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Wildfire Risk in a Changing Climate

Assessing spatiotemporal trends in wildfire risk in Sweden based on meteorological indices and their alignment with past fires

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Risken för skogsbränder i ett föränderligt klimat – En utvärdering av rumsliga och tidsmässiga trender i risken för skogsbränder i Sverige utifrån meteorologiska index och hur dessa stämmer överens med tidigare bränder

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Abstract

Forest fires are a natural disturbance in the Swedish landscape. These are largely dependent on meteorological conditions. However, anthropogenic interference and climate change are shifting natural patterns of fire behaviour. The present study examined trends in weather parameters influencing forest fire activity to improve the understanding of changing fire risk in Sweden. Data from twelve weather stations of the Swedish Meteorological and Hydrological Institute in three geographical regions (northern, central and southern Sweden) were analysed to assess spatial differences between these changes. Using the Canadian Fire Weather Index (FWI), this study identified an increase in the number of fire risk days and the duration of the fire season.

Evaluating ERA 5 reanalysis data revealed an increase in maximum daily temperature and a wetting trend based on the Standardised Precipitation Evaporation Index (SPEI) across Sweden. Positive trends in fire risk were relatively stronger in the South compared to the North of Sweden. Fire risk is increasing more rapidly in spring and earlier compared to later in the summer.

Burnt areas were moderately well correlated to temperature anomalies and SPEI while FWI showed nearly no predictive power. There was an overall weak correlation of parameters with fire size. However, for all large fires, a certain threshold had to be exceeded across all parameters.

Overall, the results suggest an increasing wildfire risk across Sweden with especially strong trends in the South and earlier in the year. This will put additional pressure on firefighting resources making continuous research in this field crucial to protect lives and ecosystems.

Roavve – *a place where there has been a forest fire*

(Svonni, M. 2013, North Sami – Swedish dictionary)

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1 Introduction

Wildfires are a natural part of the boreal landscape (Flannigan et al., 2006) and an important ecological landscape process around the world (Flannigan & Wotton, 2001). Annually around 348Mha of land burn during wildfires globally (Giglio et al., 2013).

The occurrence of a wildfire is determined by three factors. The ignition source, the abundance and dryness of fuels and lastly the weather conditions (Pausas & Keeley, 2021). All these factors are influenced by meteorological variables. These include ignition sources such as lightning, controlling fuel moisture through humidity, precipitation and temperature, the fire spread for example through wind and finally natural fire suppression such as precipitation (Pareira, 2020). Annual weather patterns also influence the seasonality of wildfires (Pareira, 2020). Their occurrence is furthermore related to large scale climate variations (Page, 2008).

Anthropogenic climate change modifies weather patterns around the world and thus, also influences fire activity. Severity and frequency of fire weather increase globally (Jones et al. 2020). In some parts of the world the risk of extreme fire weather has already doubled compared to pre-industrial levels (Touma et al., 2021). Fire season becomes longer, fire prone seasons more frequent and intensities higher (Pausas & Keeley, 2021). These developments also affect the European continent, including Scandinavia where forest fires are expected to become the largest forest disturbance until the end of the century (Grünig et al., 2026).

An increase in frequency and size of wildfires causes an increase of CO_2 input into the atmosphere fuelling the greenhouse gas effect (Liu et al., 2013) while also being a health risk to humans for example because of dust particles in the air (Reid et al., 2016). Additionally, wildfires can destroy ecosystems and forestry as well as homes, spiritual, cultural and recreational areas. In the current decade the damage from wildfires as a natural disaster is estimated to make about 0.012% of the share of the global gross domestic product (GDP) (Poduška & Stajić, 2024).

The 2018 severe fire season in Sweden and the 2014 Västmanlands fire with a size of over 120km^2 has drawn special attention on wildfire risk in Sweden. Events like the 2018 fires have been found to occur at a 10% higher likelihood in the current climate compared to preindustrial times (Krikken et al, 2019). With an increase of 2°C models predict the probability of such events to double (Krikken et al, 2019). According to the Swedish Meteorological and Hydrological Institute (SMHI), fire weather risk modelled with the Canadian Fire Weather Index (FWI) will increase in southern Sweden towards the end of the 21st century while it will decrease in northern Sweden (Yang et al., 2015). Similar results were found ten years later in a new SMHI report. An increasing trend in fire weather risk for southern and central Sweden is likely, while results for northern Sweden showed a slight increase but results were not robust (Berg et al., 2024). On the other hand, data from the Copernicus Emergency Management Service (CEMS) predicts a decrease in fire weather risk according to the FWI for Sweden for 2°C warming and a decrease in the North and increase in the South for 3°C warming until the end of the century (Climate Adapt, n.d.).

Expected prolonged and more intense fire seasons in the future will increase the pressure on firefighting infrastructure (Garroussi et al., 2024). It is therefore crucial to understand spatial patterns to divide firefighting resources effectively and allow for early planning of infrastructure. Additionally, understanding the weather factors influencing wildfire risk is valuable to apply fire bans. For example, heavy machinery ignited fires accounting for 40% of the area burnt in Sweden between 1998-2015 (Sjöström et al., 2019) which could be avoided when not allowing the operation of machinery on days with high fire risk.

Therefore, this study aims at creating a better understanding of historical trends of parameters influencing fire weather risk to produce a baseline for future predictions. Additionally, it aims at analysing the performance of parameters influencing wildfire risk and their spatial distribution to allow for better planning of infrastructure and communication of wildfire risk in Sweden.

The aim is addressed following two main questions:

Q1. A) Are trends in fire weather risk already visible in historical weather data?
B) How do these trends differ spatially in Sweden? Much attention is drawn to the boreal region (e.g., Lund et al., 2023) while this study tries to make comparable spatial estimates for regions in southern, central and northern Sweden.

Q2. Which of the studied weather parameters are the best indicators of fire behaviour, namely area burnt, in Sweden?

To answer these questions the FWI was calculated based on SMHI weather station data to determine days with different risk levels and the beginning of the fire season. Since fire weather indices cannot capture all climatic changes affecting wildfires (Lund et al., 2023), additionally, a drought index, namely the Standardised Precipitation Evaporation Index (SPEI) and maximum temperature based on ERA5 data were investigated. In previous studies, drought conditions and temperature have been found to be the most influential weather variables influencing local scale wildfire behaviour and were therefore chosen to complement the FWI (Migliavacca et al., 2013; Pareira, 2020). This study focused on local weather conditions and does account little for mesoscale weather factors and ignition sources (e.g., see Flannigan & Wotton, 2001). It is therefore important to differentiate between fire weather risk and fire occurrence. Fire weather risk is defined in this study as a state where weather conditions would potentially favour the evolvement of a wildfire if it was ignited. Fire occurrence combines weather conditions favourable for wildfires with an ignition source leading to actual wildfire activity.

Based on previous literature, this study hypothesises:

H1. Trends in historical data are expected to follow similar patterns as future predictions with strongest increase in days with high fire risk in southern Sweden and a less pronounced increase or no increase in northern Sweden.

H2. The strongest correlation between wildfire behaviour and weather parameters is expected to show between FWI and burnt area as the FWI is specifically designed to predict wildfire risk.

2 Background

2.1 Swedish forests

Sweden ranges from around 55° to 70°N and 10° to 25° E. Nearly all of Sweden's forests besides the most southernmost province Scania and a small part of the southern west coast can be considered boreal forest (The Royal Swedish Academy of Agriculture and Forestry, 2024).

Over 70% of the country is covered with forest (Kumar et al., 2020) which relates to 27.9Mha forested land (SLU, n.d.). The area with forest cover is increasing and has nearly doubled during the last century (Lundmark et al., 2014). Scots pine covers 39% of this land, Norway Spruce 42% while broad-leaved species make up for about 19% of the land (Kumar et al., 2020). The distribution of these species differs spatially in Sweden (Nilsson et al., 2025). In northern Sweden Scots pine makes up nearly 50% of all trees while birch is the most abundant deciduous species. In central Sweden pine and Spruce are equally frequent with slightly higher distributions of pine and a small share of different deciduous species. Southern Sweden has the highest and most divers share of deciduous trees in Sweden. Spruce is the most abundant species with 44% (Nilsson et al., 2025).

Forestry is a strong driver of the Swedish economy (Kumar et al., 2020). Nearly 24 million hectares are declared productive forest (2024) of which the largest share is owned by individual owners followed by private companies and state-owned companies (Skogstyrelsen, n.d.). The proportion of old grown forests has decreased in Norrland over the last century while it has increased in southern Sweden (Jansson, 2011). The age of a forest can influence its fire susceptibility and fire spread (Erni et al., 2018; Binkley et al., 2007).

2.2 Fire Occurrence in Sweden

In Sweden wildfires have been part of the natural and cultural landscapes for millennia (Lindberg et al., 2020). They are a crucial part of functioning ecosystems and biodiversity in Sweden's boreal forests with many species adapted to wildfire disturbances (Eseen, 1997).

Yearly burnt area by wildfires in Sweden is approximately 3600ha in most years. Some years exhibit more extreme fire behaviour such as the fire seasons in 2018. In number of wildfires, 50% of fires are grass fires and 50% are forest fires which tend to grow larger and account for about 80% of burnt area (Plathner et al., 2026).

Historically, three major wildfire regimes can be identified for Sweden (Plathner et al., 2026). After the last ice age, Sweden experienced large fires with long return periods of 70 to 120 years depending on the region. These were naturally ignited by lightning strikes in dry summers with additionally small influence of indigenous burning practices (Plathner et al., 2026). From the 17th century expansion of settlements introduced more burning management practices. This decreased the size but increased the number of fires which began to occur more frequently (Plathner et al., 2026). Since the 18th century regulatory on burning became stricter due to an increase in industrial forestry and mining. This led to nearly full fire suppression in most of Sweden up until today (Plathner et al., 2026). This had not only implications for biodiversity (Plathner et al., 2026) but also on other sectors such as indigenous Sami land use (Cogos et al., 2019).

Though, long-term widespread fire suppression can finally result in an increase in severity of wildfires and burnt area, a phenomenon that is also described as the "suppression paradox". Fuels accumulate as they do not burn during smaller fires. As a result, these fires become more intense and suppression resistant (Kreider et al., 2024). Projects to counteract this phenomenon using prescribed and managed fires are in place in some regions such as the Life2Taiga project cofounded by the European Union (European Commission, n.d.). It is worth noting that prescribed burns are not recorded in the Swedish fire statistic (Ramberg et al., 2017).

In Sweden most fires are ignited by anthropogenic influence (Sjöström & Granström, 2023). Lightning, the only non-anthropogenic cause, accounts for the ignition of around 8% of all incidents. More common triggers are campfire and arson, less frequent than lightning is children's play and the burning of grass. For approximately 41% of all fires the ignition cause is unknown (Sjöström & Granström, 2023). However, for larger fires (>10ha) the most frequent ignition cause is lightning with above 16% and the sparking of heavy machinery. These larger fires most commonly occur in sparsely populated regions where anthropogenic influence is less pronounced (Sjöström & Granström, 2023). Thus, spatial differences between ignition sources exist in Sweden (Ou, 2017).

Yet, fires in Sweden can threaten people and livelihoods. As an example, during the Västmandlänsfire 2014, 71 houses were destroyed (Plathner et al., 2026). Additionally, fires can destroy infrastructure such as railways, streets and power lines (Plathner et al., 2026).

Given Sweden's size, there are spatial variations in wildfire activity across the country. Historically, between 1400 and 1900, large fire years had shorter return periods in the South compared to the North of Sweden (Drobyshev et al., 2014). Today, northern Sweden (Norrland) experiences least fires while area burnt is similar to the other Swedish regions. Fire frequency and area burnt in central Sweden (Svealand) and southern Sweden (Götaland) are overall similar but show variability between respective years (Ou, 2017). These differences are related amongst others to population density, forested area and climate (Touma et al., 2021). The start of the fire season varies spatially beginning about 6-8 weeks later in northern Sweden compared to the South. This can be partially explained by a longer snow cover and colder temperatures in the spring (Sjöström & Granström, 2023).

3 Methods

3.1 Data

All data is summarised in Table 2.

3.1.1 Weather station data

Weather station data was retrieved from the Swedish Meteorological and Hydrological Institute (SMHI) (SMHI, n.d.-a). The data was separately downloaded for every station and weather parameter. The downloaded data sets included historical data for the following weather parameters:

- Hourly temperature [°C]
- Daily Precipitation [mm]
- Hourly relative humidity [%]
- Hourly wind speed [m/s] and direction

Twelve weather stations were chosen for their geographical position close to past fires and full data availability for the input variables of the FWI (Table 1 and Map 1). The selected timeframe was 1995 to 2025 while some stations first included records from 1996 onwards. They were clustered into stations in northern, central and southern Sweden.

Table 1. Studied weather stations including name, location description and geographical position.

Station name	Station location	Longitude	Latitude
Arvidsjaur A	North	19.2642	65.5941
Gällivare A	North	20.6413	67.1407
Laatnivaara A	North	20.2704	67.2551
Lakatrask A	North	21.1285	66.2789
Dravagena A	Central	13.6086	62.0936
Edsbyn A	Central	15.7144	61.3607
Hamra A	Central	14.9918	61.6599
Sala A	Central	16.6843	59.9093
Ljungby A	South	13.8794	56.8525
Tomtabacken A	South	14.4645	57.4981
Ullared A	South	12.7732	57.1134
Växjö A	South	14.8296	56.8463

The data was handled using MS Excel and Python. For the input data, 12:00 noon temperature, relative humidity and wind speed were extracted. Daily precipitation is measured at 6 am while the original FWI input variable is 12:00 noon daily precipitation. Hourly precipitation was not available for all stations and the error resulting from this 6-hour difference was accepted for larger data availability. Missing dates were found using Excel's XLOOKUP function. Missing data was filled using linear interpolation, calculating the mean value of the two closest in date available data points.

