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Journal of Physics: Conference Series **2885** (2024) 012066 doi:10.1088/1742-6596/2885/1/012066

Study of fire characteristics of forest vegetation in the Atlantic coastal region of Norway

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Abstract. Understanding of wildfire risk requires an understanding of the natural species' fire dynamics. This study investigates fire characteristics of common wildland species in Norwegian forests - stair-step moss, lingonberry shrub, juniper, bilberry, and heather. Cone calorimetry experiments were conducted after conditioning samples to similar moisture content. Stair-step moss and bilberry stems exhibited longer burning times and lower peak heat release rates, suggesting a slower, more sustained combustion. Heather, despite age differences, showed similar fire behaviours, indicating moisture content's role in wildfire risk. Evergreens displayed the most intense fire development, with juniper potentially acting as a ladder species for vertical fire spread.

1. Introduction

Over the last years there have been several large wildfires in Norwegian coastal heathlands and nearby forests, some occurring in dry winters with strong winds and others due to high temperatures combined with low precipitation [1]. Wildfire risk depends on many factors, such as temperature, wind conditions, humidity, and characteristics of the vegetation. Due to changing climate conditions, wildfires in Norway are expected to increase in frequency and severity.

An important factor influencing the flammability of vegetation is its moisture content. Linear relationships have been found between moisture content and time to ignition in dead fuels, but the ignition of live fuels appears more complex [2]. Suggested explanations include different manners of water storage and release of water in live fuels and differences in chemical composition. The geometry of the fuel is also influencing the fire characteristics. Cone calorimetry studies of two types of pine needles suggested that the needles with a lower surface-to-volume ratio had longer time to ignition and higher heat release rate (HRR) [3], while cone calorimetry studies of twigs of different sizes have displayed how the burn times increased with increasing twig thickness, while the peak HRR was reduced [4]. While research has been conducted on wildfire fuels internationally, a significant gap exists in understanding the fire characteristics of native species in Norway.

In this study, the fire characteristics of potential wildfire fuels in a fjord forest in Norway were measured using cone calorimetry. Stair-step moss, lingonberry shrub, juniper, bilberry (leaves and stem) and heather were studied.

2. Methods

2.1. Sample harvesting

The vegetation samples were harvested from six locations in the forest Tomsetmarka in Trondheim. Trondheim is located by a fjord, in mid-country, and the area is part of the Atlantic coastal region in Norway [5]. The samples were collected on two occasions in October 2023.

Samples of stair-step moss, *Hylocomium splendens*, were collected from a spruce forest area. The stair-step moss usually produces only one new level of leaves each year, [6]. Based on this, the collected samples were estimated to be 4-6 years old.

Samples of heather, *Calluna vulgaris*, were collected from a hillside in a coniferous area facing south-west. Both young, green samples of maximum height 30 cm, and larger, browner samples stretching up to 50 cm from the top of the root to the tips, were collected. Cone calorimeter experiments were conducted separately for young, green heather, and older brown heather.

Samples of lingonberry shrubs, *Vaccinium vitis-idaea*, were collected from the same hillside as the heather. These plants were less than 13 cm tall, which is typical for lingonberry in Norway.

Samples of bilberry shrubs, *Vaccinium myrtillus*, were collected in two locations near forest trails, surrounded mostly by deciduous trees. These were about 30-60 cm tall, where the smaller plants were mostly green and taller plants had thicker, brown stems. Experiments were conducted for the thin bilberry branches and the thicker stems separately.

Samples of juniper, *Juniperus communis*, were collected from a plant standing on a small hilltop with both pine and spruce trees present. The plant reached about 50 cm over the ground and its green shoots were collected.

2.2. Experimental method: Conditioning, set-up, and procedure

The vegetation harvested was conditioned in accordance with ISO 5660-1 [7] in a climate conditioning room holding a temperature of 23 °C and with a relative humidity of 50% until equilibrium moisture content (EMC) was reached, hence limiting the influence of different moisture contents between the different types of fuels.

