


Report

Knowledge compilation on

Forest fires in the Nordic region





**Facilitating and accelerating Nordic learning
and collaboration on forest management
and fire prevention under changing climate conditions**

Foreword

■ In 2018 the Nordic countries witnessed their biggest-ever forest fires. The extreme weather conditions of the summer months led to a severe drought and created favourable conditions for fires to spread. The extreme conditions of 2018 have not yet reoccurred and various initiatives implemented in response to the 2018 fires already have had some visible impacts on Nordic forests. Forecasts for future climate conditions however point toward further temperature increases.

Following the 2018 forest fires, the Nordic Council of Ministers commissioned a working group, coordinated by Nordic Forest Research (SNS), to analyse the effects of the extensive fires. As a consequence of this work the Nordiska nätverket för skogs- och vegetationsbrand was formalised in 2020. It gathers forest stakeholders from the Nordic region around the common goal of preventing and responding to forest fires.

This report continues the network's efforts by focusing on producing a Nordic knowledge base about preventive measures to adapt forests to climate conditions and protect them from fires. The project has been commissioned by the Nordiska nätverket för skogs- och vegetationsbrand, under the leadership of Samnordisk skogsforskning (SNS). Toward the network's goal of joint Nordic action, this report is the result of a network-wide collaboration. We would therefore like to warmly thank all the network members who participated by providing feedback throughout the project.



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Summary

■ The climate is changing in the Nordic region, increasing the risk of forest fires. Higher temperatures and increasingly erratic precipitation are creating extreme weather conditions, increasing the risk of larger and more frequent forest fires.

Climate and forests both vary considerably within the Nordic region. However, similarities among the countries make cross-border collaboration and knowledge exchange on managing increased fire risk valuable. This report contributes to this work, compiling knowledge to facilitate and accelerate Nordic learning and collaboration on forest management and fire prevention under changing climate conditions.

Forest management is a key component in fire prevention. Suitable management practices can promote stand diversity, fuel discontinuity, and easy access to vulnerable sites, factors mitigating the risk of uncontrollable fire. These preventive measures however have conflicting impacts on goals for biodiversity, conservation, productivity, fire safety, carbon sequestration, and public acceptance. It is also crucial to raise general public awareness of individuals' responsibilities for preventing fires. This can be done through initiatives spreading knowledge and awareness to residents, hikers, campers, silvicultural workers, and firefighters.

FIVE ACTION POINTS

■ Existing Nordic cooperation needs to be continued and deepened. This report raises five points for joint Nordic action:

- Forest management creating fire resilience while embracing multiple perspectives
- Cross-border communication and harmonisation of terminology and methods
- Developing legislative frameworks
- Spreading information and raising awareness
- Rapid action through adequate information, monitoring, and multi-level cooperation.

Contents

1 Introduction	1
2 Climate change in the Nordic region	2
2.1 Historical climate changes	2
2.2 Predicted climate changes	3
2.3 Impacts of climate change	4
2.4 Predicted impacts of climate change	4
3 Nordic forests	6
3.1 Forest composition in the Nordic region	6
3.2 Forest composition impact on fire regimes	6
3.3 Comparison with Mediterranean forests	7
4 Forest fires in the Nordic region	9
4.1 A brief history of forest fires	9
4.2 Predicted future forest fires	9
4.3 Comparison with Mediterranean forest fires	10
5 Preventive forest management	11
5.1 Forest Management	11
5.2 Data gathering	13
5.3 Legislation	14
6 Prevention of forest fires	16
6.1 Prevention at the source	16
6.2 Legislation	17
7 Concluding remarks and suggestions for joint Nordic actions	18

1 Introduction

■ Climate change is linked to several uncertainties and risks and its effects are observable worldwide^{1 2 3}. The Nordic region faces considerable challenges as its climate is changing faster than in most other parts of the world⁴. A recent manifestation of Nordic climate change is the heatwave of 2018 and the intensity of forest fires it exacerbated⁵.

Forest fires can be ignited by people or nature. Lightning is a common natural fire ignition source^{6 7}, but most forest fires are caused by humans^{8 9}. These ignition risks combined with drier, warmer, and less stable weather patterns can lead to intense "megafires". Megafires cannot be countered with firefighting responses and entail heavy infrastructural, natural, human, and economic costs^{10 11}.

The integration of forest management through Nordic cooperation and knowledge sharing is a key measure to prevent the escalation of fires into megafires. However, many elements require further research, general acceptance, and implementation in practice. Forest management involves a myriad of actors with varying needs and goals. Each decision to plant, cut, clear, or protect must combine a fire management perspective with economic, carbon sequestration, biodiversity, conservation, and public views.

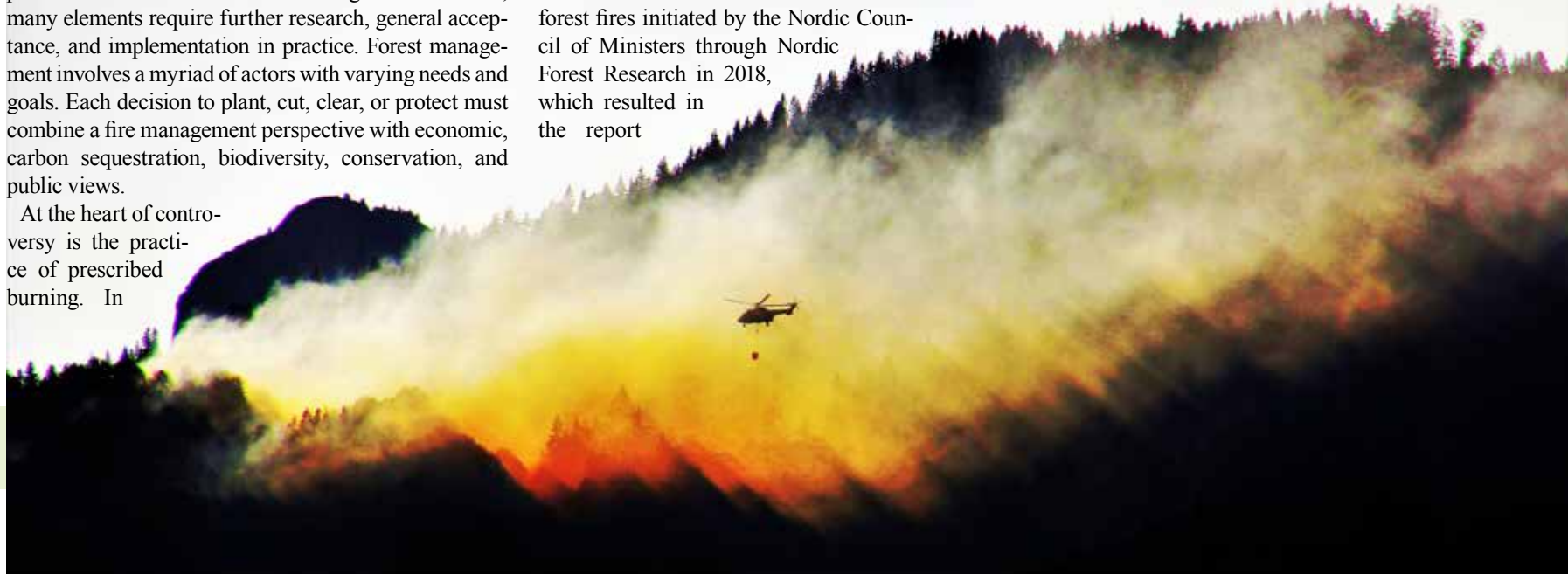
At the heart of controversy is the practice of prescribed burning. In

recent history, the Nordic countries have aimed to extinguish all fires immediately. This practice has led to the accumulation of forest fuel and what some call the "wildfire paradox"¹² or "fire deficit"¹³. Fire is an integral part of many ecosystems and many species depend on it to maintain suitable habitats^{14 15}. Management-ignited, prescribed burning of forest understories can help reduce the risk of uncontrollable forest fires¹⁶. This approach must, however, be implemented by skilled actors in cooperation with local governments and fire departments¹⁷. Moreover, burning in forests sometimes remains culturally difficult to accept¹⁸.

This report is commissioned by the Nordiska nätverket för skogs- och vegetationsbrand. It provides a knowledge compilation to facilitate and accelerate Nordic learning and collaboration on forest management and fire prevention under changing climate conditions. It thereby constitutes a continuation of the Nordic collaboration on forest fires initiated by the Nordic Council of Ministers through Nordic Forest Research in 2018, which resulted in the report

"Det Nordiska Skogsbruket: utmaningar i en framtid präglad av mer extremväder" published in 2019.

This report is based on document analysis and compilation of existing academic research and public reports. Climate change in the Nordic region is first assessed. This is followed by a description of forest composition in the region and the links between forest composition and fire regimes, complemented with a comparison with Mediterranean forests. The history of Nordic forest fires is described, with predictions of future changes, and compared with Mediterranean wildfires. Several approaches to forest management for fire risk mitigation are then explored, along with a comparison of relevant Nordic legislative frameworks. This is followed by a discussion of preventative measures to reduce fire risks. The report concludes by developing suggestions for joint Nordic actions.



2 Climate change in the Nordic region

■ This chapter covers historical changes in the Nordic climate including average temperatures, precipitation, and groundwater levels.

The effects of such changes on forests are then presented.