The geographical classifications South, Central and North are chosen by the author and do not align with the exact North-South position in Sweden but rather their relative position to one another (see Map 1).

3.1.2 ERA5 data

ERA 5 data was chosen to complement the weather station data due to a larger temporal distribution. Additionally, the drought index was not available from weather station data.

The ERA5 data set is the fifth generation of global climate reanalysis data since 1940 from the European Centre for Medium-Range Weather Forecasts (ECMWF). It is based on data assimilation combining weather forecasts and observations. It contains atmospheric, ocean-wave and land-surface estimates for the time span 1940 until now. The temporal resolution is hourly, the horizontal resolution for atmospheric reanalysis data 0.25° x 0.25° (Hersbach, 2020).

Gridded ERA5 data was retrieved from the Copernicus online data portal (Copernicus Climate Change Service, 2023). The data sets downloaded included:

- Maximum temperature since closest data assimilation 15:00 UTC [°C]
- Standardised Precipitation Evapotranspiration Index (SPEI) (daily) [unitless]

All data was downloaded for all days and years available. Larger data sets needed to be downloaded for two time periods and later be combined using Python. Maximum temperature was chosen at 15:00 UTC as an approximation for daily maximum temperature. Time was converted from Kelvin to Celsius using a value of absolute zero of -273.15°C. Time series for the locations of the SMHI weather stations were retrieved for one point in the gridded data using Python. Despite the dataset being gridded the data points were chosen at the exact same locations as the weather stations for better comparability rather than closer proximity to past wildfires.

To determine monthly anomalies, a mean value for every month of the year was determined over the course of all available years. This mean value was then compared to the mean value of the month of a respective year.

3.1.2.1 SPEI

The SPEI is a widely applied drought index (Beguería, 2014). It was developed by Vicente-Serrano et al. and proposed in 2010. It combines precipitation and temperature data in one index. The SPEI uses monthly or weekly differences between precipitation and potential evapotranspiration as input data. It is based on the original Standardised Precipitation Index (SPI) which is based solely on monthly or weekly precipitation data (Vicente-Serrano et al. 2010). The SPEI follows the drought severity classification scheme of the standardised drought indicators with 7 subcategories ranging from extremely dry (indicator ≤ -2) over near normal or mild (-1 < indicator ≤ 1) and finally extremely wet (indicator ≥ 2) (Rosso et al., 2025). Thus, the lower the indicator the drier the soil. Rosso et al. (2025) highlight the importance of including temperature through potential evapotranspiration in their study of drought indices in Sweden while Ou (2017) demonstrates the applicability of the SPEI to monitor droughts conditions in Sweden. It was therefore chosen for this study.

3.1.3 Fire data for Sweden

Data on fire occurrence was retrieved from a data set provided by the Copernicus Climate Data Store and is in the following referred to as the "Copernicus fire data set" (Matsala & Jones, 2025). This data includes fires in Sweden with a size above 10ha for the time span 2016 to 2023 and additionally the Västmanland's fire from 2014. Fire data is based on the Skogstyrelsen

Skogsbränder Map 2020, the EFFIS burned area map and satellite products (Matsala & Jones, 2025).

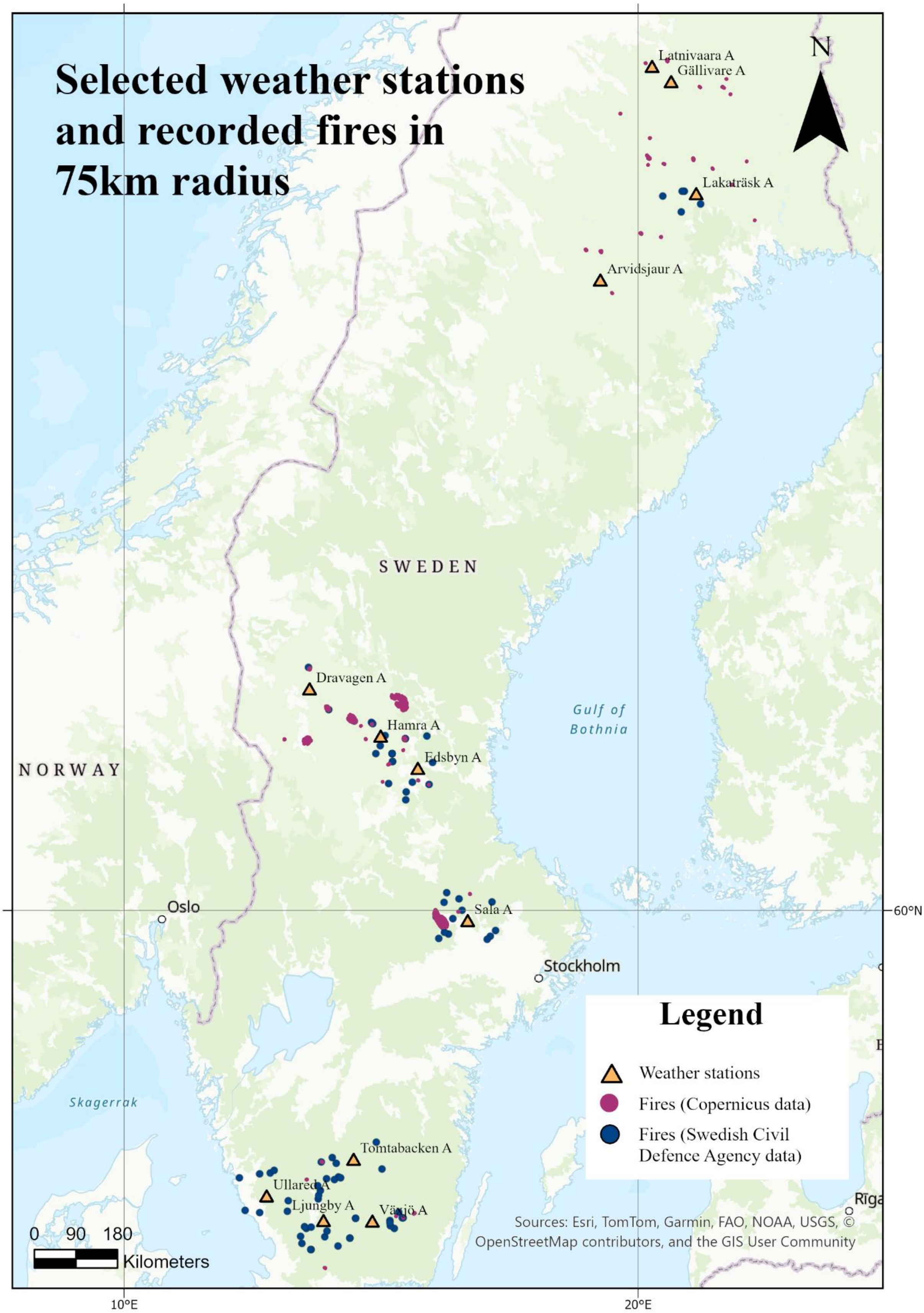
Additional fire data was requested from the Swedish Agency for Civil Defence (Myndigheten för Civil Försvar) via email. This data included two data sets were one ranging from 1998 to 2017 and on ranging from 2018 to 2025. The two datasets differentiated between different landscape sub-classes. However, both data sets were summed, and all landscape types were counted together as the research question does not specify or analyses the effect of landscape types on wildfire. Only fires of 10ha and above were considered to account for weather as driving factor for fire risk using the threshold proposed by Lehtonen et al. (2016) and to make data more comparable to the Copernicus data set. This tries to eliminate fires that occurred due to an ignition source but did not evolve due to insufficient fire weather conditions.

Trends in fire occurrence and area burned were analysed in different geographical regions. For this purpose, Sweden was divided into three equal parts of North-South distance.

The data lacked coordinates for nearly one third of the total recorded fires above 10ha. Only municipality (*kommun)* was recorded. These were deleted from the dataset as location was not clear, especially in regions such as northern Sweden where municipalities are large in size. Additionally, assigning one coordinate per commune would have resulted in several fires being recorded in the exact same spot.

Table 2. Summary of all data names, description, time span and data sources.

Data name	Description	Time span	Source
(SMHI) weather station data	Hourly temperature [°C]; daily precipitation (mm); hourly relative humidity; hourly wind speed [m/s] and direction; based on station measurements	1995/1996 - 2025	SMHI, n.d.-a
(ERA 5) Reanalysis data	Drought index (SPEI) daily; Maximum temperature at 15:00 UTC [°C]; based on reanalysis data	1940-2025	Copernicus Climate Change Service, 2023
Copernicus fire data set	Fire data in Sweden based on local and satellite data	2016 – 2023 + one fire in 2014	Matsala & Jones, 2025
Fire data from the Swedish Civil Defence Agency	Fire data in Sweden based on records from firefighting instances	1998-2025	Email contact with Myndigheten för Civil Försvar



Map 1. Locations of the studied wildfires and weather stations in Sweden. Displayed are all wildfires in a radius of 75km around a weather station for the dataset from Copernicus (polygons) and the dataset from the Swedish Civil Defence Agency (points).

3.2 The Canadian Fire Weather Index

Different indices exist to describe the relationship between the risk of wildfire occurrence and spread and weather parameters (Eriksson et al., 2023). The Canadian fire weather index was introduced in 1970 and is a widespread unitless index for fire weather risk not only in Canada but many parts of the world (van Wagner, 1987). It is often and, in the following, referred to as Fire Weather Index (FWI). The FWI is a measure to assess weather conditions on their fire risk for a standard pine forest. Thus, it measures the danger of fire spread if an ignition source were to be present. It is a crucial tool for fire management teams to understand the spatial distribution of daily fire risk and communicate it to the public (Government of Canada, 2025). It uses the four meteorological input variables Temperature, Relative Humidity, Wind and Rain to assess the fuels' flammability in three different soil layers. The Fine Fuel Moisture Code is an indicator for the highest soil level, the Duff moisture code for the second soil layer and the drought code for the deepest soil layer. Combining these codes with wind computes fire behaviour indices for two soil layers which are finally combined in one fire weather index (Fig. 1) (Government of Canada, 2025).

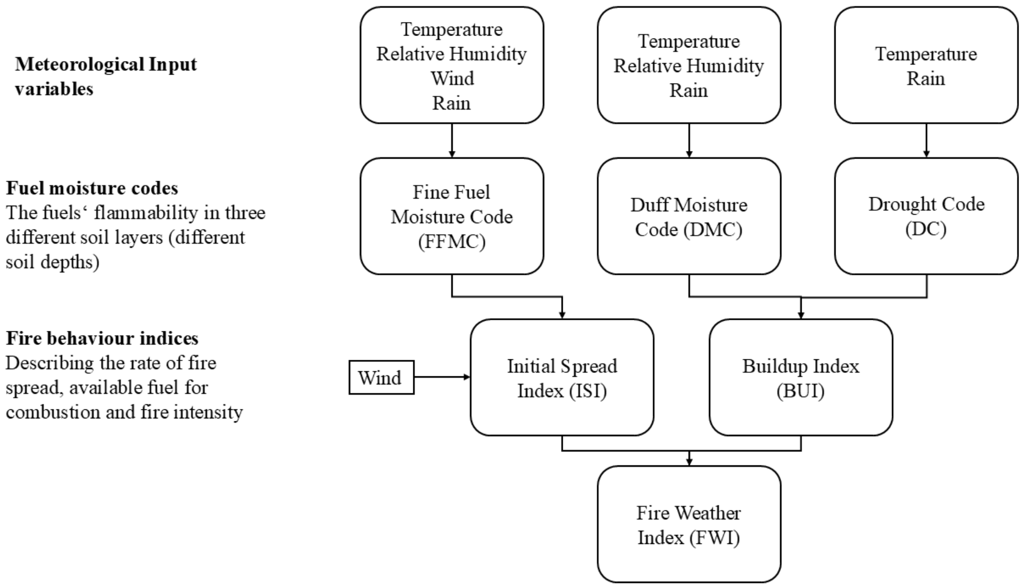


Figure 1. The Structure of the Canadian Fire Weather Index based on meteorological input variables (Government of Canada, 2025).

In a review by Erikson and Johansson (2020) several wildfire indices were analysed for Sweden. Four were found to be most applicable and were tested in their alignment with actual past fire behaviour (Eriksson et al., 2023). The Canadian Fire Weather Index (FWI) was found to be most applicable for Sweden and was therefore chosen to be analysed in this study. Furthermore, despite being originally designed for standard pine forests the FWI is the index used commonly in Sweden and the European Forest Fire Information System for all forest types (EFFIS – fire danger forecast, n.d.) to determine fire weather risk.

3.2.1 Calculation of the FWI

The Canadian Fire Weather Index was computed in Python using a code provided by the Canadian Government (Wang et al., 2015) based on the calculations presented in the original brochure on the FWI (van Wagner & Pickett, 1995). Daily fire rating is based on the conditions of previous days. Therefore, to begin the calculation starting values are required as no data on previous days is available for the first day in the calculation. These starting values are reset in the beginning of each year. Starting values were adapted from Lawson and Armitage (2008) with FFMC = 85, DMC = 6 and DC = 15. The conversion of units was performed beforehand in Excel.