The EMC was measured by drying specimens in an oven at 105 °C until two consecutive mass measurements with minimum 24 h apart deviated less than 0.1% or 0.1 g, as described in NS-EN 13238:2010 [8], using a Mettler PM34 DeltaRange scale (range 0-3200 g, accuracy ± 0.01 g). The samples had EMC values from 9.7% - 12.9% (Table 1), which is slightly higher than the prediction by the Hailwood-Horrobin relationship for wood, 9% [9,10]. Notice that EMC is often significantly lower than the moisture content of live vegetation.

Table 1: Equilibrium moisture contents (wet minus dry, divided by wet) after conditioning.

Specimen	Stair-step moss	Lingonberry shrub	Juniper	Bilberry branch	Bilberry stem	Green heather	Brown heather
Wet mass [g]	10.0	20.0	20.0	40.0	27.7	30.0	20.0
Dry mass [g]	8.7	18.0	18.1	35.1	24.2	27.0	17.8
EMC	12.9%	9.9%	9.7%	12.4%	12.4%	10.3%	11.0%

The sample was exposed to 35 kW/m^2 irradiation heat flux (chosen based on preliminary tests for a balance of time to ignition accuracy vs. burn time) with spark ignition using a FTT Dual Cone Calorimeter (oxygen depletion calorimeter) with a Servomex 4100 Gas Purity Analyser and a load cell (capacity 5.0 kg, balance sensitivity 0.01 g), according to ISO 5660-1 [7]. 24 experiments were conducted of which two were pre-tests and one experiment had software failure.

Samples of 7 g were used, sample height 48 mm for all specimens except bilberry stems at ~5 mm, measured with a ruler. Sample material was uniformly distributed, and natural packing density differences affected filling degree (see Figure 1c-1i). Stair-step moss had natural vegetation structure, for the others individual shoots or stems were used. The samples were wrapped with aluminium foil

(Figure 1a), and backed with refractory fibre blanket thermal insulation until the specimen was flush with the top of the sample holder, in accordance with ISO 5660-1 [7].

The sample holder was positioned, the spark ignition was started, and the mass measurement was tared. When the sample ignited, the ignition spark was turned off. Ignition time and time to flameout were observed visually and noted. Heat release rate (HRR) was recorded. The total experimental duration was 600 seconds + 60 seconds baseline recording. Visual observations after the experiment were made, with sample mass being close to zero (Figure 1b). The total heat release (THR) was calculated by numerical integration from the first positive HRR value after the last negative value before ignition until the HRR reached the baseline. Three repetitions were made for each specimen.

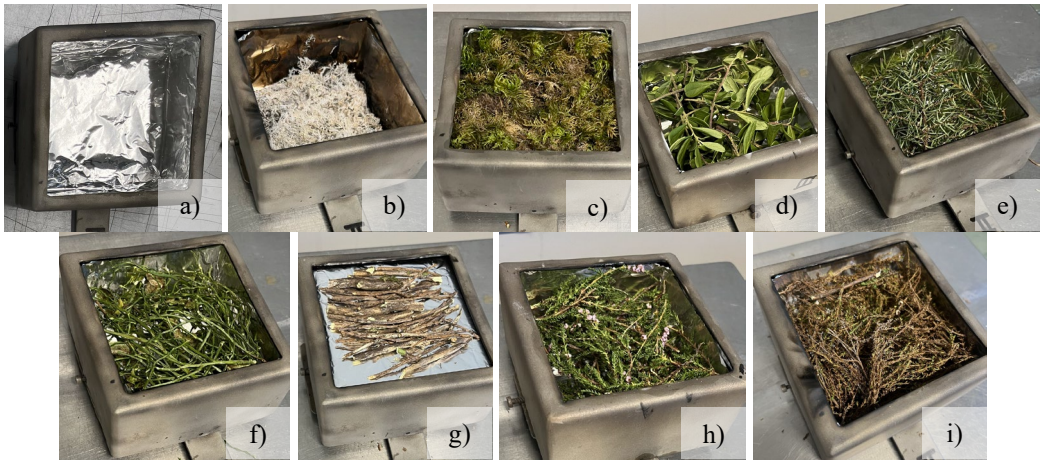

Figure 1: a) Aluminium sample holder before and b) after an experiment, and with c) stair-step moss, d) lingonberry shrub, e) juniper, f) bilberry branch, g) bilberry stem, h) green heather, i) brown heather.

