: <https://en.ilmatieteenlaitos.fi/wildfire-index> (accessed on 3 July 2025).
39. Regional State Administrative Agency for Northern Finland, Statistics Finland 2022. Available online: <https://avi.fi/en/services/individuals/guidance-and-advice/aerial-forest-fire-surveillance> (accessed on 3 July 2025).
40. Ristikangas, V.; Kuurne, L.; Rinne, A.; Kinnunen, S. *FIREBAR—Developing Wildfire Observation in the Barents Region*; Project Report; The Finnish National Rescue Association SPEK: Helsinki, Finland, 2024; ISBN 978-951-797-739-5.
41. Björckman, F.; Nilsson, B.; Elmquist, C.; Fridlund, B.; Blom, Å.R.; Svensson, A. Fire and Rescue Services’ Interaction with Private Forest Owners During Forest Fires in Sweden: The Incident Commanders’ Perspective. *Fire* **2024**, *7*, 425. [[CrossRef](#)]
42. Restás, Á. Drone Applications for Supporting Disaster Management. *World J. Eng. Technol.* **2015**, *3*, 316–321. [[CrossRef](#)]
43. Chandrasekharan, R.; Ashiq, M.I.; Prakash, V. Forest Fire Detection using temperature Sensors Powered by Tree and Auto Alarming using GSM. *Int. J. Res. Sci. Innov.* **2015**, *2*, 23–28. Available online: <https://rsisinternational.org/Issue12/23-28.pdf> (accessed on 3 July 2025).
44. Momeni, M.; Soleimani, H.; Shahparvari, S.; Afshar-Nadjafi, B. Coordinated routing system for fire detection by patrolling trucks with drones. *Int. J. Disaster Risk Reduct.* **2022**, *73*, 102859. [[CrossRef](#)]
45. Heyns, A.; du Plessis, W.; Kosch, M.; Hough, G. Optimisation of tower site locations for camera-based wildfire detection systems. *Int. J. Wildland Fire* **2019**, *28*, 651–665. [[CrossRef](#)]
46. McGarey, P.; Srikanth, S. Autokite Experimental Use of a Low Cost Autonomous Kite Plane for Aerial Photography and Reconnaissance. In Proceedings of the 2013 International Conference on Unmanned Aircraft Systems (ICUAS) 2013, Atlanta, GA, USA, 28–31 May 2013. [[CrossRef](#)]
47. Averin, D.; Borovytsky, V.; Mykytenko, V. Drone Positioning Systems that Use Digital Cameras. *Bull. Kyiv Polytech. Inst. Ser. Instrum. Mak.* **2022**, *63*, 20–25. [[CrossRef](#)]
48. Restás, Á. Analysis of the effectiveness of fire detection systems in different dimensions. In *Advances in Forest Fire Research*; Viegas, D.X., Ed.; ADAI: Coimbra, Portugal, 2014; pp. 1319–1328. [[CrossRef](#)]
49. Bodnár, L.; Restás, Á.; Xu, Q. Conceptual Approach of Measuring the Professional and Economic Effectiveness of Drone Applications Supporting Forest fire Management. *Procedia Eng.* **2018**, *211*, 8–17. [[CrossRef](#)]
50. Saffre, F.; Hildmann, H.; Karvonen, H.; Lind, T. Monitoring and Cordoning Wildfires with an Autonomous Swarm of Unmanned Aerial Vehicles. *Drones* **2022**, *6*, 301. [[CrossRef](#)]
51. National Land Survey of Finland. Drones and AI Can Help Suppress Wildfires in the Future, FireMan Research Project. Available online: https://www.maanmittauslaitos.fi/en/topical_issues/drones-and-ai-can-help-suppress-wildfires-future (accessed on 3 July 2025).
52. Restás, Á. The Regulation Unmanned Aerial Vehicle of the Szendro Fire Department Supporting Fighting Against Forest Fires 1st of the World. *For. Ecol. Manag.* **2006**, *234*, S233. [[CrossRef](#)]
53. Karjalainen, T. Research Promises Revolutionary Technology for Preventing Forest Fires—A Flock of Drones Can Chase Aerial Patrolling off the Map, Forest News, 2022. Available online: <https://forest.fi/article/research-promises-revolutionary-technology-for-preventing-forest-fires-a-flock-of-drones-can-chase-aerial-patrolling-off-the-map/> (accessed on 3 July 2025).