From the daily fire weather risk, the number of days with moderate, high, very high and extreme fire weather index were retrieved. The thresholds for moderate, high, very high and extreme fire weather index were based on the values from EFFIS and applied to the daily calculated FWI value (*EFFIS - Fire danger forecast*. (n.d.) (Table 3).

Table 3. Fire weather risk classes for the FWI following EFFIS -Fire danger forecast (n.d.) rating.

Danger class	FWI value
Low	<11.2
Moderate	11.2-21.3
High	21.3-38.0
Very High	38.0-50.0
Extreme	50.0-70.0
Very Extreme	>70.0

The category "very extreme" was not observed for any station or time and was therefore neglected. The year 1995 was not counted in for the analysis of trends as data was only available from August 1995, and thus, the number of days with risk is not representative for the whole year.

3.2.2 Calculation of season length

To determine the length of fire season different approaches exist. Most only consider the beginning of the fire season which was adapted in this study. One approach is temperature based (e.g.,Wotton & Flannigan 1993), marking the beginning of the fire season with 3 consecutive days over 12°C. Alternatively, fire season length can be based on the exceedance of a FWI threshold for a certain period (Moriondo, 2006). For this study the beginning of the fire season is defined as three consecutive days over the threshold for moderate fire risk (FWI≥11.2).

3.2.3 Analysis of the input variables

Trends for all input variables were calculated for the study period (1996 to 2025). Additionally, further analysis was performed.

3.2.3.1 Heatwaves

Heatwaves were defined following the SMHI definition for "Värmebölja" with 5 consecutive days above 25°C (SMHI, n.d.-b). Using this, the number of heatwaves per year was calculated on the input data for the FWI. Time of measurement of these values is 12 pm rather than maximum temperature per day which can underestimate the number of heatwaves per year.

3.2.3.2 Peak temperature

The peak value for temperature was defined as the highest temperature value achieved per year. Trends were based on this value for every station.

3.2.3.3 Dry days

The number of dry days was counted per year as the number of days with less than 1mm of rain over 24h.

3.3 Statistical analysis

3.3.1 Statistical analysis of trends

To assess the statistical significance of historic trends p-values were calculated using linear regression. Statistical significance was defined as $p < 0.05$.

3.3.2 Alignment with past fires

The three main variables FWI, SPEI and maximum temperature anomaly were correlated with the area burnt of each wildfire in 75km range around a weather station. This distance was chosen as a compromise to both allow for similar weather conditions between station and fire position but also to guarantee a sufficient amounts of fires within the radius of each station. These fires were retrieved using ArcGIS' spatial selection too. Monthly maximum temperature anomaly instead of maximum daily temperature was chosen to investigate whether hotter conditions than normal favour larger fires and to account for spatial differences in average temperature between southern and northern Sweden. The anomaly was calculated based on temperature data between 1940 and 2025 for each month respectively. For SPEI and maximum temperature anomaly only one value per month was available. This one monthly value was matched with every day with a recorded fire in that month. For FWI the daily value was matched with the exact day of the fire occurrence. Correlation analysis was performed using MS Excel's built-in correlation function. The analysis of the strength of correlation coefficients (r) was based on Cohen's conventions for correlation coefficients (Cohen, 1969).

Both datasets included the Västmansland fire which is over two times larger than the second largest fire in the data set. Correlation was performed once including this fire and once treating it as an outlier as it is the only fire of its size. To assess spatial differences the analysis was additionally performed for the three different regions individually

4 Results

4.1 FWI

4.1.1 Development of days with moderate, high and very high fire weather

Trends vary strongly between the different stations. The increase in days with moderate fire weather risk is higher than the increase in high fire risk in southern Sweden and northern Sweden while the opposite is true for three out of four stations in central Sweden (Table 4). Days with very high risk are rare over all stations and trends very low.

In most cases stations in the South experience the highest increase in days with moderate and high fire risk. The strongest increase is found for Tomtabacken A where the number of moderate risk days increases by more than one day per year and the number of high-risk days by nearly one day every two years. This station also showed the most significant trend. Ullared A has a distinctively lower increase in moderate fire risk days than the other stations in southern Sweden with less than one day per three years.

On average stations in central Sweden showed the least increase in days of moderate fire days (0.2/year) while northern Sweden showed the least increase for days with high and very high fire risk (0.17 and 0.01/year). However, one station in northern Sweden, namely Lakaträsk A, showed a deviating trend from the other stations in this region with comparably lower and even negative trends (0.04 and -0.01/year).

Differences between trends in moderate fire risk were more pronounced between the South and the other two regions compared to the increase in days with high fire risk which was more similar between all regions. In all regions most trends were not significant possibly because of high climate variability and a short data period. However, more significant trends were found in southern Sweden, making this region the area with the highest likelihood of increasing trends.

Days with extreme fire risk were only recorded for Ljungby A and Växjö A in 2008 (both 1 day) and Växjö A (2 days), Tomtabacken A (1 day) and Arvidsjaur A (2 days) in 2018. They occur rarely in Sweden but most frequently in the South.

*Table 4. Trends for the occurrence of days with moderate, high and very high daily FWI for each SMHI station individually and the mean over all stations [change in days with x fire risk/year]. Significant results are marked with * for p<0.05, ** for 0.01 and *** for p<0.001. 1996-2025.*

	Moderate	**p-value**	**High**	**p-value**	**Very High**	**p-value**
Tomtabacken A	1.09*	<0.001***	0.43*	0.04*	0.04	0.08
Ullared A	0.3	0.33	0.22	0.18	0.004	0.78
Växjö A	0.84	0.05	0.48	0.08	0.08	0.18
Ljungby	0.62	0.06	0.39	0.05	0.04	0.23
Edsbyn A	0.12	0.75	0.27	0.15	0.03	0.05
Hamra A	0.18	0.48	0.19	0.11	0.004	0.40
Sala A	0.33	0.36	0.17	0.51	0.05	0.30
Dravagen A	0.17	0.54	0.18	0.16	0.005	0.59
Gällivare A	0.3	0.27	0.14	0.19	0.003	0.40
Latnivaara A	0.4	0.13	0.24*	0.02*	0.007	0.45
Asrvidsjaur A	0.4	0.31	0.28	0.18	0.04	0.21
Lakaträsk A	0.1	0.78	0.04	0.85	-0.007	0.48
South	0.71		0.38		0.04	
Central	0.2		0.20		0.02	
North	0.29		0.17		0.01	

FWI mostly increased in the spring and early summer while decreased in August and September. There is little change in the winter months which are outside the Swedish fire season. The strongest increase is given for southern Sweden in April, May and June (0.1, 0.19 and 0.22/year) while northern Sweden experiences the strongest increase between the regions in July (0.13/year) (Fig. 2).

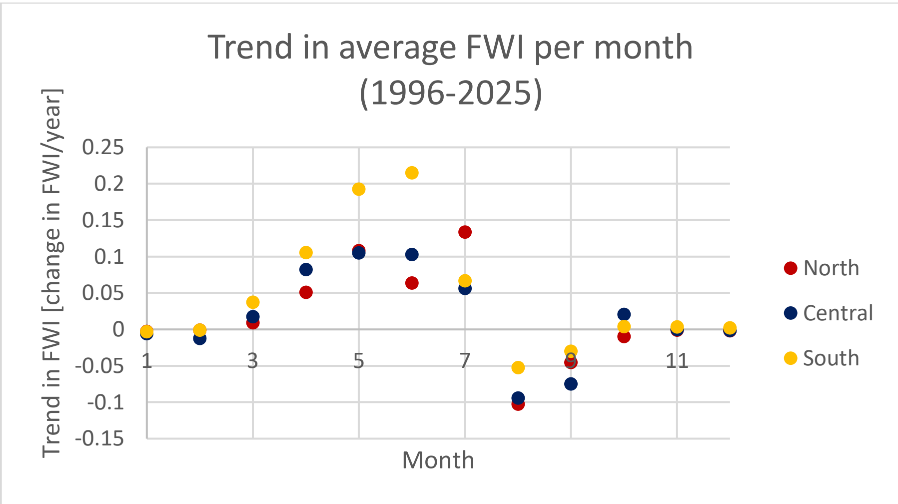


Figure 2. Trends in FWI per month averaged over four weather stations in each region (North, Central, South). Increase is highest in spring and early summer. 1996-2025.

4.1.2 Beginning of fire season

For most stations fire season starts on average earlier every year varying to an earlier shift to 0.34 and 1.03 days per year. Two stations in central Sweden show a trend to a later season start with 0.05 and 0.25 days per year. The strongest change can be observed for Ljungby A (-0.88 days/year) while on average the stations in the North have the strongest shift towards an earlier season start (-0.82 days/year) (Table 5). Thus, a stronger increase in moderate and high fire days not necessarily align with the strongest shift to an earlier fire season date following the described definition.

It is worth noting that for some stations the defined threshold was not met for all years meaning that in some regions according to the definition fire season did not start in that year. Gällivare A and Latnivaara A missed 4 and 5 years, while Ullared A missed 3 and Dravagen A and Edsbyn A both missed one year. For these stations no p-value was computed due to the lack of full data. Thus, most years without a recorded beginning of fire season were present in northern Sweden. This could have created an observation bias towards strongest shift in Gällivare A, Latnivaara A and Dravagen A as it is possible that only years with high fire risk were recoded which also exhibited an earlier fire season start. However, the two stations in the North where fire season start was dated for every year showed the highest shift towards an earlier season start (-0.61 and -0.63 days/year) after Ljunby A and also had the low p-values (0.05 and 0.07).

*Table 5. Trends for the begin of the fire season based on the FWI for each SMHI station individually and the mean over all stations in one geographical area [days/year]. A negative trend indicates a shift to an earlier start of the fire season. Significant results are marked with * for p<0.05, ** for 0.01 and *** for p<0.001. 1996-2025.*

	Beginning of season start trend [days/year]	**In days (over 30 years)**	**p-value**
Tomtabacken A	-0.44	-13.13	0.54
Ullared A	-0.34	-10.25	
Växjö A	-0.59	-17.61	0.14
Ljungby	-0.88	-26.30	0.62
Edsbyn A	0.05	1.56	
Hamra A	0.25	7.60	0.62
Sala A	-0.37	-10.98	0.42
Dravagen A	-1.00	-29.94	
Gällivare A	-1.03	-31.04	
Latnivaara A	-1.00	-29.88	
Asrvidsjaur A	-0.61	-18.31	0.07
Lakaträsk A	-0.63	-19.01	0.05
South	-0.56	-16.82	
Central	-0.26	-7.94	
North	-0.82	-24.56	

4.1.3 Input variables

The input variables from the weather station data showed a minimal change in relative humidity, precipitation, temperature and wind speed over the last 30 years.

4.1.3.1 Heatwaves

In most stations a small increase in the number of heatwaves per year is present with one to two more heatwaves per century. The only region with significant results is northern Sweden. The increase ranges between 2.5 and 1.2 heatwaves per century while Latnivaara A did not record any heatwaves over the study period and thus no trend is given. Both in southern and central Sweden one station respectively shows a decreasing trend. However, changes are only visible on a century scale.

4.1.3.2 Peak temperature

When only considering the maximum 12 pm temperature reached per year a trend is visible with values between 0.04° and 0.11° per year over the past 30 years for all regions. This was strongest and most significant in the North and weakest in the South (Table X1). This aligns with the results for heat waves which also found the strongest increase in northern Sweden.

4.1.3.3 Dry days

The number of days without rain decreased for all stations. Trends showed significant results for Latnivaara A, Gällivare A and Dravagena A. The strongest decrease was visible in northern Sweden with on average 1.68 days/per year, followed by central Sweden with 1.66 days/year. The weakest increase is present in southern Sweden with 1.33 days/year. Thus, all regions become wetter with a higher spread of rain days while this trend is stronger in northern and central Sweden compared to the South.

Looking at months individually a decrease in dry days is given for January, March, August September and December for all regions. February, April, June and November showed an increase for all regions. All other months showed increasing trends for southern Sweden while either central or northern Sweden showed a decreasing trend. The strongest increase in dry days can be found for November and February in Northern Sweden (0.13 and 0.15 days/year) as well as April, Mai and June in southern Sweden (0.08, 0.11 and 0.11 days/year) (Fig. 3). Most stations found significant trends in December, January and February while trends in summer generally showed lower significance.