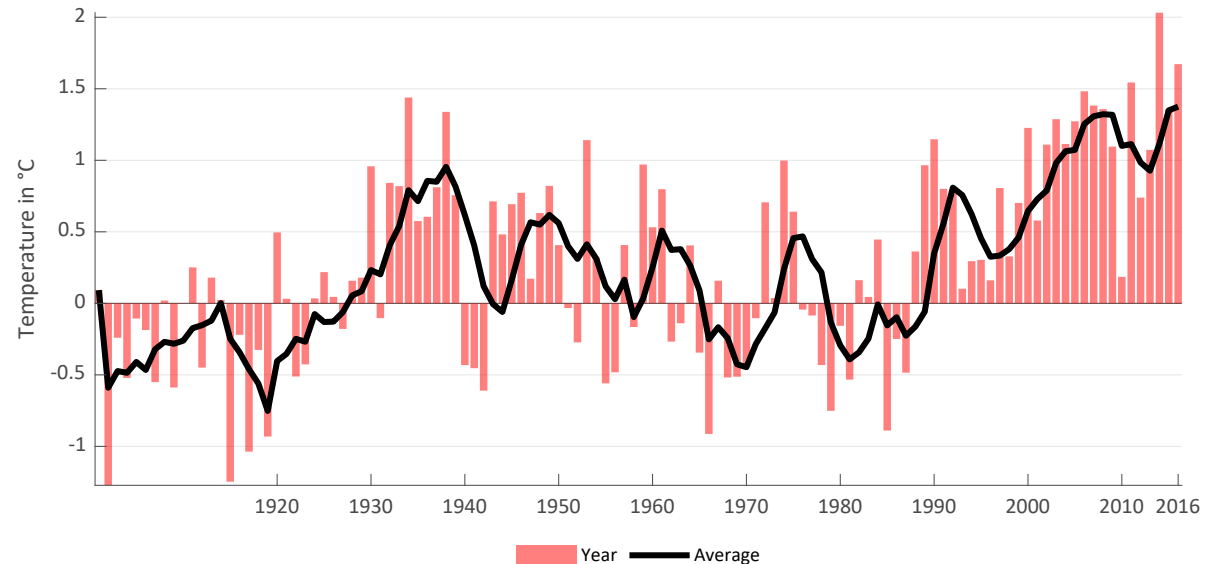
2.1 Historical climate changes

Global temperature increases are accelerating^{19 20 21}. This trend is particularly strong in the Nordic countries where temperatures have recently reached unprecedented levels.

According to World Bank data²², since 1987 the average yearly temperature in the Nordic region has exceeded the average temperature between 1961-1990 (Figure 1).

Regional precipitation has also increased; since the late 1980s, average annual precipitation has consistently exceeded the baseline period average (1961-1990; Figure 2). The heatwave and drought in spring and summer 2018 are an example of the trend toward extreme weather induced by climate change²³.

These figures represent an average of the entire Nordic region, and variations occur between and within countries. For example, during the 2018 heatwave, a few regions of Norway had below-average temperatures while most of the country experienced record heat. Moreover, unlike other Nordic countries, Iceland had near-average temperatures in summer 2018.



2.2 Predicted climate changes

Climate in Nordic Europe is changing faster than in many other parts of the world²⁷. Average annual temperatures will continue to increase, and extreme heatwaves are expected to become more frequent²⁸. It is however important to note that different parts of the Nordic region will show localized changes in precipitation and temperature.

In 2017, the European Environment Agency (EEA) identified five regions with distinct climate change expectations (Figure 3)²⁹. Temperatures are expected to

Figure 1 Temperature in the Nordic region relative to the observed average temperature between 1961 to 1990.

Note: The black curve is a moving average of the previous five years. Countries included: Denmark, Norway, Sweden, Finland, Iceland, and the Faroe Islands.

Data source: World Bank²⁴

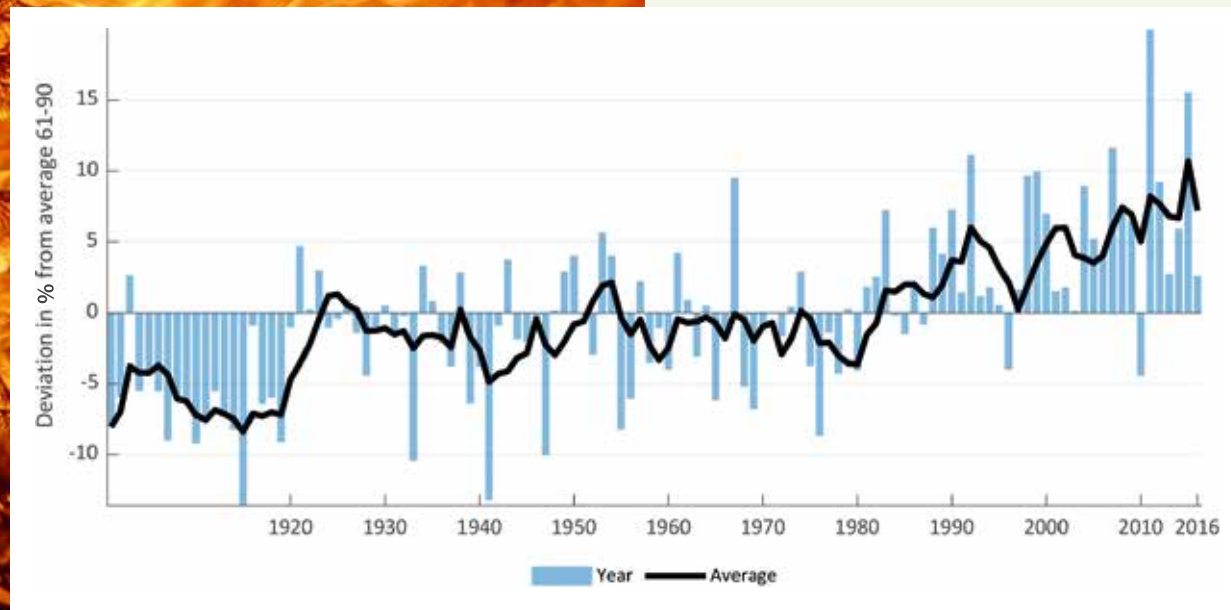
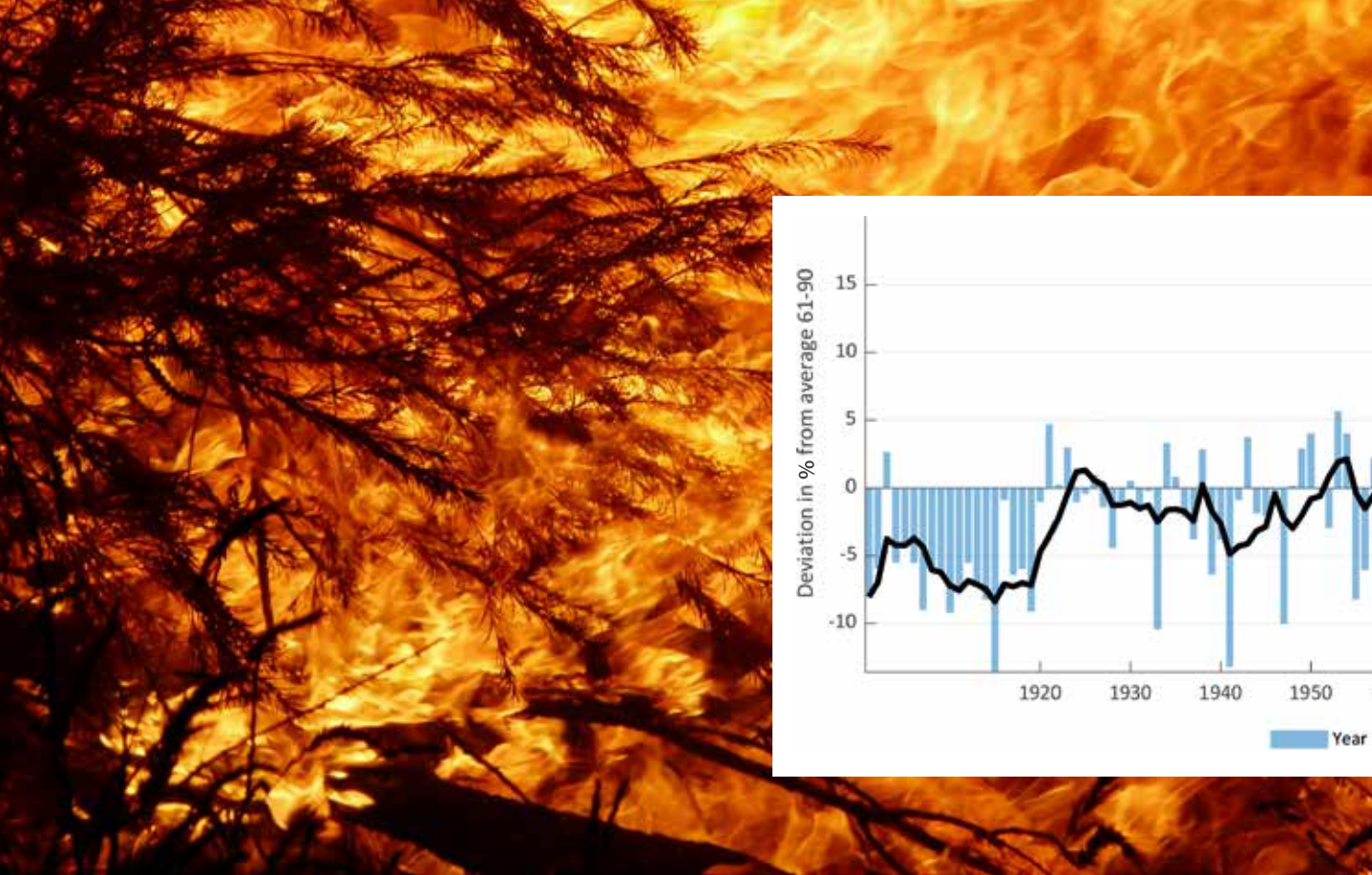


Figure 2 Precipitation in the Nordic region relative to the observed average precipitation between 1961 to 1990.