54. Kularatne, S.D.M.W.; Casado, C.Á.; Rajala, J.; Hänninen, T.; López, M.B.; Nguyen, L. FireMan-UAV-RGBT: A Novel UAV-Based RGB-Thermal Video Dataset for the Detection of Wildfires in the Finnish Forests. In Proceedings of the 2024 IEEE 29th International Conference on Emerging Technologies and Factory Automation (ETFA), Padova, Italy, 10–13 September 2024. [[CrossRef](#)]
55. Takkinen, S. Autonomous Drones May Join Finland’s Forest Fire Fight; Report, YLE News Technology. 2024. Available online: <https://yle.fi/a/74-20112912> (accessed on 3 July 2025).
56. Ryan, D. *Firefighting Drones Could Change the Way B.C. Fights Wildfires, Especially During the Night*; Report; VancouverSun: Vancouver, BC, Canada, 2025. Available online: <https://vancouversun.com/news/firefighting-drones-gamechanger-bc-wildfires> (accessed on 3 July 2025).

57. Commission Delegated Regulation. Commission Delegated Regulation (EU) 2019/945 of 12 March 2019 on Unmanned Aircraft Systems and on Third-Country Operators of Unmanned Aircraft Systems. Available online: <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R0945> (accessed on 3 July 2025).
58. Commission Implementing Regulation. Commission Implementing Regulation (EU) 2019/947 of 24 May 2019 on the Rules and Procedures for the Operation of Unmanned aircraft. Available online: <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R0947> (accessed on 3 July 2025).
59. Muntean, P.; McCleary, K.; Legge, J. Canadian ‘Super Scooper’ Plane Grounded After Hitting Civilian Drone Over Los Angeles Wildfires, CNN News, Report. 2025. Available online: <https://edition.cnn.com/2025/01/10/us/super-scooper-drone-collision-la-fire-canada-hnk-intl> (accessed on 3 July 2025).
60. Bednar-Friedl, B.; Biesbroek, R.; Schmidt, D.N.; Alexander, P.; Børsheim, K.Y.; Carnicer, J.; Georgopoulou, E.; Haasnoot, M.; Le Cozannet, G.; Lionello, P.; et al. Europe. In *Climate Change 2022: Impacts, Adaptation and Vulnerability*; Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change; Pörtner, H.-O., Roberts, D.C., Tignor, M., Poloczanska, E.S., Mintenbeck, K., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., et al., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2022; p. 1839. [CrossRef]
61. Aakala, T.; Pasanen, L.; Helama, S.; Vakkari, V.; Drobyshev, I.; Seppä, H.; Kuuluvainen, T.; Stivrins, N.; Wallenius, T.; Vasander, H.; et al. Multiscale variation in drought controlled historical forest fire activity in the boreal forests of eastern Fennoscandia. *Ecol. Monogr.* **2018**, *88*, 74–91. [CrossRef]
62. Kinnunen, O.; Backman, L.; Aalto, J.; Aalto, T.; Markkanen, T. Projected changes in forest fire season, the number of fires, and burnt area in Fennoscandia by 2100. *Biogeosciences* **2024**, *21*, 4739–4763. [CrossRef]
63. Aalto, J.; Harrison, S.; Luoto, M. Statistical modelling predicts almost complete loss of major periglacial processes in Northern Europe by 2100. *Nat. Commun.* **2017**, *8*, 515. [CrossRef]
64. Hernández Paredes, E.; Iglesias Rodrigo, Á.; Rodero Merino, C. Forest Fires Assessment and Advisory Team of Spain. A Jointly Integrated Approach for Efficiency and Solidarity, Número Especial: 7a Conferência Internacional sobre Incêndios Florestais—Resumos. 2019. Available online: https://portal-miteco-stage.adobecqms.net/content/dam/miteco/es/biodiversidad/temas/incendios-forestales/11_doc11_presentacionfast_2019_tcm30-544304_tcm30-524546.pdf (accessed on 3 July 2025).

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.