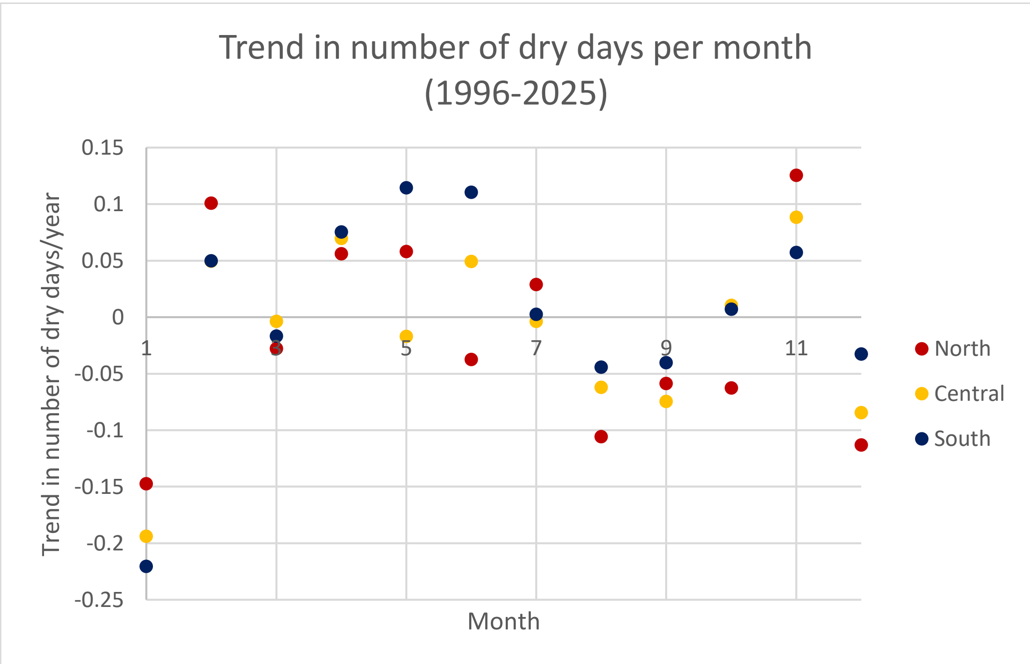


Figure 3. Trends in the occurrence of dry days per month averaged over four weather stations in each region (North, Central, South).Dry days become more frequent in spring and early summer. 1996-2025.

4.2 Development of maximum temperature

Maximum afternoon temperature increased over all stations varying between nearly 2° and over 2.5° per century. On average, the strongest increase in maximum afternoon temperature is found for stations in southern and central Sweden with on average 2.5° and 2.3° per century. The North experienced the smallest increase in maximum temperature over the past 86 years with on average 2.1°C/century (Table 6). The variability between stations of one region is lower than between the results for the FWI (Table 4) possibly related to the difference between reanalysis and weather station data. Trends in maximum temperature were significant for all stations ($p < 0.001$).

*Table 6. Trends in maximum temperature for the 12 stations and mean values for the trends in the specific regions based on ERA5 data [°C/year]. Significant results are marked with * for p<0.05, ** for 0.01 and *** for p<0.001. 1940-2025.*

	Maximum temperature trend [°C/yr]	**Increase over the measuring period [°C]**
Tomtabacken A	0.024***	2.05***
Ullared A	0.024***	2.02***
Växjö A	0.025***	2.12***
Ljungby	0.025***	2.14***
Edsbyn A	0.024***	2.04***
Hamra A	0.022***	1.88***
Sala A	0.024***	2.07***
Dravagen A	0.022***	1.88***
Gällivare A	0.021***	1.81***
Latnivaara A	0.023***	1.95***
Asrvidsjaur A	0.020***	1.67***
Lakaträsk A	0.020***	1.71***
South	0.025	2.08
Central	0.023	1.97
North	0.021	1.79

Maximum temperature has increased in all 12 months of the year. The strongest increase is present during the winter months (over 5°C/century in January), with less pronounced change during the summer months (up to 1°C/century in July). In most months, southern Sweden shows the strongest increase in temperature while this trend is less pronounced in northern Sweden. The opposite is true for May and June (Fig. 4).

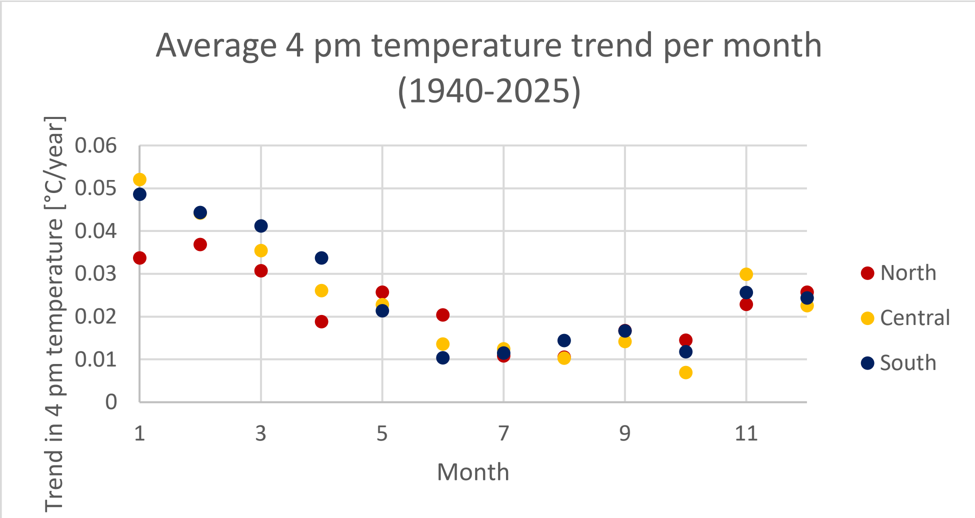


Figure 4. Trends in afternoon temperature (15:00 UTC, 16:00 CET) per month averaged over four weather stations in each region (North, Central, South). Increase is highest winter. 1940-2025.

4.3 Development of Drought Conditions in Sweden (SPEI)

A positive trend in the SPEI exists for all stations ranging from 0.003 to 0.006 meaning that all stations experience a wetting trend. This wetting trend is strongest in the North with on average 0.006 index points per year, while it is lowest in central Sweden with on average 0.002 index points per year. Thus, on average, the increase in SPEI is nearly three times as large in the North compared to the stations in central Sweden (Table 7). Generally, this wetting trend is counteracting the increase in fire risk based on increasing temperature and FWI. However, this opposing trend is strongest in the North where wildfire risk is predicted to increase least.

*Table 7. Trends in SPEI for the 12 stations and mean values for the trends in the specific regions based on ERA5 data [change in SPEI/year]. Significant results are marked with * for p<0.05, ** for 0.01 and *** for p<0.001. (1940-2025)*

	SPEI trend [SPEI/year]	p-value
Tomtabacken A	0.003*	0.02*
Ullared A	0.004***	<0.001***
Växjö A	0.002	0.12
Ljungby	0.003*	0.04*
Edsbyn A	0.001	0.3
Hamra A	0.002	0.22
Sala A	0.001	0.42
Dravagen A	0.004***	<0.001***
Gällivare A	0.006***	<0.001***
Latnivaara A	0.006***	<0.001***
Asrvidsjaur A	0.005***	<0.001***
Lakaträsk A	0.007***	<0.001***

South	0.0029
Central	0.002
North	0.0057

A wetting trend is visible for most months except April where all regions experience a drying trend. This drying trend is most pronounced in southern Sweden with nearly 0.01 index points per year. Additionally, southern Sweden also shows a slight drying trend or no trend for August, September and May. The wetting trend is most pronounced in northern Sweden in most months except February, June and October where southern Sweden shows the strongest wetting trend. In general January and October are the months with the highest wetting trends reached (0.017 index points/year in northern Sweden and 0.013 index points/year in southern Sweden) (Fig. 5).

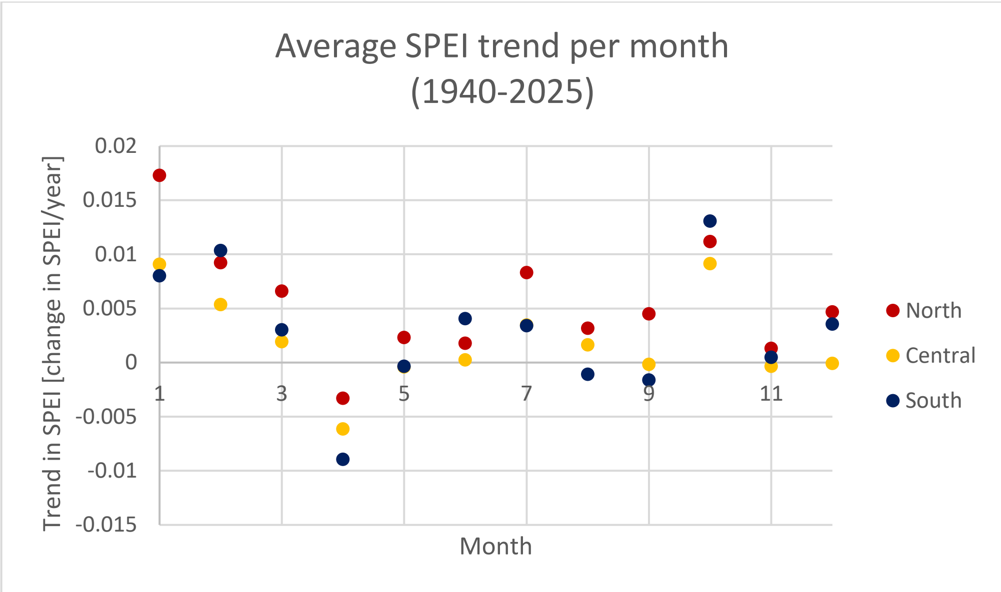


Figure 5. Trends in SPEI per month averaged over four weather stations in each region (North, Central, South). Positive trends relate to a wetting trend, negative trends to a drying trend. 1940-2025.

4.4 Alignment with past wildfires

4.4.1 Evolvement of past fires

Using the data set from the Swedish Civil Defence Agency a slight declining trend can be observed for the number of fire occurrences with a size above and equal 10ha with -0.3 fires/year (1998-2025). This trend is strongest in the South. Trends are not statistically significant. Area burnt in fires of 10ha and above increased over the whole of Sweden with a factor of 70.96 ha/year ($p = 0.54$).

The Copernicus dataset only covers eight years, making trends less robust. A significant decrease of -4.52 counts/year ($p = 0.04$) from 2016 to 2023 was found for all of Sweden. Area burnt decreased by -3.000.000 ha/yr ($p= 0.14$).

4.4.2 Correlation of fire size and meteorological parameters

Using the dataset from the Swedish Civil Defence Agency, the lowest correlation coefficient (r) is found for FWI and fire size with r=0.07 meaning that nearly no correlation exists. The highest correlation was found between temperature anomaly and fire size with r=0.23. SPEI and fire size are negatively correlated with r= -0.14 meaning that drier conditions lead to larger fires. However, these two correlations indicate a weak to moderate relationship between area burnt and meteorological parameters. The correlation between any two of the three factors is larger than the correlation between fire size and meteorological indices. When treating the one fire above 5000ha as an outlier, correlation coefficients become higher for all parameters with temperature anomaly (r=0.31), SPEI (r= -0.21) and FWI (r=0.1). The strongest correlation is found for temperature anomaly followed by SPEI.

Nevertheless, when classing fires in small (10-100ha) and large fires (>100) a relationship between large fires and all parameters is visible (Table 8). Looking at FWI, on average, smaller fires (10-100ha) correspond to a FWI value below 20. On the other hand, for nearly all fires above 200ha the FWI shows values above 20 and for most even above 25. Similar can be observed for temperature anomaly and SPEI where larger fires are related to temperature anomalies above 2° and SPEI below -1. For the fires 400-500ha one outlier of FWI = 4.37 causes the FWI for this size class to be below 20.

Using the dataset from Copernicus correlation coefficients are lower. All correlations are weak with temperature anomaly r=0.11, FWI r=0.08 and SPEI r=0.01. The dataset is smaller than the dataset from the Civil Defence Agency with 135 in comparison to 308 recorded fires.

When treating the large fire as an outlier, the correlation coefficients of the Copernicus dataset become r=0.06 (FWI), r=0.29 (Temperature anomaly) and r=-0.23 (SPEI). Temperature anomaly seems to have the strongest impact on the size of a wildfire, followed by SPEI which is the same finding as for the other dataset.

As for the dataset from the Swedish Civil Defense Agency, despite the low correlation coefficients sorting fires in bins shows that larger fires typically relate to average higher values in FWI and temperature anomaly and drier conditions according to the SPEI (Table 8). Thus, larger growing fires are connected to larger FWI and temperature anomaly as well as lower SPEI values even if no clear linear relationship between fire size and FWI exists. This also becomes visible when comparing the correlation coefficients with and without the >5000ha fire: Taking one very large fire out increases the strength of the correlation.

The different values for the three indices for the one fire with size >5000ha (Table 8) can be explained by different recording dates of the same fire with 04.08.2014 from Copernicus and 31.07.2014 from the Civil Defence Agency. Thus, the dates in the fire statistic are not always reliable and weather conditions might have been different between actual fire occurrence and the day that the fire was recorded.

Table 8. Mean values of FWI, temperature anomaly [°C] and SPEI for different sizes of wildfires with data from the Swedish Civil Defence Agency (SCDA) and Copernicus (COP).

	FWI		**Temperature anomaly [°C]**		**SPEI**	
Fire size [ha]	**SCDA**	**COP**	**SCDA**	**COP**	**SCDA**	**COP**
[10–50]	18.06	20.75	1.72	2.49	-0.52	-1.06
(50–100]	22.15	32.42	1.87	3.71	-0.73	-1.41
(100–200]	19.96	23.72	2.96	4.63	-0.94	-1.51
(200–300]	25.78	N/A	3.84	N/A	-1.40	N/A
(300–400]	28.81	N/A	4.62	N/A	-1.56	N/A
(400–500]	19.13	N/A	1.68	N/A	-1.05	N/A
(500–1000]	28.76	26.26	5.87	5.71	-1.69	-1.65
(1000–5000]	24.12	24.6	5.64	5.71	-1.71	-1.65
> 5000	20.71	30.78	3.18	0.08	-0.75	0.3

Spatial differences exist between the performance of wildfire parameters (Table 9). FWI did not show strong correlation for any region but for southern Sweden in the Copernicus data set.