Note: The black curve is a moving average of the previous five years. Countries included: Denmark, Norway, Sweden, Finland, Iceland, and the Faroe Islands.

Data source: World Bank²⁵

rise in the arctic region covering parts of Norway and Iceland. Heavier precipitation is expected in the Atlantic region covering parts of Denmark and Norway. The mountainous region covering parts of Norway, Finland, and Sweden is expected to get hotter. Both higher temperatures and precipitation are expected in the boreal region covering parts of Norway, Sweden, and Finland³⁰.

The continental region, covering parts of Denmark and Sweden, will see warmer temperatures and less precipitation during the summer³¹.

2.3 Impacts of climate change

In 2018 Europe had its most extensive wildfire season, with fires burning simultaneously in Portugal, Greece, and Sweden³³. This period of extreme weather provides insights into the effects of climate change.

During the spring and summer months of 2018, most of the Nordic countries experienced lengthy hot periods with very little precipitation. In contrast, Iceland and parts of Norway recorded average-to-cool temperatures and heavier precipitation³⁴.

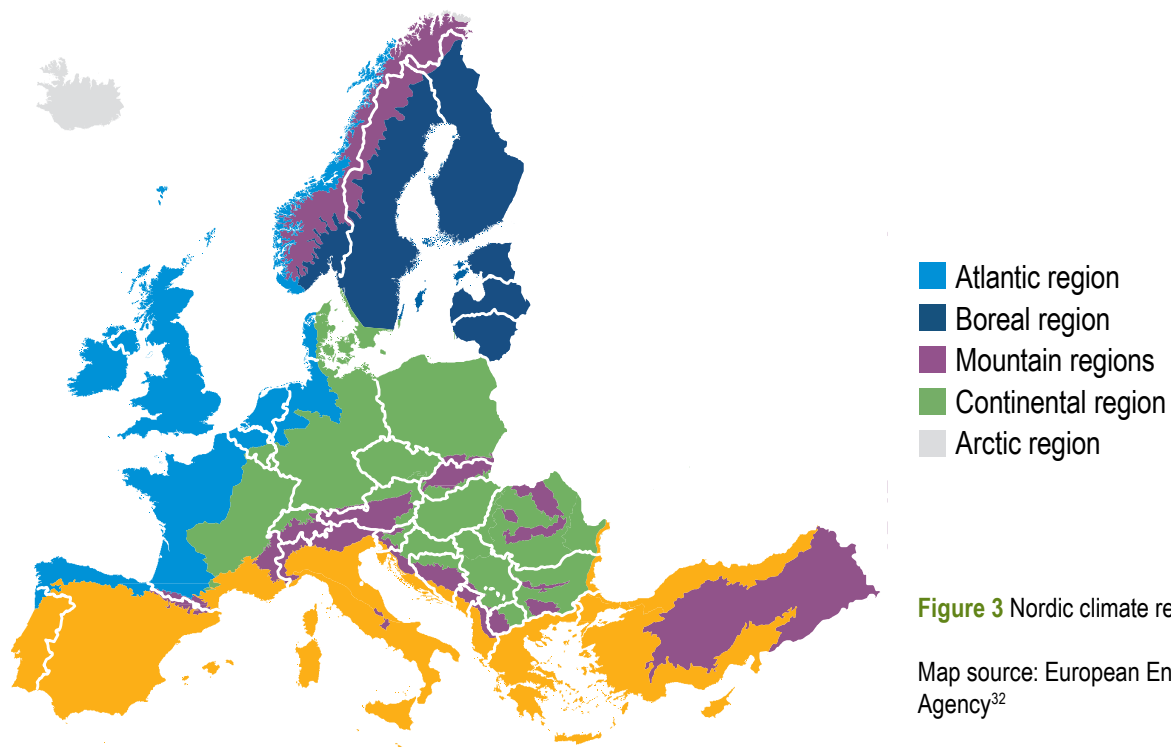


Figure 3 Nordic climate regions.

Map source: European Environment Agency³²

The observed effects of this extreme weather episode were a sharp increase in the number and growth of forest fires. Various Nordic areas suffered multiple fires in 2018, some of which were significantly larger than usual. Sweden, Finland, and Norway were the hardest hit countries. In Sweden, around 23,000 hectares of forest were affected by fires, the largest area since comparable statistics were first compiled in the 1990s. The fire risk was extreme in almost all of Sweden, but four major fires accounted for around 40 percent of the burnt area. In Norway, almost twice as many fires were registered compared to the average of the last five years. However, only 250 hectares of forest were affected. Finland also exceeded the five-year average number of forest fires, and around 1,200 hectares were affected³⁵.

2.4 Predicted impacts of climate change

Foreshadowed by the events in 2018, the weather in Northern Europe is predicted to become more extreme and uneven.

Hotter temperatures can be expected to make the Nordic region more fire prone^{36 37}.

Warmer temperatures due to climate change are directly linked to increased forest fire risk³⁸. Moreover, warmer weather can also accelerate fire spread. Fires therefore tend to last longer and burn larger areas with more intensity³⁹. Warmer temperatures also impact groundwater reserves. If warmer temperatures happen earlier in the year, snow melts sooner⁴⁰ leading to lower fuel moisture during the summer⁴¹, increasing fire risk.

SUMMARY

Climate change is increasing the risk of more frequent and intense forest fires. Temperatures are rising in the Nordic region. Since 1987, the average yearly temperature has exceeded the observed baseline temperature from 1961-1990. Precipitation is also rising, with annual precipitation consistently exceeding the baseline period in recent decades. The weather is becoming more variable and extreme in Nordic regions. It is therefore expected that more frequent and larger fires will occur in Nordic forests.

3 Nordic forests

■ This chapter describes the composition of Nordic forests, with a focus on links between forests, vegetation, and fire regimes. The chapter concludes with a comparative presentation of Mediterranean forests.

3.1 Forest composition in the Nordic region

Europe has about 215 million hectares of forest, covering about 33 percent of the total land area. In addition, other wooded areas cover around 36 million hectares⁴². Forests are distributed heterogeneously within Europe depending on climate, soil type, altitude, topography, and silvicultural activities⁴³.

Northern Europe is the most forested region with 53 percent of land covered by trees⁴⁴. 45 percent of forests in Europe are mainly coniferous, 36 percent are predominantly broadleaved, while the remaining share is mixed. The Nordic region is dominated by boreal forests (Figure 4) with about 75 percent of the growing stock composed of coniferous species, which is different from the forest structure in southern Europe⁴⁵.

Despite the dominance of coniferous species such as pine and spruce, forest types vary within the Nordic countries. Sweden, Norway, and Finland have some of the highest forest area per capita in Europe due to their forest covers of 69%, 37%, and 66%, respectively⁴⁶. In these countries, most forest is in remote and sparsely populated zones⁴⁷. On the other hand, Denmark and Iceland have some of the lowest forest area per capita⁴⁸. Moreover, most forests in Denmark are deciduous.



Nordic vegetation is divided into five zones: alpine, subalpine, boreal, boreonemoral and nemoral. The alpine zone has few trees. In the subalpine zone, mainly in Norway, Finland and Sweden, birch is predominant. Boreal zone forests are dominated by two coniferous species, Scots pine and Norway spruce. The boreonemoral zone is a mixed-forest transition between the boreal and nemoral zones. In the nemoral zone, covering Denmark and parts of Sweden, oak, beech, hornbeam, among other broadleaved species are native⁴⁹. Appendix 1 has a detailed map and list of Nordic forest types.

3.2 Forest composition impact on fire regimes

Tree species composition is tightly intertwined with fire regimes⁵⁰. Three main types of fire can be identified: ground fires, surface fires, and crown fires. Ground fires occur in areas with a thick but compacted organic litter layer. They can smoulder for a long time and escalate into surface or crown fires if weather or fuel conditions change. Surface fires occur in areas with abundant shrubs, herbs, mosses, lichens, leaf litter, and fallen branches. Surface fires have low flames and temperatures. Taller trees usually survive surface fires. Crown fires burn intensely among trees' canopies consuming woody biomass. It is important to note that individual fires can include various forms of fire types⁵¹.

Megafires are characterised not only by their extent and the amount of land they burn but also by their socioeconomic and environmental impacts. They are generally fires of exceptional dimensions, escalated by extreme weather. Megafires may be minimally af-

fected by firefighting efforts. Putting out megafires is costlier and more dangerous than for average forest fires, leading to longer lasting impacts on society and the environment^{52, 53}.

Vegetation zones and their ecosystems differ within Nordic Europe. This explains the variation in fire risks and regimes. Norway, Finland, and Sweden tend to be the countries hardest hit by forest fires due to their extensive forest areas. Moreover, these countries' forests are dominated by pine and spruce which are more prone to intense crown fires^{54, 55}. Deciduous species are usually moister and tend to burn more slowly or to resist fire. Tree species also influence fire regimes via the ground vegetation beneath them. Vegetation like moss and lichens depend on precipitation as a water source. They readily dry out during droughts, becoming more flammable⁵⁶.