3. Results and discussion

Heat release rate as function of time, and the time to ignition and burning times observed in the cone calorimeter experiments are shown in Figures 2 and 3. Labels give experiment number, pre-tests (#1,3) and failed experiment (#21) are not shown.

The stair-step moss had the fastest ignition, in the range 5-12 s. This was the plant with the finest structure and highest moisture content (12.90%). The longest time to ignition was observed for the bilberry branches (32-44 s). Interestingly, the bilberry stems ignited more easily than its branches despite a lower surface-to-volume ratio. The ignition times of juniper and bilberry stems were the most consistent between repeated experiments, while the lingonberry shrub, bilberry branch and heather samples had ignition times varying with more than 10 s between repetitions. A possible source of variation in the time to ignition between samples of the same vegetation type is deformation during heating, which can cause parts of the samples to move above or below the sample holder edge.

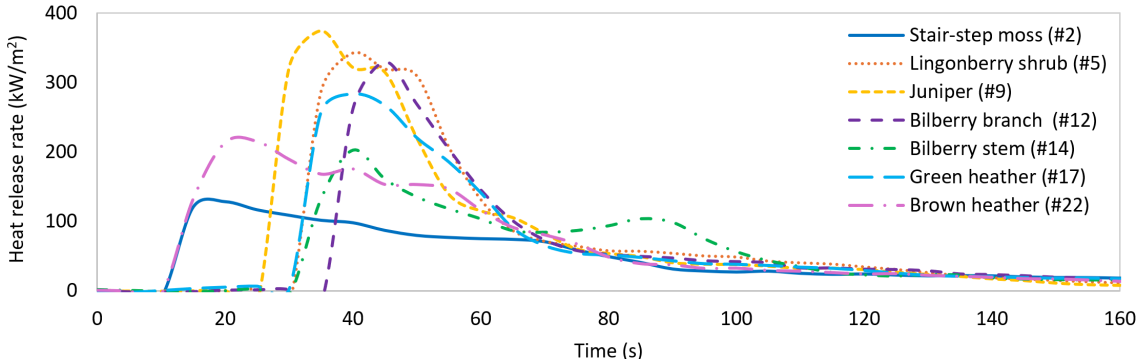

Figure 2: Heat release rate (HRR) as function of time (0-160 of total 600 sec) for one representative sample of each vegetation type. The full data set may be found in Rosnes [11].

Stair-step moss and bilberry stems had the longest burning times. Stair-step moss grows in thick ground-covering layers and can be found in both coniferous and deciduous forests, open fields, and mountains in Norway. Given the short time to ignition and long burning time of the stair-step moss samples, they have a high potential for igniting nearby plants. With their continuous cover of the forest floor, they may have the potential to spread a fire over a large area, indicating that this is a high-hazard species for wildfire spread. The bilberry stems were the thickest type of vegetation tested, giving a low surface area-to-volume ratio, and longer burning times. The differences in burning times between the bilberry stem samples can be related to differences in the thickness of the stems in different samples, as #15 had slightly thicker stems than #13 and #14.

The peak HRR and THR are shown in Figure 4. Peak HRR were the lowest for the stair-step moss and bilberry stems. These samples also had the highest burning times, displaying a longer and more even combustion process than the other samples. This indicates that even if stair-step moss represents