However, the Copernicus data set in southern Sweden was small with only 14 entries. Only one large fire was recorded (>100ha) that had comparatively low FWI and temperature anomaly values which caused the correlation to be negative. Furthermore, two fire days were connected to six and three fires respectively making up for over half of all records. Results are therefore not robust. Results for central Sweden were taken without the fire above 5000ha.

Temperature anomaly performed best in three cases, in central Sweden for both datasets (r=0.33 and r=0.42) and in the North (r=0.46) according to the Copernicus data set. Temperature anomaly additionally had the highest positive correlation coefficient amongst all data. SPEI performed best in two cases with r= -016 in southern and r= -0.25 in northern Sweden. Overall, it showed the highest correlation coefficients in northern Sweden (-0.36 and -0.25).

Table 9. Correlation coefficients for three weather parameters and burnt area based on the fire data set from Copernicus and the fire data set from the Swedish Civil Defence agency. Correlation was performed for the whole data set and for the three regions separately. The correlation treated the Västmanslands fire (fire above 5000ha) as an outlier. The strongest correlation per region and dataset is marked in bold.

		Overall	**South**	**Central**	**North**
Copernicus	**FWI**	0.06	**-0.67**	0.09	0.07
	Temperature anomaly	**0.29**	-0.48	**0.33**	**0.46**
	SPEI	-0.21	-0.12	-0.29	-0.36
Civil Defence Agency	**FWI**	0.1	0.12	0.13	0.09
	Temperature anomaly	**0.31**	0.08	**0.42**	0.21
	SPEI	-0.23	**-0.16**	-0.31	**-0.25**

5 Discussion

5.1 The Fire Weather Index

5.1.1 Trends in days with moderate, high and very high fire risk

Looking at trends for days with moderate, high and very high fire weather risk all three regions experienced an increase in fire risk days over the past 30 years. The increase is strongest in southern Sweden (0.71 moderate and 0.38 high risk days per year) (Table 4). This is in line with trends for future climate predictions where days with high FWI will become more frequent in Sweden with significant and strongest results in the South (Berg et al., 2024; Yang et al., 2015). It is opposing the model from the CEMS which predicts a decrease in fire weather risk with 2°C warming (Climate Adapt, n.d.). However, CEMS only considers trends in FWI rather than days with certain risk levels. Yang et al. (2015) additionally explain the importance of region specific bias correction which was not applied for the data set from CEMS. FWI seems to exhibit a slight decrease in the North (Torres-Vázquez et al., 2025) which is the region with weakest increasing trends in this study (Table 4). Torres-Vázquez et al. (2025) explain this with a lower susceptibility to atmospheric blocking and a weaker influence of persistent extreme weather conditions in this region.

Torres-Vázquez et al. (2025) do not find an increase in fire synchronicity in northern Europe contrary to central and southern Europe. Changes in fire patterns seem to be more localised rather than affecting the whole region (Drobyshev, 2012). With global warming FWI is expected to show even increased variability (Lund et al., 2023). This variability could also be the reason for low significance in trends as data only covered a short time period of 30 years where climate variability can influence trends.

Looking at individual trends for risk days of FWI the station Ullared A shows a different trend from the other stations in southern Sweden (Table 4). Of the four stations it is located closest to the Swedish Westcoast with only 30km distance from the sea, making maritime influence an important driver for humidity (Mascaut et al., 2026). In southern Sweden an east-west gradient was found with a generally more humid summer climate along the western coast (Drobyshev et al., 2012) as predominantly westerly winds in Sweden in the summer can transport humid air to coastal regions (Mascaut et al., 2026). Thus, humidity in this region is more regulated while being an important factor for wildfire behaviour which could explain weaker trends for Ullared A.

When analysing monthly trends (Fig. 2) August and September show a decrease in average FWI while April, May, June and July show an increase in average FWI. Thus, fire risk increased in late spring and early summer and decreased in later summer. The strongest increase can be observed for June and July. Between the regions, the South was again the region with the strongest increase aligning with results in Table 4 and predictions from Berg et al. (2024). This can be related to an increase in drought frequency in spring in Scandinavia found between 1981 and 2015 especially for southern Sweden (Spinoni et al., 2017) which affects the FWI output. Similar is found for the results in figure 3 which show an increase in dry days especially in southern Sweden in the spring. On the other hand, wetting trends during the summer could be an explanation for decreasing fire risk and number of dry days in August and September (Spinoni et al., 2017).

Comparing the FWI to actual fire occurrence over the past 25 years, Sjöström and Granström (2023) did not find an increasing trend in fire occurrence and burnt area or a shift in beginning of the fire season. Despite this being a short observation period, it does not align with the increase in FWI (Table 3) and the shift to an earlier season start (Table 4) found in this study while being similar to the analysis of fire occurrence (section 4.4.1). However, the study mainly focused on the triggers of wildfires rather the affecting weather parameters. Nevertheless, the authors assume shifts in meteorological indices which have not manifested yet but will influence wildfire occurrence in the future (Sjöström & Granström, 2023). While overall fire frequency has decreased, the largest fires by area burnt have occurred in recent years (Ou, 2017). Thus, the shift to more frequent fire prone weather and increased temperature could have already shown an effect while fire suppression decreased the frequency of fires. Climate change is expected to cause an increase in mean and upper tail of the FWI distribution relating to more intense fires (Lund et al., 2023). For Finland, the number of fires and area burnt is expected to increase towards the end of the century due to increased fire weather risk. However, variability is expected to be high, and some large fires might account for a strong increase as most fires are currently effectively suppressed (Lehtonen et al., 2015). When looking at seasonal differences, the South experiences most fires in the spring, while the North records most fires in August (Drobyshev et al., 2012). This could increase fire occurrence in the South as fire weather risk and dry conditions increased strongest in the South and in Spring (figures 2, 3 and 5). On the other hand, fire weather risk decreased in August and most pronounced for northern Sweden meaning that fire season in this region might decrease in intensity.

Trends in FWI were more similar between northern and central Sweden compared to values obtained in southern Sweden for days of moderate and high fire risk (Table 3). Drobyhev et al. (2012) suggest that two different climate systems influence the development of fire prone weather in Sweden. The authors set the threshold at 59° meaning that the four stations in the South fall into one climate system, namely the North Atlantic jet stream, while the other 8 stations are stronger influenced by Arctic air masses (Drobyshev et al., 2012). Fire weather in northern Sweden is further connected to sea ice cover extent, the Atlantic Meridional

Overturing Circulation, sea-surface temperature and the development of low-pressure systems in February and March (Drobyshev et al., 2016). Nevertheless, sub-regional patterns might have a bigger impact on fire weather risk while being influenced indirectly by large-scale circulation patterns (Drobyhev et al. 2012).

5.1.2 Fire season

Fire season showed to begin earlier in all of Sweden with the strongest increase in northern Sweden with on average 8 days per decade and the lowest in central Sweden with 2 days per decade. Results were not significant but for one station in northern Sweden (Table 5). Berg et al. (2024) predict an earlier start of fire season for all of Sweden in the future with significant results only along the east coast. Yet, this study used a different definition of fire season start. Garroussi et al. (2024) expect an increase in fire season length in northern Europe with 30% more days that will require fire assistance. This increase in duration of extreme fire season could cause limitations in the possibility to adapt to this new fire risk (Carnicer et al., 2022). An earlier fire season can be partially explained by earlier snowmelt, higher spring temperatures and beginning of the growing season. However, a later ending of fire season is unlikely due to an increase in relative humidity once days become shorter in the autumn (Lehtonen et al., 2015). Changes in spring fire weather were also found when looking at monthly trends of the FWI (Fig. 2) where spring months showed a strong increase. Yet, northern Sweden experienced the lowest increase for most stations in the spring. However, season start in northern Sweden compared to the South is naturally later (Sjöström & Granström, 2023) meaning that the observed shift to earlier dates of the fire season start happens in different months.

5.1.3 Input data of the FWI

The raw input variables of the FWI did not show strong trends. However, the FWI is a complex calculation that incorporates accumulated values from previous days and combines four parameters (van Wagner, 1987). Even though on average wind, precipitation, relative humidity and temperature remained on similar levels for the past 30 years more extreme events could drive the number of days exceeding certain FWI thresholds. Dry spells and heatwaves can be driving factors for wildfire behaviour (Flanningan & Wotton, 2001). However, the data only showed a significant increase in heatwaves for northern Sweden where on the other hand the lowest increase in FWI was observed. Nevertheless, the number of dry days increased during spring and early summer making this season especially prone to wildfires. Additionally, it is also possible that even if the number of hot, dry and windy days does not change strongly these conditions coincide more frequently for example during cold frontal passages (Flannigan & Wotton, 2001).

Sensitivity analyses have been performed analysing the most contributing parameters to FWI. For Australia wind was found to be the most sensitive variable in the FWI followed by relative humidity and temperature (Dowdy et al., 2009). Wind, however, is only taken for 12 pm in the FWI and cannot account for strong winds blowing in the evening limiting the accuracy of the FWI in relationship to fire risk. Furthermore, wind is expected to show little change in Fennoscandia (Lund et al. 2023). Therefore, Lund et al. (2023) suggests a stronger focus on relative humidity and extreme temperature as they are expected to show a strong change to drier and hotter conditions in April and May in predictions for Fennoscandia. This can increase droughts in spring and influence fire season which is already observable in the results in Table 4.

5.1.4 Effect of vegetation

It is important to connect spatial changes in the FWI to species distribution around Sweden. Fuels beneath Scots pine dry faster compared to fuels beneath Norway spruce due to higher surface-to-volume ratio and less shading from the crown. Thus, pine trees are more vulnerable to high temperatures and fire occurrence in general (Plathner et al., 2026). This vegetation fire dependency is for example present in Norway where an increase in Norway spruce abundance was coupled with a decrease in fire activity (Rolstad et al., 2017). Especially northern Sweden has a high share of pine making these forests particularly vulnerable to increased fire risk. While distributions are relatively even in central Sweden, southern Sweden has a much larger share of spruce than pine. Additionally, fire resistant broadleaf specious are more abundant and diverse (Nilsson et al., 2025). Thus, southern Sweden has on average vegetation more resistant to wildfires.

This relates to findings from Drobyshev et al. (2014) who suggest that northern and mid-boreal forests were more sensitive to climatic changes than vegetation in the South. This is additionally coupled with a higher percentage of forest cover in northern Sweden (Drobyshev et al., 2014). Thus, despite weaker trends in fire risk in northern Sweden compared to southern Sweden (Table 3) vegetation in northern Sweden is more vulnerable to increasing fire risk.

In boreal North America a shift in wildfire activity due to anthropogenic climate change has already shifted the species composition of post fire regrown forests (Baltzer et al., 2021). However, in contrast to North America, Drobyshev et al. (2014) do not expect large changes in the distribution of tree species in Scandinavia due to shifts in wildfire behaviour. This is related to differences in fuel accumulation patterns and species distribution (Drobyshev et al., 2012). Additionally, managed forests make up around 85% of the Swedish forests (Skogstyrelsen, n.d.) making changes in tree species mostly dependent on anthropogenic influence.

5.2 Extreme Temperature

Results from Touma et al. (2021) suggest that temperature might be the most contributing factor to an increase in wildfire risk in northern Europe. Additionally, the decrease in fire activity in Scandinavia during the little ice age (around 1500 to 1850) underlines the importance of the connection between temperature and wildfire behaviour in Sweden (Drobyshev, 2014). As seen in Table 6 maximum daily temperature has increased in all three regions with an increase ranging between 2°C in the South and 1.7°C in North since 1940. Results are up to ten times lower than results obtained by Marcaut et al. (2026) who find an increase between 2010 and 2024 of 0.15°C per year with the strongest increase in winter of 0.3°C per year. However, the study period was shorter and only captured the more recent effects of intensified anthropogenic climate change. In future predictions temperature could rise up to 6° in Sweden by the end of the century in winter with northern Sweden expected to experience the strongest warming (Lind & Kjellström, 2008). This aligns with findings from this study which find the strongest warming trend in the winter months with up to 5°C per century (Fig. 4). However, northern Sweden only showed the strongest increasing trend amongst the three regions in December, May and June. Marcau et al. (2026) on the other hand find the strongest increase in winter temperatures in southern and central Sweden which relates closer to the findings of this study (Fig. 4). Increased winter temperatures can influence snow cover, snow covering season and vegetation growth affecting drought conditions later in the season (Dierauer et al., 2021). Additionally, earlier snowmelt reveals dry fuels that are easily ignited while vegetations has not started to green yet favouring winter and spring fires (Miller et al., 2025). This effect is also known as “spring-dip” (Parisien et al. 2023). Warming winter temperatures are especially important in northern Sweden where snow cover reaches the largest extent amongst the three study regions. Not considering snow cover can lead to an underestimation of wildfire risk (Lund et al., 2023).

Even though the winter months experienced the most pronounced increase in temperature, it is also expected to increase during the summer months with northern Sweden experiencing the strongest increase in May and June (Fig. 4). Additionally, the increase in peak temperature

(Table X1) and heatwaves (section 4.1.2.3) was found strongest in the North. Drier and warmer conditions during the summer months not only favour wildfire behaviour during the summer but also the possibility for holdover fires. These are fires that extinguish over land but smoulder in the soil during the winter months until weather conditions reignite these fires as overground fires in the spring (Scholten et al., 2021). Lastly, temperature changes are interconnected strongly with changes of other weather parameters such as relative humidity. This can lead to drier fuels and increase fire intensity (Lund et al. 2023).