3.3 Comparison with Mediterranean forests

A broad range of forest types with various ecosystems and dynamics can be found in Europe, with Nordic and Mediterranean forests being extremes of this diversity. Several trends can be highlighted by comparing Mediterranean and Nordic forests. South-eastern Europe is the least forested part of the continent, with 23 percent of the land area forested. However, species diversity tends to be higher in southern Europe than in more northerly countries⁵⁷. Broadleaved forests are more common in Mediterranean compared to Nordic Europe (Figure 4).

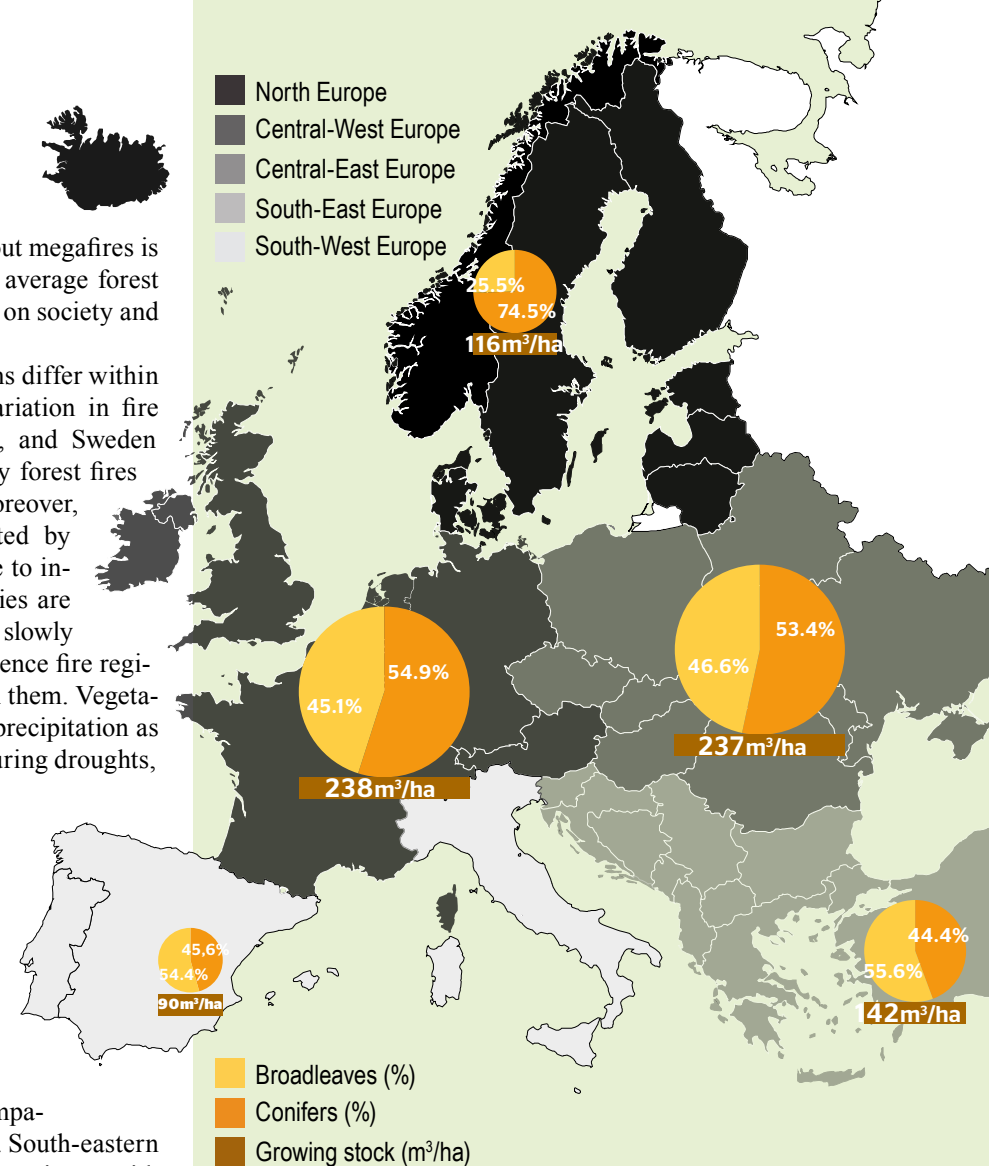


Figure 4 Growing stock of conifers and broadleaves in Europe

Map source: Forest Europe (2015)⁵⁹

The high species diversity in the Mediterranean is related to variations in topography and climate.

The main Mediterranean forest types are alpine coniferous, Mediterranean coniferous, broadleaved

evergreen, montane beech, and thermophilous deciduous⁵⁸.

Appendix 1 presents detailed maps and lists of Nordic and Mediterranean forest types.

SUMMARY

■ European forests are extremely diverse, with important differences between Nordic and Mediterranean areas. Nordic forests are not homogeneous as the region comprises multiple climates and topographies resulting in a myriad of natural vegetation types. These differences in species and climate play a crucial role in fire regimes.



4 Forest fires in the Nordic region

■ This chapter covers the history of forest fires in the Nordic region. A summary of current projections of the future of forest fires in the region is also presented. The chapter then concludes with a comparison with observed fire patterns in the Mediterranean.

4.1 A brief history of forest fires

Forest fires are a common hazard in Nordic forests and play a crucial role in the development of natural vegetation^{60 61}. Fires in Nordic Europe are typically small. Between 2000 and 2017, the average forest fire in Sweden and Finland was smaller than one hectare in every year except for 2006, 2008, and 2014. Norway is the Nordic country with the largest fires. In the same period, the average Norwegian fire was under 8 hectares in all years except for 2006, 2008, 2009, and 2010^{62 63}.

A general historical trend of decreased forest fire activity has been observed throughout northern Europe since the introduction of efficient fire suppression during the 19th century^{64 65 66}. However, fire regimes can change depending on topography, climate, and available fuel^{67 68}. In the past few years, this decreasing trend has reversed. Wildfire frequency and intensity are now increasing in Nordic Europe, with rare small fires evolving into potential megafires^{69 70}.



4.2 Predicted future forest fires

A well-grounded understanding of historic fire regimes and their sources is crucial to comprehend and predict potential future fire regimes⁷¹. Notably, the interactions between human actions and climate change appear to be key elements for predicting changes in wildfire regimes⁷².

There is a strong link between climate and fire regimes⁷³. Warmer temperatures and decreased precipitation create conditions for fires to escalate by drying vegetation and dead fuels. In turn, forest fires' emissions directly impact climate change and the environment. For example, black carbon emitted by Nordic forest fires is often deposited in the Arctic where it absorbs sunlight, accelerating ice melting⁷⁴.

Current predictions show Nordic fires becoming more frequent and intense. Several specific trends can be identified. Northern and mid-boreal forests are more sensitive to summer weather compared to southern-boreal forests. This means there could be some divergence between future fire regimes in the Nordic region, even when similar changes in climate^{75 76 77}.

Another trend is the densification of forest cover. This increases fuels density and decreases barriers to fire spread⁷⁸. Forest fragmentation can vary, depending on ownership models, management traditions, and decision making. Further research is needed, particularly in relation to its impact on ecosystems and forest fires^{79 80 81 82}. The boreal forest is characterised by few tree strata and species. Species such as pine have been preferred in managed forests, notably in Sweden and Norway, due to their fast growth. They are, however, often at greater risk of crown fires^{83 84}. Further, large plantations of certain exotic species, like lodgepole pine, are linked with an increased risk of fire escalation^{85 86}.

4.3 Comparison Mediterranean forest fires

Fire occurrence and intensity are also increasing in southern Europe, similarly due to climate change and anthropogenic activities. Additionally, the region is facing increased fire escalation risks related to the planting of exotic eucalyptus species⁸⁷.

Forest type, ground vegetation, and climate are radically different between the Mediterranean and Nordic regions. Fire is a natural and fairly common element of most Mediterranean ecosystems; large wildfires are a long-known disturbance regime. The current fire regime is much more intense than in Nordic Europe. Fires above 50 hectares account for more than 75% of the land burned annually, although they only represent 2.6 percent of all wildfires, meaning numerous smaller fires occur without escalation⁸⁸. However, in the past few years the region has seen fewer small fires and more megafires, overwhelming available firefighting resources⁸⁹. Challenges from increasingly uncontrollable fires in the Mediterranean can be contrasted with the Nordic area.

The Mediterranean is densely populated and the fire season coincides with the peak tourism season. Uncontrolled fires are therefore a more immediate threat to human lives in the Mediterranean⁹⁰.

SUMMARY

■ Historic fire regimes are key to understanding potential changes in fire patterns. Additionally, climate and human actions have powerful impacts on fire regimes and are therefore crucial to forecast future fire patterns. A general trend observed within the Nordic and Mediterranean regions is an increase in large intense fires, challenging fire suppression resources.



5 Preventive forest management

■ This chapter explores the impacts of forest management for fire prevention. The importance of harmonised data gathering is then presented, followed by an overview of current Nordic legal frameworks regulating forest management.

5.1 Forest Management

Human intervention is a double-edged sword for the future of forests. Up to 90 percent of forest fires are caused by human activities⁹¹ and global warming is directly related to their increased abundance and swifter escalation. Indeed, the unprecedented rise in temperatures makes forests more vulnerable to fires, which are likely to escalate to megafires. Yet preventive forest management appears to be key to safer forests.