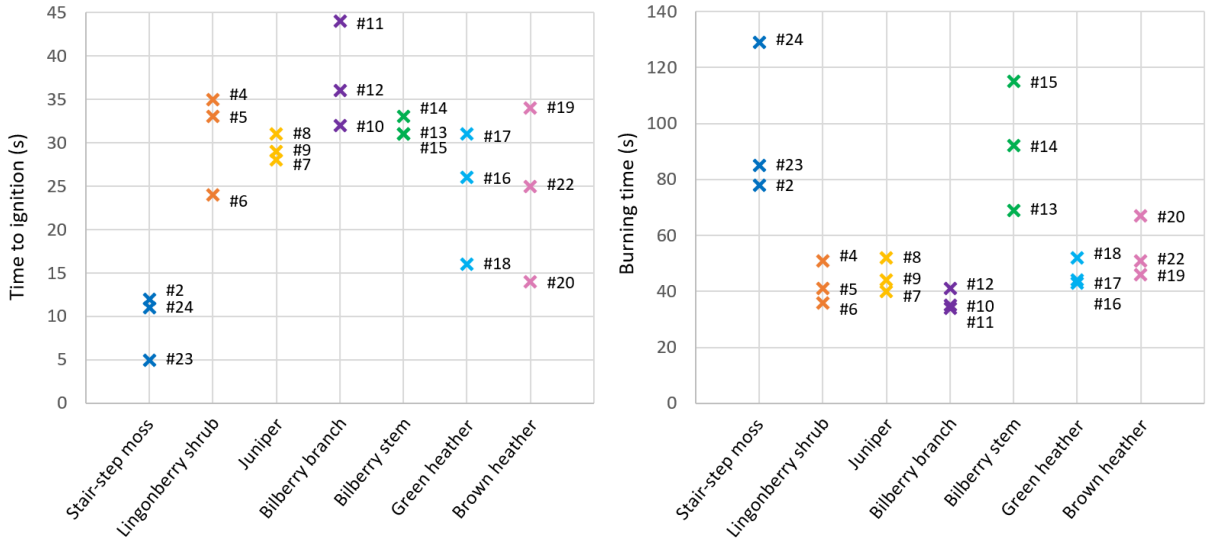

Figure 3: Time to ignition and burning time (time to flame-out) for vegetation samples exposed to 35 kW/m^2 in a cone calorimeter.

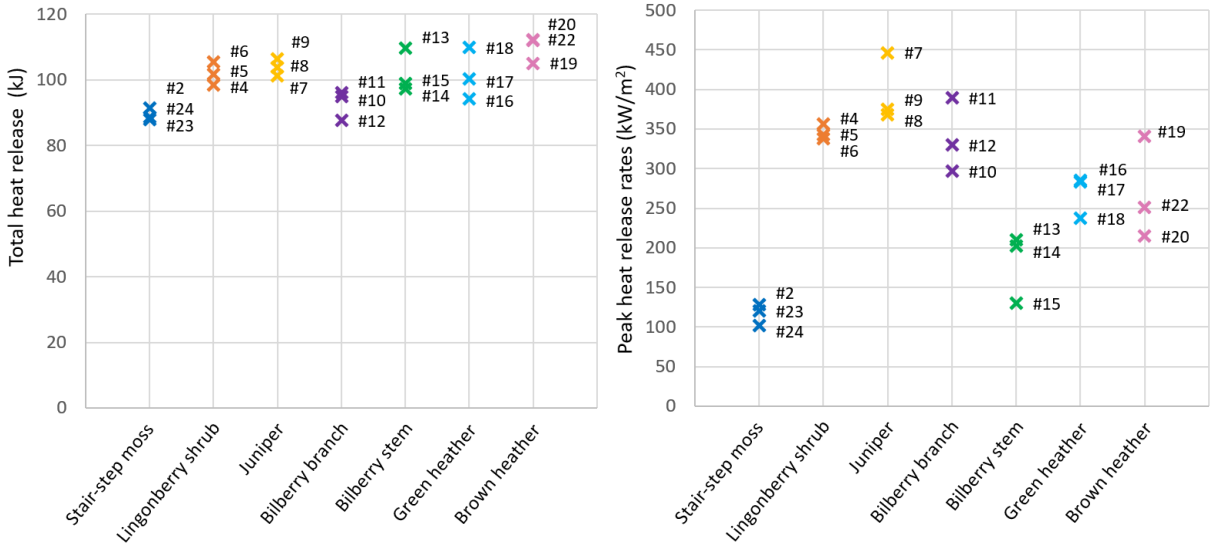

Figure 4: THR and peak HRR for vegetation samples exposed to 35 kW/m^2 in a cone calorimeter.

a hazard for fire spread along the forest floor as mentioned, it could be speculated that it does not pose a high-hazard species in terms of fire intensity. Here, further studies with natural vegetation structure and natural moisture contents are needed.