5.3 Drought conditions

In northern Europe wildfire activity is mostly restricted by moisture and not like in southern Europe by fuel availability (Miller et al., 2025). A reduction in precipitation can therefore have a large impact in this region (Garoussi et al., 2024). Thus, it is especially valuable to consider drought indices alongside fire weather indices (Barbero et al., 2019). The results show an increase in SPEI for all three regions of 0.01 to 0.07 per decade (Table 7). Given that the index only ranges from -2 to 2 this is a noticeable change. Thus, a wetting trend is visible over the last 85 years in all regions. Results were significant, especially in northern and southern Sweden. Additionally, the number of dry days decreased for most stations according to the weather station data meaning that rainfall is also more evenly distributed. Chen et al. (2021) find a generally increasing wetting trend in Sweden since 1950 with the strongest trend found in northern Sweden which is also the region with the strongest wetting trend in the results of this study (Table 7). The wetting trend is likely due to an increase in rainfall in Sweden (Martin, 2018). Wetter conditions can decrease fire risk as fuels are more humid and rain can extinguish wildfires (Pareira, 2020). The only region that is expected to have an increase in drought frequency is central-eastern Sweden (Chen et al., 2021). However, this region was not covered by this study. Nevertheless, central Sweden showed the weakest increase in SPEI. This could be partially coupled to a Föhn effect (Stull, 2016) which introduces warm and dry air from the Norwegian mountains.

Looking at monthly trends, April shows a drying trend for all three regions (Fig. 5) favouring fires caused by the “spring-dip” as described above (Miller et al., 2025). Additionally, the number of dry days increased especially in the spring and early summer (Fig. 3). According to the SPEI (Fig. 5), only southern Sweden shows a slight drying trend in August and September while all other months and regions show a wetting trend or nearly no change. Spinoni et al. (2017) suggest a similar trend with a wetting over the last decades in Sweden and only a slight increase in drought frequency in spring between 1981 and 2015. Predictions, however, expect a decrease in severe droughts till the middle of the 21st century followed by an increase until 2100. More frequent droughts are especially likely in southern Sweden while northern Sweden might only experience a wetting trend (Ou, 2017). With more frequent droughts in southern Sweden fire risk would increase in this region in the future (Garoussi et al., 2024).

Furthermore, drought conditions do not only directly impact wildfire behaviour but also wildfire behaviour in later years (Miller et al., 2025). They influence fuel moisture and forest health. Together with other factors such as insect outbreaks which become more frequent with global warming (Hof & Svahlin, 2015) this decreases a forest’s resistance to fire outbreaks leading to larger and more intense fires (Millar & Stephenson, 2015).

Drought conditions just as temperature are influenced by large scale climatic circulations. In southern Sweden (below 59°N) westerly transfer of wet Atlantic air has influence on soil water content during the growing season (Drobyhev et al. 2012). Another example is the North Atlantic Circulation (NAO) influencing wildfire behaviour in Sweden. A negative NAO relates to negative precipitation anomalies in northern Europe due to decreased cyclonic activity which again increases the fire hazard especially in southern Sweden (Drobyhev et al. 2012). A negative NAO was also observed during the exceptional fire year 2018 (García-Burgos, 2023).

5.4 Alignment with past fires

This study finds a neglecTable linear relationship between fire size and FWI. Correlation coefficients were found at 0.07 and 0.08 which is smaller than results from Eriksson et al. (2023) who find correlation coefficients between 0.14 and 0.4 between burnt area and FWI in Sweden. However, Eriksson et al. (2023) used a different correlation method and distance (60km) between weather station and fire. The relationship between FWI and burnt area is lower than for the other parameters. FWI was the only variable that was based on weather station data and not reanalysis data. The reanalysis data is gridded and can even out local differences that are more pronounced in the raw weather station data which might have created a bias towards higher correlation of the reanalysis products. This is especially true given that fire weather in Sweden has been found more localised (Drobyshev, 2012).

Despite the low correlation coefficient, a difference exists between the FWI of smaller fires (≤100ha) with on average values below 20 and larger fires (>100ha) with values above 20 (Table 8). Fires that occur at an FWI<20 are usually manageable while fires above this threshold are expected to grow larger (Garroussi et al., 2024). Not all fires ≤100ha had a FWI below 20, though, wildfire behaviour and how well a fire is manageable is related to many factors. On the other hand, for a fire to grow large a FWI above 20 seems to be crucial in most cases.

SPEI and maximum temperature anomaly showed higher correlation coefficients, though, these values were still only weak to moderate. Temperature has been found to be a main driver for wildfire behaviour (Migliavacca et al., 2013) and high temperature anomaly has been found to be an indicator for larger growing fires (Hernandez et al., 2015). This relates to the results in Table 8 where most larger fires (>100ha) were related to a strong temperature anomaly. Additionally, in historic records in Fennoscandia, Rolstad et al. (2017) find a correlation between especially hot years and wildfire spread while precipitation showed less connection to wildfire activity. In this study, temperature anomaly was calculated based on the whole data period from 1940 to 2025 which already experienced a strong increasing trend (Table 5). Thus, more recent years are likely to show already a positive anomaly due to overall warmer base conditions. Nevertheless, this bias towards higher anomalies in recent years was present for all recent records and therefore accepted.

SPEI also finds a connection between larger fires and a higher index value (Table 6) while linear correlation is weak with -0.21 and -0.23. However, a strong correlation between SPEI and burnt area has been found for summer months in boreal Canada (Couillard et al., 2026). In Sweden, years with low SPEI can be associated with larger burnt area (Ou, 2017). Additionally, Drobyshev et al. (2012) find that for southern Sweden a drought index based on temperature and precipitation (in the study PDSI) is the best proxy for wildfire activity. This was explained by the temporal distribution of fires in the earlier part of the fire season when forests are still dry from the winter and land relatively open allowing for grass fires (Drobyshev et al., 2012). This relates to findings of this study (Table 9) where SPEI performed best amongst the three parameters for southern Sweden.

Temperature anomaly on the other hand was found to be a stronger indicator for wildfire size especially in central and northern Sweden. Most fires in northern Sweden occur in August and September (Drobyshev et al., 2012) when temperatures are higher and have a higher effect on fire behaviour compared to the spring. These connections additionally highlight the complexity of determining the perfect wildfire indicator as seasonality and spatial differences influence their performance (Drobyshev et al., 2012).

Another potential factor could be the root depth of different abundant species in each region. Norway spruce has a shallow root system making it more susceptible to droughts than Scots pine which has a deeper root system (Kalliokoski, 2008, Kuehne et al., 2025). Thus, drought indices are especially valuable in southern Sweden where Norway Spruce is the prevalent species which relates to findings in Table 9. Nevertheless, Norway spruce also makes up a large share in central and northern Sweden (see section 2.1) underlining the importance of assessing fire risk not only based on weather parameters but coupling these with local vegetation conditions.

Moreover, this study was limited to evaluating the direct interconnection between two single variables and did not consider lag time. However, Hernandez et al. (2015) suggest that after a long drought, high temperature and wind speed are a strong indicator for the risk of large fires. Additionally, large fires years are connected to climatic conditions of previous years. This is possibly related to atmospheric circulations (Drobyshev, 2014). Nevertheless, in a scenario of increased drought risk and temperature assessing SPEI will become especially important as it accounts for the temperature effect on evapotranspiration and can detect larger and more severe droughts than indices only based on precipitation (Li et al., 2020).

In both fire data sets, at a number of occasions several fires are recorded in the same region on the same day. Thus, some larger fires were potentially split into smaller areas lowering the correlation. Most fire sizes were given in increments of ten meaning that sizes were rounded or only estimated leading to errors. Another potential error source is the distance of 75km which might have not been able to account for local weather phenomena. A 60km radius was tested following the approach from Eriksson et al. (2023) which resulted in a much smaller data set. Finally, the error resulting from a larger distance was accepted to increase the number of data points especially in northern Sweden.

Furthermore, Sjöström and Granström (2023) found that different ignition triggers require different FWI to evolve. Lightning, children's play and burning of grass caused fires at relatively low FWI while reignition and other sparks required a higher FWI value (Sjöström & Granström, 2023). Thus, the ignition source also interplays with FWI making the correlation between the FWI and fire size more complex. This is especially true for southern Sweden where human-related noise makes correlation difficult (Drobyhev et al. 2012). Given that heavy machinery is one of the main drivers in less populated areas, forestry companies likely avoid work during especially windy and dry conditions. Thus, despite wind and drought being main drivers of fire risk, less of those days correlate to actual fires as precautions are taken (Sjöström et al., 2019). This could cause a bias to fire occurrence on days with lower fire risk contributing to the low correlation coefficients.

5.5 Outlook

The 2018 fires in Sweden have drawn special attention on the importance of firefighting resources. They were part of the reason for a new EU framework supporting transnational disaster risk management (Hopkins & Faulkner, 2021). Additionally, according to the Swedish Civil Defence Agency, Sweden has learned from the 2018 fires and increased their resistance to fire including better firefighting infrastructure (Myndigheten för Civil Försvar, n.d.). An increase in days with fire risk especially in southern Sweden can already be seen in the last 30 years (Table 4) making sustainable wildfire treatment increasingly important. This is especially crucial for Sweden as forestry is one of the main drivers of the country's economy (Kumar et al., 2020).

Nevertheless, also population density can have a strong effect on the occurrence of wildfires and area burnt. The expected depopulation of many rural areas in Sweden will likely decrease the number of fires ignited. However, fires are likely to grow larger due to less firefighting infrastructure (Sjöström & Granström, 2023). Additionally, lightning is becoming more frequent in northern Europe (Kahraman et al., 2022) increasing the possibilities for natural ignition which is most common in northern Europe.

Yet, the focus remains on the suppression of wildfires which is expected to lead to more build-up and more intense fires in the future. For example, in Norway the number of dead woods has increased by four times over the last two centuries increasing the risk of large growing fires (Rolstad et al., 2017). Therefore, Moreira et al. (2020) suggest that a paradigm shift is needed from sole fire suppression to mitigation, prevention and preparation. Additionally, it will not be sufficient to solely analyse weather and fuel factors, but also communities' vulnerability must be considered when making predictions (Eriksson et al., 2023). This is especially crucial given the increase in fire season length (Table 5) putting resources under additional stress (Garroussi et al., 2024). Therefore, this study suggests more sustainable forestry with less dense forests, prescribed burns, the choice of fire-resistant species and additional fire suppression forces in areas with high population density and increasing fire risk such as southern Sweden.

5.6 Additional limitations in the methodology

While meteorological and hydrological factors influence wildfire activity, a large set of other parameters exists that determine actual wildfire risk. These include management, fuel sources and amounts, urban growth, the development of the wildland-urban interfaces and changes in lightning frequency (Touma et al., 2021). As the present study focused solely on meteorological parameters, the understanding of the wider picture is limited. Future research should consider more comprehensive approaches.

The influence of different weather parameters is dependent on many factors with different regions responding differently to fire weather (Barbero et al. 2019). Generalising over a large country like Sweden is therefore challenging. Due to time constraint only 12 stations were analysed making statistical evident results more difficult to achieve. The example of Ullared A and Lakaträsk A with deviating results from the other stations highlights the importance of averaging over a larger data set. Additionally, more stations could cover more regions in Sweden and allow for an analysis of the West-East extent of the country. The southern east coast of Sweden showed an increase in fire risk in different predictions (e.g. Berg et al., 2024) but was not covered in this study.

The SMHI data was limited to 30 years of data. A larger data set could provide more insights about trends to better relate changes to anthropogenic climate change rather than natural climate variations and long-term oscillations. Furthermore, missing dates were filled using linear interpolation which is only an approximation especially for larger data periods with missing data. The fire data also was limited to 7 and 26 years of records depending on the data set. The data set from the Swedish Civil Defence Agency set is additionally lacking geographical data for around one third of the fires above 10ha especially in the years between 1995 and 2005. These entries were taken out of the calculation as the fire location was difficult to determine. However, this might have caused an observation bias towards newer dated fires and municipalities in which recording is more accurate.

6 Conclusion

Several predictions have been made for future fire weather risk while this study focused on the analyses of historical trends. Trends were found for all studied variables with most but drought index and dry days showing a trend towards higher fire risk in Sweden. As hypothesised in H1, trends in fire risk days have increased over the past 30 years based on the FWI with the strongest increase in southern Sweden. Similar results are found for maximum temperature which showed a significant increase in all stations and especially in the South. A continuous mostly significant wetting trend in all of Sweden but especially in northern Sweden opposes the increasing fire risk of the other two variables during late summer underlining the importance of the combined analysis of several weather parameters on fire risk. Thus, southern Sweden has experienced the strongest trends towards higher fire risk in Sweden over the past 30 years. Additionally, looking at seasonal distributions, spring and early summer show the highest trend for increased fire risk due to drier and warmer conditions coupled with a higher FWI and an earlier season start.

Opposing the hypothesis H2, FWI was not found to be the best indicator for large fire spread but rather temperature anomaly followed by drought conditions. Nevertheless, it showed that for large fires to grow, a parameter specific threshold needs to be exceeded for every parameter. Thus, although no direct strong linear relationship could be found, high values for all three parameters relate to a higher risk for a fire to grow large. This study suggests that all parameters can be important indicators for fire risk and should be assessed together to create fire risk forecasts which are crucial to communicate fire bans and allocate firefighting resources. However, this study compared weather station data and reanalysis data due to data availability while future studies should focus on one data product to make the analysis more robust.