Current efforts to battle forest fires tend to focus on fire suppression which yields visible short-term results⁹². Some research suggests, however, that long-term investments in defensive strategies are an efficient and cost-effective integrated fire management approach. Forest fires are therefore presented as a landscape problem requiring adaptation to climate change rather than solely a firefighting problem. In fact, prevention through forest management will facilitate fire suppression in the future⁹³.

Natural cycles of burning and new growth have been disrupted by fire suppression efforts and are no longer sufficient protection against fire escalation⁹⁴. Systematic fire suppression efforts have created thick



fuel layers in forests, multiplying risks of uncontrollable large fires; this mechanism is referred to as the “wildfire paradox”⁹⁵. Moreover, efforts to reduce human-caused ignitions are highly recommended but complete risk elimination is impossible to reach. Accidents and natural ignitions are unpredictable and cannot be avoided. Attention needs to be brought to factors that can be changed, notably forest composition and structure, and fuel loading. Forest management is therefore necessary to prepare forests for increased fire risks^{96 97}.

Forests, fuel, and fire

Removing fire fuels is a crucial and yet complex matter requiring several perspectives. On one hand, fuel loading in forests and the magnitude of fires are directly related⁹⁸. Also, accumulated dead wood can lead to insect and fungus infestations harmful to ecosystems⁹⁹. On the other hand, dead wood is crucial habitat for some threatened species¹⁰⁰. Moreover, fuel removal can reduce carbon sequestered in forests which can lead to climate-mitigation trade-offs¹⁰¹. It would therefore be beneficial to expand Nordic-specific knowledge about fuel management. This practice needs to fully consider biodiversity conservation while avoiding dangerous fuel accumulation within forests¹⁰².

Additionally, several other trends can lead to the accumulation of fuel. Agricultural abandonment and afforestation can generate important quantities of fuel if no management is implemented, or animals do not graze or browse the affected parcels^{103 104 105}. These trends may be interesting to research further in a Nordic context.

Expansion of wildland-urban interfaces (WUI), where human development expands into forested areas, is another risk factor for the development of forest fires, which requires special landscape management measures. Management of wooded areas surrounding WUIs is a crucial focal point as these zones are at a high risk of dangerous fires¹⁰⁶. Efforts must include the removal of fuels within a sufficient radius of buildings^{107 108 109 110}. A similar forest management approach is also important for isolated buildings and dwellings in forested areas. Isolated buildings also present a high risk of fire ignition. The fire ignition potential is twice as high for isolated dwellings^{111 112}.

Fuel accumulation also increases fire intensification risks in forests. The type and quantity of fuel combined with topography and climate can lead to a myriad of fire behaviours^{113 114}. Forest management through forest fuel extraction¹¹⁵, prescribed burning, or grazing in at-risk parcels^{116 117} can help prevent fire escalation and curb the wildfire paradox.

Prescribed burning

Prescribed burning is considered an efficient solution to the wildfire paradox, yet remains controversial. A history of efforts to prevent and suppress fires has led to a general negative opinion of forest fires. However, it is recommended to foster public support for prescribed burning. These techniques are consistent with integrated and adaptive forest and wildland management approaches as they help balance management of existing natural resources with the management of unintentional fires¹¹⁸.

Moreover, prescribed burning can help local com-



munities and fire departments to develop theoretical and practical knowledge about fire patterns, control, and suppression¹¹⁹.

An additional feature of prescribed fires is the role they can play for biodiversity. As previously mentioned, fires are natural part of many ecosystems' development, regulation, and variation. Most natural fire cycles have disappeared due to automatic and immediate fire suppression actions. It is therefore possible to reintroduce the role played by fire in biodiversity conservation through prescribed fire¹²⁰. Various fire-dependent species of insects, birds, plants, and fungi rely on charred wood and soil to develop, germinate, or reproduce. Many such organisms are rare and some appear on the Swedish national red list. Strategic prescribed burning can therefore contribute to biotope conservation efforts¹²¹. Additionally, fires can counter soil acidification through balancing soil surface pH and mineralisation. Finally, competitive development of fire-adapted species follows burning.

Forest structures and composition

Unsuitable forest management can be detrimental. For instance, dense and extensive pine-dominated forests are more prone to fire escalation^{122 123} and crown fires. Indeed, as described previously, Scots pine crowns are highly flammable; if planted densely, fire can readily propagate among their crowns^{124 125}.

Suitable forest management, on the other hand, can make forests more resilient. Creating discontinuities within forests can slow fire escalation and spread. Adjacent forest areas with different tree species and age structures, and therefore different fire regimes, can help



create discontinuity that slows fires¹²⁶. However, some species need continuity in their ecosystem. The trade-offs between biodiversity conservation and fire prevention need to be assessed in a Nordic context when choosing the most suitable forest structures¹²⁷. Further research on this topic is requested to facilitate the implementation of best forest management practices^{128 129 130}.

Forest roads

Much forest is in remote, sparsely-populated areas¹³¹. Developed road structures within forests facilitate

fuel treatment, fire detection, and rapid suppression¹³². However, such infrastructure cannot be implemented in all dense and remote Nordic forests. Roads can also cause undesired effects like habitat fragmentation and more frequent visitation, leading to increased ignition risk¹³³.

Some topographies can hinder firefighting access. Where roads are absent or impossible to build, forest management can contribute through the creation of various types of fire breaks, such as mineralized strips of bare soil or zones of reduced fuel density. In the latter, superficial fire-prone cover is removed, creating empty strips between designated forested

zones^{134 135 136}. This strategy helps compartmentalise vegetation areas and create fire barriers.

5.2 Data gathering

Sufficient data is crucial to plan forest management strategies and to disseminate knowledge about risks and adaptation measures. Planting and thinning initiatives need to be well informed regarding risks related to topography, tree species, surrounding forest structure and climate patterns^{137 138}.

The creation and dissemination of harmonised risk-monitoring procedures, databases, and maps



gathering information about soil types and forest structures are considered as solutions to encourage cooperation among forest owners, agencies, and decision-makers^{139 140}. Similarly, gathering harmonised information on regional weather patterns and their influence on local vegetation and tree species is necessary to create tailored regional forest management initiatives¹⁴¹. Monitoring can therefore contribute to the creation of knowledge and rapid fire suppression measures. However, monitoring does not prevent the ignition of fire.

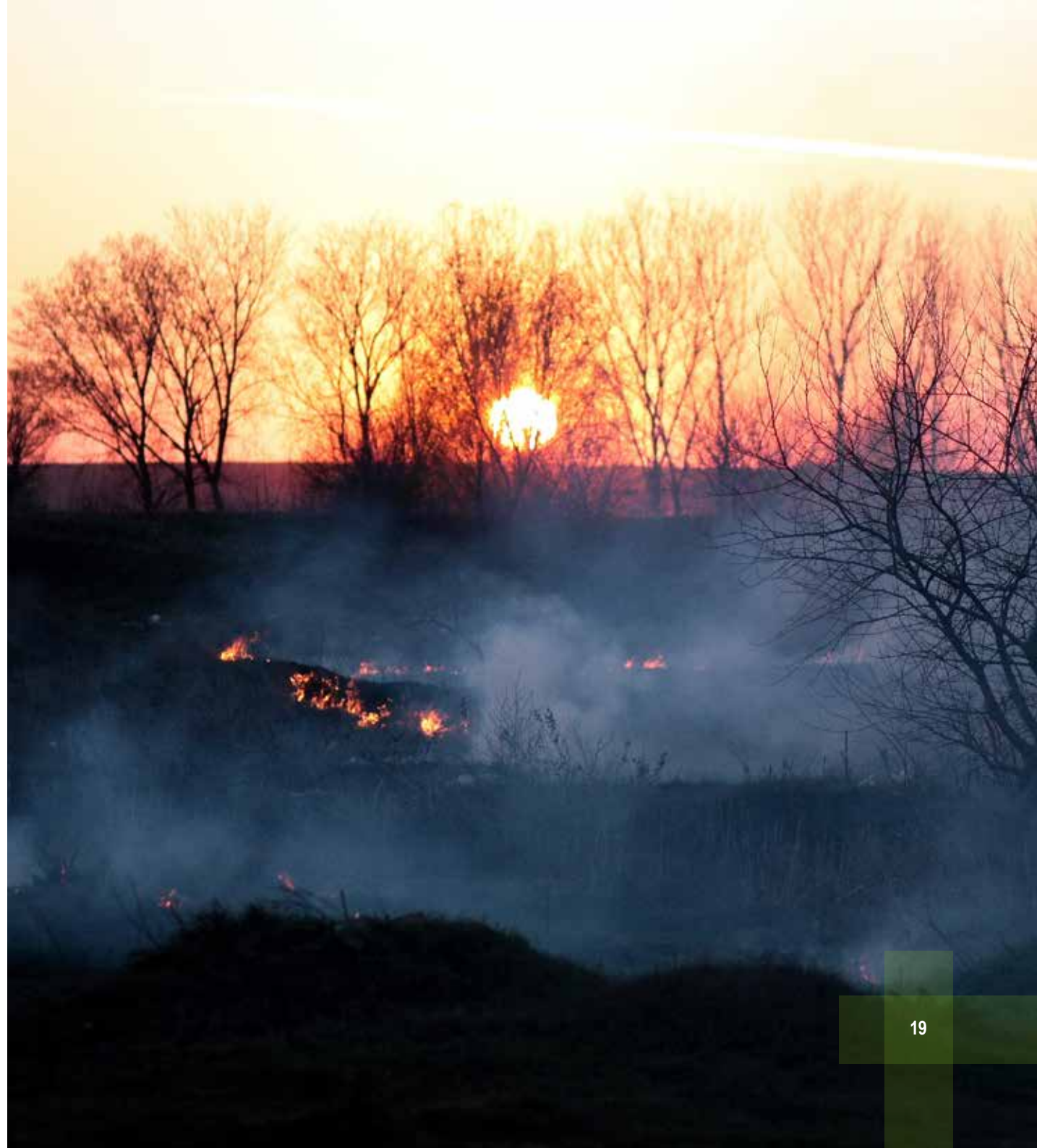
WUIs also require gathering of data. It is necessary to map dwelling locations: isolated, scattered, and clustered. Data gathering needs to be coupled with a symbiotic mapping of forest density in areas surrounding dwellings. This joint measure can help identify risk zones requiring immediate forest management responses¹⁴².