The highest peak HRRs were observed for lingonberry shrub, juniper, and bilberry branches. Juniper and lingonberry had the lowest moisture contents and are evergreen plants. Mechanisms enabling the survival of leaves and needles in subzero temperatures may well interplay with their fire characteristics. For example, juniper is known for its intense combustion due to the presence of volatile oils [12,13]. When considering the overall wildfire hazard of these species, the fuel density of the species in nature as well as the height of the vegetation must also be considered. With this in mind, despite having similar peak HRRs, juniper will most likely represent an overall higher fire hazard compared with the lingonberry and bilberry. The height of the juniper combined with the intense fire development means that juniper can be a so-called ladder species [14], enabling a wildfire to move from the forest floor to tree canopies. As Norwegian winter fires have occurred in recent years, a further understanding of fire characteristics of evergreen plants, also on larger experimental scales, will be beneficial for wildland management.

The THR of the vegetation samples varied less between the different types of vegetation and between samples of the same type of vegetation than the time to ignition, burning time and peak HRR. The THR values were in the range 87.55-112.08 kJ, corresponding to a surface area normalized THR of 9.90-12.68 MJ/m^2.

For the green and brown heather, there were no clear differences between the time to ignition, burning time, peak HRR and THR. This is interesting as the presence of old and unmanaged heather is considered a wildfire risk whereas young heather is not [15]. In this study, the specimens were not studied at their natural moisture levels, but after conditioning to similar EMC. Given the high overlap between fire characteristics of green and brown heather in our study, our results support the hypothesis in literature that the wildfire risk of heather is associated with moisture content and drying times; with rapid drying of old and dead heather (drying halftimes <10 h) and slower drying of green, live heather (drying halftimes ca. 13-42 h) [16].

The vegetation in this study was collected from a single forested area and within one month. The flammability of plants varies through the season [17], which can be related to the presence of leaves and young shoots, and the contents of substances such as monoterpenoids in plants which can vary with the seasons [13]. Further work should therefore study species sampled at different times of year.

In this study, conditioning of vegetation in the same temperature and humidity resulted in different equilibrium moisture contents. Investigations of the effect of chemical composition, vegetation structure and manners of water storage and release in live fuels are important next steps to fully understand the fire characteristics of different types of live vegetation.

4. Conclusions and practical implications of results

This study provides fire characteristics for five common wildland species in Norway: stair-step moss, lingonberry shrub, juniper, bilberry branches and stems, and heather. The species were not studied as-is, but conditioned to equilibrium moisture content in the same temperature and relative humidity before testing, leading to moisture contents of 9.70-12.90%. The fire dynamics were studied using the cone calorimeter.

Both stair-step moss and bilberry stems had low peak HRR and high burning times, displaying a longer and more even combustion process than the other samples. The other species had similar ignitability and burning times, except the bilberry stems that burned longer due to higher fuel thickness. Stair-step moss was identified as a potential hazard species for wildfire spread along the forest floor, as it ignited easily and had long burning times.

There were no clear differences between the time to ignition, burning time, peak HRR and THR values for the green and brown heather, although older heather is associated with higher wildfire risk. This supports existing hypotheses that the old heather mainly constitutes a fire hazard due to low moisture content and its ability to dry rapidly.

The most intense fire development, with highest peak HRR, was observed for the lingonberry shrub, juniper, and bilberry branches. When also considering how the species grow in nature, our findings are in line with literature that juniper represents a potential ladder-species for vertical wildfire spread to tree canopies and is therefore identified as a species of particular interest to consider for wildland management.

Further work should investigate seasonal variations of the species, including natural moisture content and natural vegetation structure. Experimental studies of the fire dynamics also at larger scales would also be beneficial, in order to study the impact of important factors such as natural fuel density, vegetation height etc.

5. Acknowledgements

This work is part of TREEADS, with funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101036926. Special thanks to Morten Daffinrud and Lei Jiang (RISE Fire Research) & Frida Vermina Plathner and Johan Sjöström (RISE Sweden).

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