Additionally, this analysis underlines the complexity of fire growth. Only three main weather parameters were studied, yet, for a more accurate picture other factors should be analysed in future studies. These include the relationship of snow cover, past year drought conditions, landscape management, vapour pressure deficit and vegetation type. The studied time periods were relatively short while a longer data period could additionally provide more robust results. A strong focus in literature is on future climate predictions while current climate conditions can give valuable insights about evolving fire risk to create a baseline for accurate prognosis.

Long-term fire suppression has made Swedish forests more vulnerable to fire occurrence and anthropogenic climate change making continuous research more important than ever. Firefighting infrastructure needs to be adapted to increasing fire risk and longer fire seasons in all of Sweden with special focus on the South to protect nature and communities in the future.

7 Statement of use of AI

Generative AI was used to support the production and debugging of python codes.

8 References

Baltzer, J. L., Day, N. J., Walker, X. J., Greene, D., Mack, M. C., Alexander, H. D., Arseneault, D., Barnes, J., Bergeron, Y., Boucher, Y., Bourgeau-Chavez, L., Brown, C. D., Carrière, S., Howard, B. K., Gauthier, S., Parisien, M., Reid, K. A., Rogers, B. M., Roland, C., . . . Johnstone, J. F. (2021). Increasing fire and the decline of fire adapted black spruce in the boreal forest. *Proceedings of the National Academy of Sciences*, *118*(45). https://doi.org/10.1073/pnas.2024872118

Barbero, R., Curt, T., Ganteaume, A., Maillé, E., Jappiot, M., & Bellet, A. (2019). Simulating the effects of weather and climate on large wildfires in France. *Natural Hazards and Earth System Sciences*, *19*(2), 441–454. https://doi.org/10.5194/nhess-19-441-2019

Beguería, S., Vicente-Serrano, S. M., Reig, F., & Latorre, B. (2014). Standardized precipitation evapotranspiration index (SPEI) revisited: parameter fitting, evapotranspiration models, tools, datasets and drought monitoring. *International Journal of Climatology*, *34*(10), 3001–3023. https://doi.org/10.1002/joc.3887

Berg, P., Bozhinove, D., Böhlin, J., Gustafsson, D., Jansson, A., Schützer, S., Klehmet, K., Landelius, T., Schimanke, S., Yang, W. (2024). Framtida brandrisk – föraändringar i perioder av hög brandrisk enligt FWI – modellen. *Myndigheten för samhällsskydd och beredskap.*

Binkley, D., Sisk, T., Chambers, C., Springer, J., & Block, W. (2007). The Role of Old-growth Forests in Frequent-fire Landscapes. *Ecology and Society*, *12*(2). http://www.jstor.org/sTable/26267895

Carnicer, J., Alegria, A., Giannakopoulos, C., Di Giuseppe, F., Karali, A., Koutsias, N., Lionello, P., Parrington, M., & Vitolo, C. (2022). Global warming is shifting the relationships between fire weather and realized fire-induced CO2 emissions in Europe. *Scientific Reports*, *12*(1), 10365. https://doi.org/10.1038/s41598-022-14480-8

Chen, D., Zhang, P., Seftigen, K., Ou, T., Giese, M., & Barthel, R. (2020). Hydroclimate changes over Sweden in the twentieth and twenty-first centuries: a millennium perspective. *Geografiska Annaler Series a Physical Geography*, *103*(2), 103–131. https://doi.org/10.1080/04353676.2020.1841410

Climate Adapt. (n.d.). *Fire Weather Index*. https://climate-adapt.eea.europa.eu/en/metadata/indicators/fire-weather-index

Cogos, S., Östlund, L., & Roturier, S. (2019). Forest Fire and Indigenous Sami Land Use: Place Names, Fire Dynamics, and Ecosystem Change in Northern Scandinavia. *Human Ecology*, *47*(1), 51–64. https://doi.org/10.1007/s10745-019-0056-9

Cohen, J. (1969). Statistical Power Analysis for the Behavioral Sciences. *New York: Academic Press.*

Copernicus Climate Change Service (2023): ERA5 hourly data on single levels from 1940 to present. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). DOI: 10.24381/cds.adbb2d47 (Accessed between 22-04-2026 and 15-05-2026)

Couillard, P., Laflamme, J., Frégeau, M., Cardona, L., Morneau, C., & Payette, S. (2026). Drought as the main climatic driver of major boreal fire seasons over the last century in eastern Canada. *Environmental Research Letters*, *21*(5), 054016. https://doi.org/10.1088/1748-9326/ae49a0

Dierauer, J. R., Allen, D. M., & Whitfield, P. H. (2021). Climate change impacts on snow and streamflow drought regimes in four ecoregions of British Columbia. *Canadian Water*

Resources Journal / Revue Canadienne Des Ressources Hydriques, *46*(4), 168–193. https://doi.org/10.1080/07011784.2021.1960894

Dowdy, A. J., Mills, G. A., Finkele, K., & De Groot, W. (2009). Index sensitivity analysis applied to the Canadian Forest Fire Weather Index and the McArthur Forest Fire Danger Index. *Meteorological Applications*, *17*(3), 298–312. https://doi.org/10.1002/met.170

Drobyshev, I., Bergeron, Y., De Vernal, A., Moberg, A., Ali, A. A., & Niklasson, M. (2016). Atlantic SSTs control regime shifts in forest fire activity of Northern Scandinavia. *Scientific Reports*, *6*(1), 22532. https://doi.org/10.1038/srep22532

Drobyshev, I., Granström, A., Linderholm, H. W., Hellberg, E., Bergeron, Y., & Niklasson, M. (2014). Multi-century reconstruction of fire activity in Northern European boreal forest suggests differences in regional fire regimes and their sensitivity to climate. *Journal of Ecology*, *102*(3), 738–748. https://doi.org/10.1111/1365-2745.12235

Drobyshev, I., Niklasson, M., & Linderholm, H. W. (2012). Forest fire activity in Sweden: Climatic controls and geographical patterns in 20th century. *Agricultural and Forest Meteorology*, *154–155*, 174–186. https://doi.org/10.1016/j.agrformet.2011.11.002

EFFIS - Fire danger forecast. (n.d.). https://forest-fire.emergency.copernicus.eu/about-effis/technical-background/fire-danger-forecast

Eriksson, C. P., Johansson, N., & McNamee, M. (2023). The performance of wildfire danger indices: A Swedish case study. *Safety Science*, *159*, 106038. https://doi.org/10.1016/j.ssci.2022.106038

Erni, S., Arseneault, D., & Parisien, M. (2018). Stand age influence on potential wildfire ignition and spread in the Boreal Forest of northeastern Canada. *Ecosystems*, *21*(7), 1471–1486. https://doi.org/10.1007/s10021-018-0235-3

Esseen, P. A., Ehnström, B., Ericson, L., & Sjöberg, K. (1997). Boreal Forests. *Ecological Bulletins*, (46), 16–47. http://www.jstor.org/sTable/20113207

European Commission. (n.d.). *Improved and efficient restoration by controlled burning in boreal western taiga woodlands (LIFE2Taiga)*. LIFE Programme. European Commission. https://webgate.ec.europa.eu/life/publicWebsite/project/LIFE21-NAT-SE-Life2Taiga-101074359/improved-and-efficient-restoration-by-controlled-burning-in-boreal-western-taiga-woodlands

Flannigan, M. D., Amiro, B. D., Logan, K. A., Stocks, B. J., & Wotton, B. M. (2006). Forest fires and climate change in the 21ST century. *Mitigation and Adaptation Strategies for Global Change*, *11*(4), 847–859. https://doi.org/10.1007/s11027-005-9020-7

Flannigan, M., & Wotton, B. (2001). Climate, weather, and area burned. In *Elsevier eBooks* (pp. 351–373). https://doi.org/10.1016/b978-012386660-8/50012-x

García-Burgos, M., Gómara, I., Rodríguez-Fonseca, B., González-Alemán, J. J., Zurita-Gotor, P., & Ayarzagüena, B. (2023). Abrupt and persistent atmospheric circulation changes in the North Atlantic under La Niña conditions. *Weather and Climate Extremes*, *42*, 100609. https://doi.org/10.1016/j.wace.2023.100609

Garroussi, S. E., Di Giuseppe, F., Barnard, C., & Wetterhall, F. (2024). Europe faces up to tenfold increase in extreme fires in a warming climate. *Npj Climate and Atmospheric Science*, *7*(1). https://doi.org/10.1038/s41612-024-00575-8

Giglio, L., Randerson, J. T., & Van Der Werf, G. R. (2013). Analysis of daily, monthly, and annual burned area using the fourth-generation global fire emissions database (GFED4). *Journal of Geophysical Research Biogeosciences*, *118*(1), 317–328. https://doi.org/10.1002/jgrg.20042

Government of Canada. (2025, October 1). *Canada's fire weather index system*. Natural Resources Canada. https://natural-resources.canada.ca/forests-forestry/wildland-fires/canada-fire-weather-index-system (retrieved: 07.05.2026)

Grünig, M., Rammer, W., Senf, C., Albrich, K., André, F., Augustynczik, A. L. D., Baumann, M., Bohn, F. J., Bouwman, M., Bugmann, H., Collalti, A., Cristal, I., Dalmonech, D., De Coligny, F., Dobor, L., Dollinger, C., Espelta, J. M., Forrester, D. I., Garcia-Gonzalo, J., . . . Seidl, R. (2026). Climate change will increase forest disturbances in Europe throughout the 21st century. *Science*, *391*(6789), eadx6329. https://doi.org/10.1126/science.adx6329

Hernandez, C., Keribin, C., Drobinski, P., & Turquety, S. (2015). Statistical modelling of wildfire size and intensity: a step toward meteorological forecasting of summer extreme fire risk. *Annales Geophysicae*, *33*(12), 1495–1506. https://doi.org/10.5194/angeo-33-1495-2015

Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz‐Sabater, J., Nicolas, J., Peubey, C., Radu, R., Schepers, D., Simmons, A., Soci, C., Abdalla, S., Abellan, X., Balsamo, G., Bechtold, P., Biavati, G., Bidlot, J., Bonavita, M., . . . Thépaut, J. (2020). The ERA5 global reanalysis. *Quarterly Journal of the Royal Meteorological Society*, *146*(730), 1999–2049. https://doi.org/10.1002/qj.3803

Hof, A. R., & Svahlin, A. (2015). The potential effect of climate change on the geographical distribution of insect pest species in the Swedish boreal forest. *Scandinavian Journal of Forest Research*, *31*(1), 29–39. https://doi.org/10.1080/02827581.2015.1052751

Hopkins, W. J., & Faulkner, H. (2021). To The RescEU? Disaster Response As A Driver For European Integration. In *University of Canterbury Research Repository (University of Canterbury)*. https://doi.org/10.26021/12400

Jansson, U. (2011). *Agriculture and forestry in Sweden since 1900: A Cartographic Description*.

Jones, M. W., Smith, A., Betts, R., Canadell, J. G., Prentice, I. C., & Le Quéré, C. (2020). *Climate Change Increases the Risk of Wildfires*. Tyndall Centre for Climate Change Research. http://www.jstor.org/sTable/resrep51248

Kahraman, A., Kendon, E. J., Fowler, H. J., & Wilkinson, J. M. (2022). Contrasting future lightning stories across Europe. *Environmental Research Letters*, *17*(11), 114023. https://doi.org/10.1088/1748-9326/ac9b78

Kalliokoski, T., Nygren, P., & Sievänen, R. (2008). Coarse root architecture of three boreal tree species growing in mixed stands. *Silva Fennica 42(2): 189–210*

Kreider, M. R., Higuera, P. E., Parks, S. A., Rice, W. L., White, N., & Larson, A. J. (2024). Fire suppression makes wildfires more severe and accentuates impacts of climate change and fuel accumulation. *Nature Communications*, *15*(1), 2412. https://doi.org/10.1038/s41467-024-46702-0

Krikken, F., Lehner, F., Haustein, K., Drobyshev, I., & Van Oldenborgh, G. J. (2021). Attribution of the role of climate change in the forest fires in Sweden 2018. *Natural Hazards and Earth System Sciences*, *21*(7), 2169–2179. https://doi.org/10.5194/nhess-21-2169-2021

Kuehne, C., Maleki, K., Merlin, M., & Granhus, A. (2025). Interactive effects of species composition, site quality, and drought on growth dynamics of Norway spruce and Scots pine stands in Norway. *Forest Ecology and Management*, *590*, 122804. https://doi.org/10.1016/j.foreco.2025.122804

Kumar, A., Adamopoulos, S., Jones, D., & Amiandamhen, S. O. (2020b). Forest biomass availability and utilization Potential in Sweden: a review. *Waste and Biomass Valorization*, *12*(1), 65–80. https://doi.org/10.1007/s12649-020-00947-0

Lacand, M., Asselin, H., Aakala, T., Rius, D., Vogel, M., Paradis, L., & Ali, A. A. (2025). Wildfire-induced soil erosion in northern Finland watersheds. *The Holocene*, *36*(1), 68–79. https://doi.org/10.1177/09596836251378013

Lahaye, S., Curt, T., Fréjaville, T., Sharples, J., Paradis, L., & Hély, C. (2018). What are the drivers of dangerous fires in Mediterranean France? *International Journal of Wildland Fire*, *27*(3), 155–163. https://doi.org/10.1071/wf17087