By harmonising data and terminology, it is possible to prevent redundant research and to aggregate local research into bigger-scale results, letting countries learn from their neighbours' experience. Moreover, data harmonisation can highlight how countries are impacted differently by fires. This can help identify efficient forest management practices and apply them throughout the Nordic region^{143 144}.

5.3 Legislation

The legislative response to the threat of fires in Nordic Europe can focus on local and national to international levels.

Locally, it can address allocation of responsibility for preventive forest management and role definition among forest owners, local governments, and insti-



tutions. Building fire breaks, removing fuels, setting prescribed fires, and grazing can greatly benefit from clear target identification and role distribution within concerned communities. Cooperation and initiative taking can be simpler if local communities gather around a single framework of risk identification and related forest management measures^{145 146}.

Nationally and internationally, legislative frameworks can support the creation of standardised data gathering and dissemination. Such measures are crucial to allow both national coherence in law making and identification of suitable forest management practices, and international cooperation and knowledge transfer¹⁴⁷.

One of the main obstacles to preventive forest management is the focus on and budget allocation to fire suppression. Proactive forest management needs to be supported by the correct reallocation of resources to biomass management targeting local environmental contexts. Moreover, funding allocations can encourage the integration of fire ecology in research and innovation efforts, supporting sustainable and resilient forest management¹⁴⁸.

Incentives

The importance of revenue from silvicultural activities is stressed in the Norwegian, Finnish and Swedish Forest Acts^{149 150 151}, and forestry is deeply rooted in regional cultural practices and economic history¹⁵². To decrease the risk of forest fires it may be relevant to expand legislative frameworks, for example by further encouraging cooperation of small forest owners, removing dead fuel, and potentially reintroducing agriculture in unmanaged, afforested areas^{153 154 155}.



Forestry can encourage effective clearing of fuel for economic ends with for example, thinning practices to favour tree growth and slash harvesting for bioenergy¹⁵⁶. Moreover, it can create fuel breaks by restoring heterogeneous landscapes composed of forests, farmland, and pastures¹⁵⁷.

Encouraging economic association of small forest owners through incentives can also help increase forest maintenance and support management of smaller plantations to promote fuel discontinuity and diversity¹⁵⁸. Moreover, such cooperation can be further developed by creating incentives for landowners and silvicultural actors to collaborate and take over responsibility for a coordinated organisation handling the monitoring and potential suppression of forests and fires¹⁵⁹.

Country-specific forest legislation

The Forest Act of Finland promotes socially and economically sustainable use and management of forests. Focus is given to maintaining the biological diversity of forests: felling should promote growth of remaining tree stands, and clearcutting with artificial regeneration is the main regeneration method.

Amendments to the act in 2014 emphasize the freedom of choice of forest owners in their management decisions. The Forest Damage Prevention Act (previously the Act on Preventing Insect and Fungal Damage) also requires the rapid removal of conifers damaged by storms to prevent infestations and ensure forest health. Additionally, the construction of forest roads is considered as an improvement of national infrastructure and is subsidized by the state, upon approval^{160, 161}.

The Forestry Act of Sweden presents forests as re-

newable resources that require sustainable management yielding revenue. Replanting after harvesting is an obligation, and can be done through planting seeds, saplings, or natural regeneration. Even-aged stands are encouraged. Forestry activities should consider and work with reindeer husbandry and other activities.^{162 163}

The Forestry Act of Norway promotes sustainable management of forest resources, economic development, and biological diversity. Felling should be followed by adequate regeneration efforts. Focus is also given to the public use of forest, which should not be hindered by silvicultural activities.^{164 165}

Forest Certification in the Nordic region

Forest certification is widely adopted in Nordic Europe and the demand for certificates from buyers of timber and wood products is continuously increasing. Certifications ensure the sustainability of forest management by regulating standards regarding felling, thinning, and prescribed burning. The Programme for the Endorsement of Forest Certification (PEFC) and the Forest Stewardship Council (FSC) are the two main certification organisations in the Nordic region.^{166 167}

Different certification preferences can be seen in Finland, Sweden, and Norway. In Norway, most forest is held by small owners using the PEFC certification. In Finland, 90 percent of commercial forest follows the PEFC system, while the remaining 10 percent uses the FSC system. In Sweden, forest ownership is a mix of small owners and larger silvicultural companies and FSC certification is five times more common than PEFC certification.^{168 169 170 171 172}

SUMMARY

■ Human intervention can be both harmful and beneficial for the resilience of forests. Preventive forest management appears to offer a powerful answer to the impact of climate change on fire escalation. Knowledge gathering and dissemination across Nordic Europe is another key element to adapt forest management for fire preparedness.

Suggestions of preventive forest management measures

- Data gathering and observation of fire risk, topography, WUIs and biodiversity
- Building roads to access crucial risk areas
- Suitable fuel removal and prescribed burning in non-protected areas
- Local adaptation of forest structure and composition through segmentation and stand selection

6 Prevention of forest fires

■ In this chapter measures involving individuals and target groups are presented, followed by an overview of current incentives and sanctions applied in Nordic countries.

6.1 Prevention at the source

As mentioned previously, forest management can slow the escalation of fires and make forests more resilient to future despite climate change. Another approach to prevent uncontrolled fires is preventing ignition. Most fire ignitions are caused by human activities¹⁷³. Efforts must therefore focus on educating and raising awareness about fire ignitions. Although completely eliminating anthropogenic ignitions is impossible, efforts directed toward relevant populations can help decrease them.^{174 175 176}

Efforts to prevent forest fires tend to be overshadowed by the focus on fire suppression¹⁷⁷. However, negligence in extinguishing campfires, barbecues and cigarettes is a common cause of forest fire ignition. Sparks from trains and machines used in forests also ignite fires. Creating informational material in different formats (apps, videos, signs, brochures etc.) for people using forests for recreational purposes is therefore important. Additional fire risk information can be coupled with weather forecasts and lightning alerts on various media (TV, radio, meteorological websites etc)¹⁷⁸. It is crucial to raise public awareness about the shared responsibility of preventing fire ignition and

go beyond the idea that fire suppression is the responsibility of fire departments only¹⁷⁹. Everyone must participate in minimizing fire risk, extinguishing existing fires, and reporting any signs of fire.

In parallel, preventive information must also target forest owners and silvicultural workers¹⁸⁰. Awareness about risks of silvicultural activity in dry and hot weather should be spread widely. Focus can be put on the risk of sparks when driving heavy machinery on rocky terrain. It can be recommended when to avoid working in rocky areas. Another important point is the risk of sparks when operating machinery near accumulations of fuel. Solutions for silvicultural activities during heatwaves and droughts can be to work at night when temperatures are lower and relative humidity is higher. Adequate preventive measures must also be taken, such as wetting floors before using heavy machinery, bringing suitable fire suppression equipment to working sites, and providing workers with appropriate communication equipment in areas with poor mobile phone coverage to contact firefighting services¹⁸¹.

Prevention can be complemented by early detection of fires and preparedness to respond quickly to fire ignition¹⁸². For more efficiency, automatic monitoring procedures after lightning storms can be provided to municipalities and forestry actors, such as the “Brandrisk Skog och Mark” service of the Swedish Civil Contingencies Agency (Myndigheten för samhällsskydd och beredskap, MSB) and the Swedish



Meteorological and Hydrological Institute (Sveriges meteorologiska och hydrologiska institut, SMHI) in Sweden^{183 184}. As mentioned previously, forest roads allow fast and easy access to fires. Additionally, maintaining organised and permanent firefighting capacity in sparsely-populated areas is a challenge needing to be addressed¹⁸⁵.

Finally, better cooperation between authorities, local communities, forest owners and firefighting services must be encouraged to allow more efficient flow of communication, knowledge sharing, and fast fire suppression responses^{186 187 188}.

The initiative, led by Skogforsk in Sweden, is a good example of promoting cooperation between actors against forest fires. Skogforsk provides a framework for agreements between clients and forest contractors in relation to forest work.

The framework highlights the responsibility of contractors to monitor weather conditions, and train and supply their workers with fire equipment. It also encourages continuous exchange between the parties, for instance, under elevated fire risk, contractors and customers must agree on procedures before performing further work^{189 190}. Appendix 2 lists knowledge-spreading initiatives and necessary cooperation initiatives and action points.

6.2 Legislation

Legal frameworks can be implemented to maintain and encourage preventive initiatives against forest fires.

Additionally, a sanctioning system can complement the preventive initiatives to deter non-compliance and negligence.

Sanctions

Fire bans are a common fire prevention measure throughout the region, coupled with safe outdoor recreation infrastructure. Bans are implemented in different ways.

In Finland, fire bans are enforced depending on weather conditions. During fire bans, all open fires in forests and areas surrounding forests are forbidden. The warnings are specific to each province, and municipality-specific warnings can also be issued in certain regions¹⁹¹.

In Sweden, fire bans are issued by county administrative boards or municipalities when weather conditions increase fire risk¹⁹². When bans are implemented, all fires and barbecues are forbidden in forests and open countryside¹⁹³.

In Norway, a general requirement for caution and safety is communicated to the public and a permanent ban on fires in or near forests and manipulation of flammable objects (grills, gas burners, and camping stoves) near forests is enforced from 15 April to 15 September. Exceptions apply to safe areas such as beaches and approved campfire sites. In case of extreme droughts, grills, gas burners and camping stoves are also prohibited.

Additional fire bans can be implemented in municipalities for limited periods of up to 60 days. The bans need to be lifted as soon as the risk conditions cease. They must also be clearly communicated to the public^{194 195}.

SUMMARY

■ People are the main source of fire ignition. It is therefore crucial for initiatives to spread knowledge and awareness to residents, hikers, campers, silvicultural workers, and firefighting services. Incentives to implement beneficial silvicultural activities and make them economically enticing can help support forest management efforts. Moreover, sanction frameworks, notably regarding use of fire during fire season can help prevent accidental fire ignitions.

7 Concluding remarks and suggestions for joint Nordic actions

■ Climate change is influencing fire regimes throughout Europe and the Nordic region is heavily impacted. Immediate action through forest management and preventive measures is therefore required. Collaboration among actors at various levels and among Nordic countries appears as the key element for successful fire preparedness. Focusing on Nordic and eventually European cooperation, harmonisation and mutual

learning is crucial. Indeed, Nordic countries are experiencing the effect of climate change differently due to their varying forest types and forest management approaches. Knowledge transfer between countries through harmonisation of data and the implementation of strong formalised communication channels will allow a robust Nordic base of fire knowledge to be built.



Suggestions for joint Nordic actions

Forest management to create fire resilience while embracing multiple perspectives

- Develop knowledge and share practices related to 1) forest road networks, 2) thinning, 3) fuel removal (particularly around WUIs), 4) fuel discontinuity and mineralised strips, 5) forest structures and compositions better adapted to changing and unstable climate conditions, 6) fragmentation and implementation of varying stand ages, and 7) prescribed burning.
- Create common guidelines regarding sustainability and fire resilience for Nordic forests.
- Facilitate cross-border dialogue to address conflicting perspectives (such as biodiversity, productivity, fire prevention, and carbon sequestration).

Cross border communication and harmonisation of terminology and methods

- Streamline communication among the Nordic countries
- Develop and formalise common terminologies and processes
- Harmonise data-gathering methods to facilitate efficient Nordic research projects and learning within the region.

Developing the legislative framework

- Develop knowledge and policy making regarding legislation on fire safety and forest management. For example, MSB has identified a need to address the allowed distance between buildings and forests or fuels.

Spreading information and raising awareness

- Create and share information materials via various media (apps, videos, signs, brochures etc.) to inform public and forestry actors about their roles and responsibilities in fire prevention

Rapid action through adequate information, monitoring and multiple-level cooperation

- Share knowledge to train well-informed silvicultural workers to mitigate fire risks and act correctly in case of fire
- Investigate and share knowledge on whether monitoring and extinction responsibilities can be delegated to forest and landowners, complementing firefighting services' efforts.



Appendix

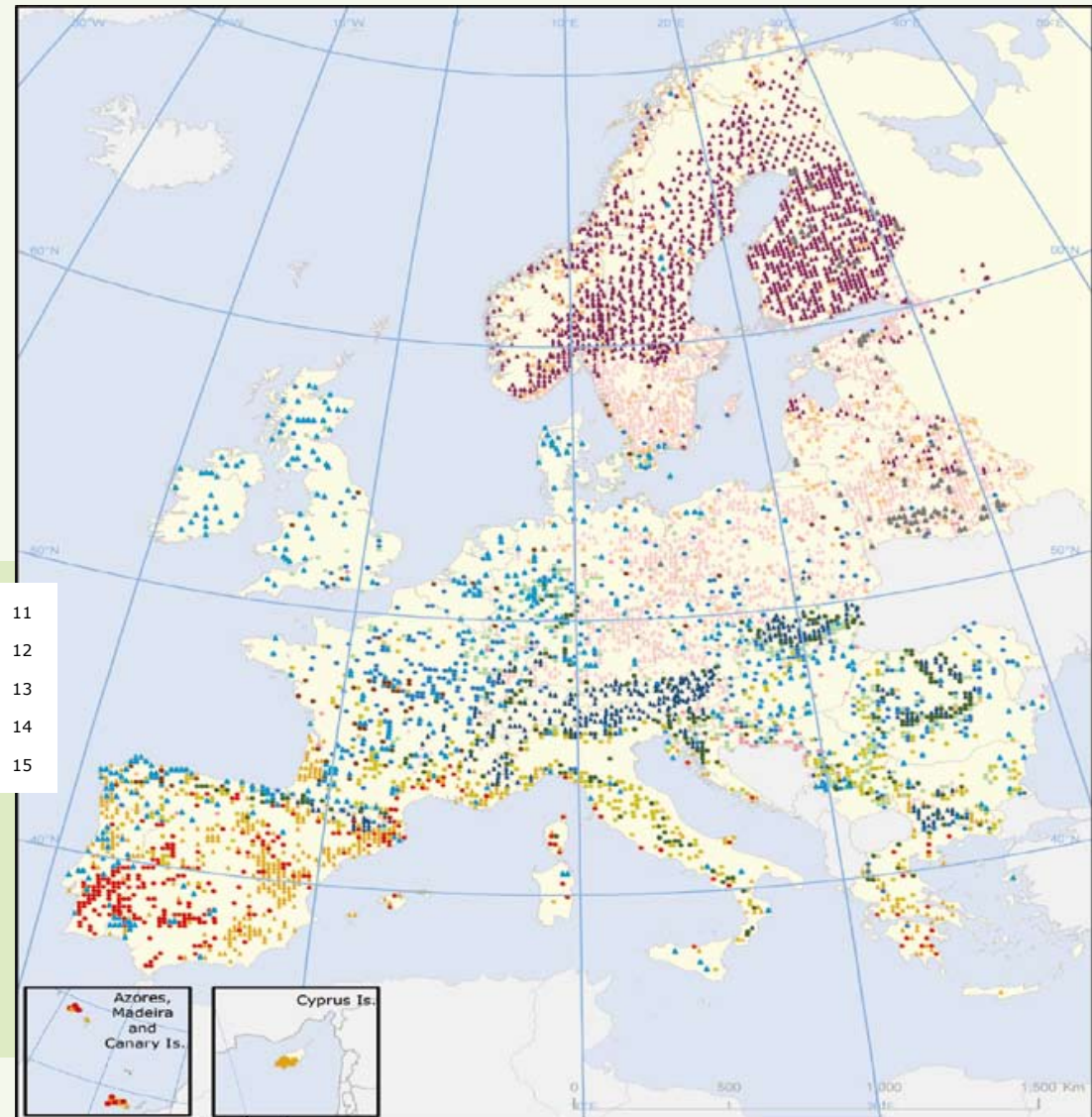
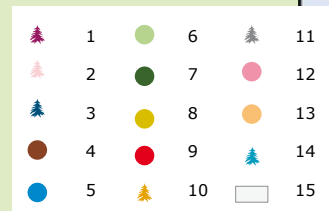
Appendix 1 a, b, c: Map, frequency rate and detailed list of forest types in Nordic Europe.

Appendix 1a: Map of distribution of forest type categories in Europe

Appendix 1a: Map of distribution of the European forest type categories, based on ICP level I plot classification. See also frequency distribution in appendix 1b and detailed list of category types in appendix 1c.

Source: EEA (2006)¹⁹⁶

1. Boreal forest
2. Hemiboreal forest and nemoral coniferous and mixed broadleaved coniferous forest
3. Alpine coniferous forest
4. Acidophilous oak and oak birch forest
5. Mesophytic deciduous forest
6. Beech forest
7. Mountainous beech forest
8. Thermophilous deciduous forest
9. Broadleaved evergreen forest
10. Coniferous forests of the Mediterranean, Anatolian and Macaronesian regions
11. Mire and swamp forest
12. Floodplain forest
13. Non-riverine alder, birch, or aspen forest
14. Plantations and self-sown exotic forest



Appendix 1b: The relative frequency of different forest types for selected European Countries

The numbers in the table correspond to the numbers listed and depicted in appendix 1a.