Lawson, B. D., & Armitage, O. B. (2008). Weather guide for the Canadian forest fire danger rating system. *Canadian Forest Service.*

Lehtonen, I., Venäläinen, A., Kämäräinen, M., Peltola, H., & Gregow, H. (2016). Risk of large-scale fires in boreal forests of Finland under changing climate. *Natural Hazards and Earth System Sciences*, *16*(1), 239–253. https://doi.org/10.5194/nhess-16-239-2016

Li, L., She, D., Zheng, H., Lin, P., & Yang, Z. (2020). Elucidating Diverse Drought Characteristics from Two Meteorological Drought Indices (SPI and SPEI) in China. *Journal of Hydrometeorology*, *21*(7), 1513–1530. https://doi.org/10.1175/jhm-d-19-0290.1

Lind, P., Kjellström, E., (2008). Temperature and precipitation changes in Sweden; a wide range of model-based projections for the 21st century. *Swedish Meteorological and Hydrological Institute.*

Lindberg, H., Punttila, P., & Vanha-Majamaa, I. (2020). The challenge of combining variable retention and prescribed burning in Finland. *Ecological Processes*, *9*(1). https://doi.org/10.1186/s13717-019-0207-3

Liu, Y., Goodrick, S., & Heilman, W. (2013). Wildland fire emissions, carbon, and climate: Wildfire–climate interactions. *Forest Ecology and Management*, *317*, 80–96. https://doi.org/10.1016/j.foreco.2013.02.020

Lund, M. T., Nordling, K., Gjelsvik, A. B., & Samset, B. H. (2023). The influence of variability on fire weather conditions in high latitude regions under present and future global warming. *Environmental Research Communications*, *5*(6), 065016. https://doi.org/10.1088/2515-7620/acdfad

Lundmark, T., Bergh, J., Hofer, P., Lundström, A., Nordin, A., Poudel, B., Sathre, R., Taverna, R., & Werner, F. (2014b). Potential roles of Swedish forestry in the context of climate change mitigation. *Forests*, *5*(4), 557–578. https://doi.org/10.3390/f5040557

Martin, E. R. (2018). Future projections of global pluvial and drought event characteristics. *Geophysical Research Letters*, *45*(21). https://doi.org/10.1029/2018gl079807

Mascaut, F., Hammargren, R., & Forkman, P. (2026). Ground-based atmospheric measurements at the Onsala Space Observatory (Sweden): data & trends (2009–2025). *Earth System Science Data*, *18*(3), 2265–2283. https://doi.org/10.5194/essd-18-2265-2026

Matsala, M., & Jones, S. (2025). Map of Swedish Forest Fires >10ha from 2016-2023 [Dataset]. In *Zenodo (CERN European Organization for Nuclear Research)*. https://doi.org/10.5281/zenodo.10885771

Migliavacca, M., Dosio, A., Camia, A., Hobourg, R., Houston-Durrant, T., Kaiser, J. W., Khabarov, N., Krasovskii, A. A., Marcolla, B., Miguel-Ayanz, J. S., Ward, D. S., & Cescatti, A. (2013). Modeling biomass burning and related carbon emissions during the 21st century in Europe. *Journal of Geophysical Research Biogeosciences*, *118*(4), 1732–1747. https://doi.org/10.1002/2013jg002444

Millar, C. I., & Stephenson, N. L. (2015). Temperate forest health in an era of emerging megadisturbance. *Science*, *349*(6250), 823–826. https://doi.org/10.1126/science.aaa9933

Miller, J., Touma, D., & Brunner, M. I. (2025). Compounding preconditions of wildfires vary in time and space within Europe. *Communications Earth & Environment*, *6*(1). https://doi.org/10.1038/s43247-025-02955-1

Moreira, F., Ascoli, D., Safford, H., Adams, M. A., Moreno, J. M., Pereira, J. M. C., Catry, F. X., Armesto, J., Bond, W., González, M. E., Curt, T., Koutsias, N., McCaw, L., Price, O., Pausas, J. G., Rigolot, E., Stephens, S., Tavsanoglu, C., Vallejo, V. R., . . . Fernandes, P. M. (2019). Wildfire management in Mediterranean-type regions: paradigm change needed. *Environmental Research Letters*, *15*(1), 011001. https://doi.org/10.1088/1748-9326/ab541e

Moriondo, M., Good, P., Durao, R., Bindi, M., Giannakopoulos, C., & Corte-Real, J. (2006). Potential impact of climate change on fire risk in the Mediterranean area. *Climate Research*, *31*, 85–95. https://doi.org/10.3354/cr031085

Myndigheten för Civil Försvar. (n.d.). *Så har vi stärkt skogsbrandsberedskapen*. https://www.mcf.se/sv/amnesomraden/skydd-mot-olyckor-och-farliga-amnen/naturolyckor-och-klimat/skogsbrand-och-vegetationsbrand/sa-har-vi-starkt-skogsbrandsberedskapen/

Nielsson, P., Markström M., Fridman, J., (2025). Skogsdata 2025. *SLU Institutionen för skoglig resurshushållning.*

Ou, T., (2017). Droughts and wildfires in Sweden. Past variation and future projection. *Myndigheten för smhällsskydd och beredskap.*

Page, Y. L., Pereira, J. M. C., Trigo, R., Da Camara, C., Oom, D., & Mota, B. (2008). Global fire activity patterns (1996–2006) and climatic influence: an analysis using the World Fire Atlas. *Atmospheric Chemistry and Physics*, *8*(7), 1911–1924. https://doi.org/10.5194/acp-8-1911-2008

Pagnon Eriksson, C., & Johansson, N. (2020). Review of wildfire indices: Indices applicable for a Swedish context. (TVBB; No. 3233). Division of Fire Safety Engineering.

Parisien, M.-A., Barber, Q. E., Flannigan, M. D., & Jain, P. (2023). Broadleaf tree phenology and springtime wildfire occurrence in boreal Canada. Global Change Biology, 29, 6106–6119. https://doi.org/10.1111/gcb.16820

Pausas, J. G., & Keeley, J. E. (2021). Wildfires and global change. *Frontiers in Ecology and the Environment*, *19*(7), 387–395. https://doi.org/10.1002/fee.2359

Pereira, M. G., Parente, J., Amraoui, M., Oliveira, A., & Fernandes, P. M. (2019). The role of weather and climate conditions on extreme wildfires. In *Elsevier eBooks* (pp. 55–72). https://doi.org/10.1016/b978-0-12-815721-3.00003-5

Plathner, F. V., Sjöström, J., & Granström, A. (2022). Garden structure is critical for building survival in northern forest fires – An analysis using large Swedish wildfires. *Safety Science*, *157*, 105928. https://doi.org/10.1016/j.ssci.2022.105928

Plathner, F., Sjöström, J., Svensson, R., McNamee, M. (2026). Vulnerability to wildfires: A Swedish perspective and comparison to international findings. *RISE Research Institutes of Sweden.*

Poduška, Z., & Stajić, S. (2024). The Cost of Forest Fires: A Socioeconomic Analysis. In *Fire Hazards: Socio-economic and Regional Issues.* (pp. 123–135). https://doi.org/10.1007/978-3-031-50446-4_10

Ramberg, E., Strengbom, J., & Granath, G. (2017). Coordination through databases can improve prescribed burning as a conservation tool to promote forest biodiversity. *AMBIO*, *47*(3), 298–306. https://doi.org/10.1007/s13280-017-0987-6

Reid, C. E., Brauer, M., Johnston, F. H., Jerrett, M., Balmes, J. R., & Elliott, C. T. (2016). Critical review of health impacts of wildfire smoke exposure. *Environmental Health Perspectives*, *124*(9), 1334–1343. https://doi.org/10.1289/ehp.1409277

Rolstad, J., Blanck, Y., & Storaunet, K. O. (2017). Fire history in a western Fennoscandian boreal forest as influenced by human land use and climate. *Ecological Monographs*, *87*(2), 219–245. https://doi.org/10.1002/ecm.1244

Rosso, C. C., Nyberg, L., & Pechlivanidis, I. (2025). Drought hazard assessment across Sweden's diverse hydro-climatic regimes. *Natural Hazards and Earth System Sciences*, *25*(11), 4577–4592. https://doi.org/10.5194/nhess-25-4577-2025

Scholten, R. C., Jandt, R., Miller, E. A., Rogers, B. M., & Veraverbeke, S. (2021). Overwintering fires in boreal forests. *Nature*, *593*(7859), 399–404. https://doi.org/10.1038/s41586-021-03437-y

Sharples, J. J. (2022). A note on fire weather indices. *International Journal of Wildland Fire*, *31*(7), 728–734. https://doi.org/10.1071/wf21134

Sedano, F., San-Miguel-Ayanz, J., Broglia, M., Durrant, T., Boca, R. et al., (2025). Forest Fires in Europe, Middle East and North Africa 2024, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2760/0649290, JRC144093.

Sjöström, J., & Granström, A. (2023). Human activity and demographics drive the fire regime in a highly developed European boreal region. *Fire Safety Journal*, *136*, 103743. https://doi.org/10.1016/j.firesaf.2023.103743

Sjöström, J., Granström, A. (2020). Skogsbränder och gräsbränder i Sverige-Trender och mönster under senare decennier. *Myndigheten för samhällsskydd och beredskap (MSB).*

Sjöström, J., Plathner, F. V., & Granström, A. (2019). Wildfire ignition from forestry machines in boreal Sweden. *International Journal of Wildland Fire*, *28*(9), 666–677. https://doi.org/10.1071/wf18229

Skogstyrelsen (n.d.). *Ownership Structure.* Skogstyrelsen. https://www.skogsstyrelsen.se/en/statistics/property-and-ownership-structure/

SLU. (n.d.). *Forest land.* https://www.slu.se/en/about-slu/organisation/departments/forest-resource-management/miljoanalys/nfi/our-data/the-latest-statistics/forest-land/

SMHI (n.d.-a). *Ladda ner Väderobservationer*. https://www.smhi.se/data/hitta-data-for-en-plats/ladda-ner-vaderobservationer/presentWeather/63510

SMHI (n.d.-b). *Värmebölja*. https://www.smhi.se/kunskapsbanken/meteorologi/temperatur/varmebolja

Stull, R. B. (2016). Practical Meteorology : An algebra-based survey of atmospheric science. In *BiblioBoard Library Catalog (Open Research Library)*. https://doi.org/10.14288/1.0300441

The Royal Swedish Academy of Agriculture and Forestry. (2024). Forests and Forestry in Sweden. *The Royal Swedish Academy of Agriculture and Forestry.*

Torres-Vázquez, M. Á., Di Giuseppe, F., Moreno-Torreira, A., Gincheva, A., Jerez, S., & Turco, M. (2025). Large increase in extreme fire weather synchronicity over Europe. *Environmental Research Letters*, *20*(2), 024045. https://doi.org/10.1088/1748-9326/ada8c2

Touma, D., Stevenson, S., Lehner, F., & Coats, S. (2021). Human-driven greenhouse gas and aerosol emissions cause distinct regional impacts on extreme fire weather. *Nature Communications*, *12*(1), 212. https://doi.org/10.1038/s41467-020-20570-w

Van Wagner, C.E. (1987). Development and structure of the Canadian Forest Fire Weather Index System. *Canadian Forestry Service, Headquarters, Ottawa. Forestry Technical Report 35.*

Van Wagner, C.E., Pickett, T.L., (1995). Equation and FORTRAN Program for the Canadian Forest Fire Weather Index System. Canadian Forestry Service.

Vicente-Serrano, S. M., Beguería, S., & López-Moreno, J. I. (2009). A multiscalar drought index sensitive to global warming: the Standardized Precipitation evapotranspiration Index. *Journal of Climate*, *23*(7), 1696–1718. https://doi.org/10.1175/2009jcli2909.1

Vitolo, C., Di Giuseppe, F., Krzeminski, B., & San-Miguel-Ayanz, J. (2019). A 1980–2018 global fire danger re-analysis dataset for the Canadian Fire Weather Indices. *Scientific Data*, *6*(1), 190032. https://doi.org/10.1038/sdata.2019.32

Wang, Y., Anderson, K. R., & Suddaby, R. M. (2015). *Updated source code for calculating fire danger indices in the Canadian Forest Fire Weather Index System*.

Wotton, B.M., Flannigan, M.D., (1993). Length of the fire season in a changing climate. *Forestry Chronicle.* 69, 187-192.

X Appendix

X.1 Peak temperature development

*Table X1. Trends for peak temperature reached per year based on weather station data. Trends are averaged for the three regions (South, Central and North). The strongest increase is found in the northern, the least in southern Sweden. Significant results are marked with * for p<0.05, ** for 0.01 and *** for p<0.001. 1996-2025.*

	Maximum temperature per year slope	p-value
Tomtabacken A	0.05	0.19
Ullared A	0.04	0.35
Växjö A	0.08	0.05
Ljungby	0.05	0.23
Edsbyn A	0.06	0.08
Hamra A	0.08*	0.04*
Sala A	0.08	0.12
Dravagen A	0.06	0.11
Gällivare A	0.10	0.05
Latnivaara A	0.11*	0.02*
Asrvidsjaur A	0.09	0.07
Lakaträsk A	0.11*	0.03*

South	0.05	
Central	0.07	
North	0.10	

X2. Code availability

The python codes used for generating the presented findings can be provided upon request to the author (pa5681he-s@student.lu.se).