Table source: EEA (2006)¹⁹⁷

Country (no of ICP level I plots)	Category (% of the ICP level I plots)														Total Country (%)
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Andorra (3)	0	0	100	0	0	0	0	0	0	0	0	0	0	0	100
Austria (136)	0	24	65	0	3	1	6	0	0	0	0	1	0	0	100
Azores (6)	0	0	0	0	0	0	0	0	67	33	0	0	0	0	100
Belarus (405)	8	62	0	0	1	0	0	0	0	0	13	1	14	0	100
Belgium (10)	0	0	0	10	10	0	0	0	0	0	0	0	0	80	100
Bulgaria (103)	0	8	26	0	5	12	7	17	0	17	0	0	0	8	100
Canaries (13)	0	0	0	0	0	0	0	0	38	62	0	0	0	0	100
Croatia (84)	0	1	6	2	15	20	11	14	2	6	0	19	0	2	100
Cyprus (15)	0	0	0	0	0	0	0	0	0	100	0	0	0	0	100
Czech Republic (140)	0	69	1	1	9	4	4	0	0	0	0	1	3	9	100
Denmark (20)	0	0	0	0	10	30	0	0	0	0	0	0	0	60	100
Estonia (92)	7	77	0	0	1	0	0	0	0	0	12	0	3	0	100
Finland (595)	88	3	0	0	0	0	0	0	0	0	4	0	6	0	100
France (511)	0	4	9	6	24	7	5	14	4	10	0	1	2	15	100
Germany (451)	0	51	4	1	8	12	6	0	0	0	0	1	3	14	100
Greece (91)	0	0	0	0	9	2	10	19	16	43	0	0	0	1	100
Hungary (73)	0	5	0	0	21	7	0	19	0	0	0	5	7	36	100
Ireland (19)	0	0	0	0	0	0	0	0	0	0	0	0	0	100	100
Italy (255)	0	0	23	1	2	0	16	40	4	4	0	0	3	6	100
Latvia (95)	19	59	0	0	0	0	0	0	0	0	0	0	22	0	100
Lithuania (63)	5	76	0	0	2	0	0	0	0	0	0	0	17	0	100
Luxembourg (4)	0	25	0	25	25	25	0	0	0	0	0	0	0	0	100
Moldova (10)	0	0	0	0	80	0	0	10	0	0	0	0	0	10	100
Netherlands (11)	0	0	0	9	27	0	0	0	0	0	0	0	0	64	100
Norway (442)	68	4	0	0	0	0	0	0	0	0	0	0	27	0	100
Poland (433)	0	75	5	1	7	2	2	0	0	0	0	1	5	1	100
Portugal (133)	0	0	0	0	1	0	0	4	48	29	0	0	1	18	100
Romania (226)	0	1	16	0	21	22	21	10	0	0	0	0	2	6	100
Russia (134)	20	75	0	0	0	0	0	0	0	0	3	0	1	0	100
Serbia (130)	0	2	1	0	11	23	11	35	0	1	0	5	1	12	100
Slovak Republic (108)	0	5	39	0	16	26	10	1	0	0	0	0	0	4	100
Slovenia (42)	0	12	19	0	2	21	29	5	0	0	0	2	2	7	100
Spain (607)	0	0	3	2	2	0	2	9	26	43	0	0	0	12	100
Sweden (775)	50	39	0	1	1	1	0	0	0	0	0	0	6	1	100
Switzerland (48)	0	15	50	0	8	6	13	6	0	0	0	0	0	2	100
United Kingdom (85)	0	4	0	4	16	14	0	0	0	0	0	1	0	61	100
Total countries (6 368)	20	25	6	1	6	5	4	6	4	7	1	1	6	7	100

Appendix 1c: Category types of European forests

The numbers in the table correspond to the numbers listed and depicted in appendix 1a. Source: EEA (2006)¹⁹⁸

1. Boreal forest

- 1.1 Spruce and spruce birch boreal forest
- 1.2 Pine and pine birch boreal forest

2. Hemiboreal forest and nemoral coniferous and mixed broadleaved coniferous forest

- 2.1 Hemiboreal forest
- 2.2 Nemoral Scots pine forest
- 2.3 Nemoral spruce forest
- 2.4 Nemoral black pine forest
- 2.5 Mixed Scots pine birch forest
- 2.6 Mixed Scots pine pedunculate oak forest

3. Alpine coniferous forest

- 3.1 Subalpine larch Arolla pine and dwarf pine forest
- 3.2 Subalpine and mountainous spruce and mountainous mixed spruce silver fir forest
- 3.3 Alpine Scots pine and black pine forest

4. Acidophilous oak and oak birch forest

- 4.1 Acidophilous oakwood
- 4.2 Oak birch forest

5. Mesophytic deciduous forest

- 5.1 Pedunculate oak–hornbeam forest
- 5.2 Sessile oak–hornbeam forest
- 5.3 Ashwood and oak ash forest
- 5.4 Maple oak forest
- 5.5 Lime oak forest
- 5.6 Maple lime forest
- 5.7 Lime forest
- 5.8 Ravine and slope forest
- 5.9 Other mesophytic deciduous forests

6. Beech forest

- 6.1 Lowland beech forest of southern Scandinavia and north-central Europe
- 6.2 Atlantic and subatlantic lowland beech forest
- 6.3 Subatlantic submountainous beech forest
- 6.4 Central European submountainous beech forest
- 6.5 Carpathian submountainous beech forest
- 6.6 Illyrian submountainous beech forest
- 6.7 Moesian submountainous beech forest

7. Mountainous beech forest

- 7.1 South-western European mountainous beech forest (Cantabrians, Pyrenees, central Massif, south-western Alps)
- 7.2 Central European mountainous beech forest
- 7.3 Apennine Corsican mountainous beech forest
- 7.4 Illyrian mountainous beech forest
- 7.5 Carpathian mountainous beech forest
- 7.6 Moesian mountainous beech forest
- 7.7 Crimean mountainous beech forest
- 7.8 Oriental beech and hornbeam oriental beech forest

8. Thermophilous deciduous forest

- 8.1 Downy oak forest
- 8.2 Turkey oak, Hungarian oak and sessile oak forest
- 8.3 Pyrenean oak forest
- 8.4 Portuguese oak and Mirbeck's oak Iberian forest
- 8.5 Macedonian oak forest
- 8.6 Valonia oak forest
- 8.7 Chestnut forest
- 8.8 Other thermophilous deciduous forests

9. Broadleaved evergreen forest

- 9.1 Mediterranean evergreen oak forest
- 9.2 Olive carob forest
- 9.3 Palm groves
- 9.4 Macaronesian laurisilva
- 9.5 Other sclerophyllous forests

10. Coniferous forests of the Mediterranean, Anatolian and Macaronesian regions

- 10.1 Mediterranean pine forest
- 10.2 Mediterranean and Anatolian black pine forest
- 10.3 Canarian pine forest
- 10.4 Mediterranean and Anatolian Scots pine forest
- 10.5 Alti Mediterranean pine forest
- 10.6 Mediterranean and Anatolian fir forest
- 10.7 Juniper forest
- 10.8 Cypress forest
- 10.9 Cedar forest
- 10.10 Tetraclinis articulata stands
- 10.11 Mediterranean yew stands

11. Mire and swamp forest

- 11.1 Conifer-dominated or mixed mire forest
- 11.2 Alder swamp forest
- 11.3 Birch swamp forest
- 11.4 Pedunculate oak swamp forest
- 11.5 Aspen swamp forest

12. Floodplain forest

- 12.1 Riparian forest
- 12.2 Fluvial forest
- 12.3 Mediterranean and Macaronesian riparian forest

13. Non-riverine alder, birch, or aspen forest

- 13.1 Alder forest
- 13.2 Italian alder forest
- 13.3 Boreal birch forest
- 13.4 Southern boreal birch forest
- 13.5 Aspen forest

14. Plantations and self-sown exotic forest

- 14.1 Plantations of site native species
- 14.2 Plantations of non site native species and self sown exotic forest

Appendix 2: Action points and reflections from Skogsbrand Forsikringsselskap Gjensidig, Norway

- Information programmes targeting the public, target groups and key players. Such programmes should be implemented at the beginning of the fire season and throughout the year.

- What is being done at national, regional, and local levels?

- Attitude-creating workshops and campaigns are a necessary approach to change mindsets and create adapted reflexes. “Skogens brannvoktere” is an example of such initiatives; children take a forest quiz and are appointed forest firefighters and given a membership card and a cap with a logo; the programme became very popular.

- Attitude-creating projects need to be developed and coordinated nationally, regionally, and locally. Moreover, they can be used and developed by fire departments and foresters.

- Teaching and awareness raising in schools and kindergartens.

- Such initiatives are already implemented to some extent. Their structure can however be improved.

- Training and education of key target groups working in forests during fire-prone periods is crucial to prevent accidental fires and create efficient reflexes.

- Focus on contractors, forest owners, employees, railroad operators, road workers.

- Campfires are linked to many accidental forest fires. It is therefore crucial to focus efforts on creating safe and enticing fire rings that hikers and campers can use throughout the year.

- Campfire sites must be located away from risky areas to direct traffic toward safer zones.

- Information does not always reach relevant target groups; this can lead to negligence and accidental fires. Additional signage can be located at trail junctions and entrances to high-risk areas.

- Supplementary temporary signs can be added during periods of increased fire risk.

- Cooperation and communication between different actors are critical. Continued collaboration and meeting points between actors working with emergency response, crisis management, and forests are necessary.

- Existing prevention plans can be reviewed and updated with formalised joint measures, meeting points, and cooperation.

- Forest actors need access to knowledge about preventive forest management measures. To this date, the Nordic region lacks a common knowledge base and no initiative to create one has yet been launched.

- Research efforts can assess the situation in the rest of Europe. Initiatives in southern Europe can help inform a Nordic-wide knowledge base.

- Fire and emergency management remain a priority. Division of tasks and responsibilities among various actors (private and public) at different levels must however be clearly elaborated and generally agreed upon. Local, regional, and national plans must also be elaborated with local communities.

- Such initiatives require the cooperation of actors such as DSB (Norwegian Directorate for Civil Protection, Direktoratet for samfunnssikkerhet og beredskap) and MSB.

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