Unprecedented Scottish megafire leads to widespread peat carbon losses

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Unprecedented Scottish megafire leads to widespread peat carbon losses

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Drier and warmer climates have allowed fires to increasingly burn carbon-dense peatland ecosystems. Here, we document the first megafire in the United Kingdom, which spread rapidly and burned severely across peatlands in Scotland with anomalously low soil moisture, emitting 39,338 MgC (25,250–64,565 MgC). Peat combustion contributed 85% of total emissions, suggesting drier climates increase fire emissions from peat, which are functionally irrecoverable on end-of-century timescales most relevant to climate change mitigation.

Fires are becoming larger and more severe in many ecosystems worldwide[1], resulting in increasing ecosystem impacts and carbon emissions[2,3]. Changing wildfire regimes in peatlands are especially concerning given that these ecosystems rarely burned historically; however, when peatlands burn, they can produce large carbon emissions when organic soil is combusted[4–6] (e.g., 78% of total fire emissions in northern systems[7]) and require centuries-millennia to re-sequester carbon in organic soils[8,9.] The multi-century recovery of carbon stocks in peat means that emissions can be considered ‘irrecoverable’ from the standpoint of climate mitigation initiatives, which typically focus on achieving a net zero exchange of carbon between the land and atmosphere during the current century[1].

High soil moisture in peatlands, sustained even during climatological dry seasons, protects belowground carbon stocks from burning most of the time[2]. In recent decades, tropical peatlands have experienced fires that combust peat, with extensive drainage for agriculture and occurrence of El Niños leading to low soil moisture and severe fires[3,4], while northern peatlands have been less affected. However, warmer and drier climates in northern peatlands[10] are increasing the occurrence of conditions conducive to wildfire (e.g., Canada’s 2023 wildfire season)[11] which lead to higher emissions from peat carbon stocks[5]. Here, we document the occurrence of the largest wildfire in at least the last twenty years (MODIS era) on peatland in the United Kingdom in June 2025 and argue that it points towards a possible shift in the UK’s fire regime and a bellwether for temperate and northern peatlands globally, many of which are forecast to experience drier and hotter climates[11,12].

The Dava Moor Fire, formed by the merger of two independently ignited fires at Dava and Carrbridge, northern Scotland, was the largest wildfire in UK history. Between June 28 and July 1, 2025, it burned approximately 10,000 hectares, making it the UK’s first megafire under a common size-threshold definition[6]. The fire was roughly twice the size of the next largest fire in the UK (Flow Country wildfire in 2019, recorded over the last 20 years in the MODIS era) and equivalent to the historical average of the UK’s total annual burned area[7] (2001-2021, *Methods*, Extended Data 1). The wildfire spread rapidly and burned severely, with the full extent of the fire burning in just four days and over 79% of the total burned area classified as high severity (*Methods*, Extended Data 2). In a country where fires are usually small, often managed, and not severe[13], the scale of this wildfire is unprecedented in the UK.

The wildfire occurred under very dry climate conditions. Soil moisture observations by the Soil Moisture Active Passive (SMAP) satellite[8,9] (*Methods*, Figure 1a,b) illustrate that much of Scotland was experiencing unusually dry soil moisture conditions preceding the fire. At the time and location of the fire, soil moisture was 1.9 standard deviations below the decadal average for that month in that location (Figure 1c). The low soil moisture at the time of the fire is consistent with dry conditions throughout 2025 following and a relatively dry 2024-2025 winter (precipitation was also very low, *Extended Data 3*). Meteorological conditions—assessed via the Fire Weather Index (FWI)[10]—illustrated that the location where the wildfire occurred had higher FWI values that other areas in Scotland, and temporally that the anomaly was substantially higher in May and marginally higher in June (1.3 and 0.4 standard deviations above decadal average, respectively, Extended Data 4). Concurrently, estimated aboveground fuel load per unit area was 1.2 standard deviations above the decadal average for June (estimated via vegetation optical depth[11]; Extended Data 5). Thus, fuel accumulation likely contributed to the rapid spread, but the dry climatic conditions primed the system to burn.

Nearly 80% of the total wildfire area was classified as severely burned (determined via differenced Normalized Burn Ratio (dNBR) from Sentinel-2 at 20 m resolution; Figure 2a,b, Table S1). Overlaying the high-resolution satellite data with a 10 m land cover map from 2023[12], we partitioned burn severity among ecosystem types (Figure 2b). Shrubland (land cover type of moorlands and heathlands) dominated the burned area (83% of burned area, Figure 2b, Table S1). Bogs accounted for 10% of burned area (Figure 2b, Table S1; bogs are defined as areas where peat depths exceed 0.50 m), while forests, woodlands and other vegetation types accounted for just 6% of burned area.

Even in typically wet bogs, 58% of the burned area was high severity (Figure 2b, Table S1). Consistent with the low soil moisture (Figure 1) and the high severity (calculated based on spectral changes of visible biomass), the fire burned into the peat (validated with 112 field measurements ca. one month after the fire; *Methods*, Extended Data 6-7). Our field sampling confirmed the presence of peat in 100% of randomly sampled points, and we were able to measure peat burn depths in areas classed as bog, moorlands and heathlands, and forests and woodlands (Extended Data 8-9).

We next quantified carbon emissions using a bottom-up emissions calculation based on soil moisture, burn depth, carbon density and combustibility of different land cover classes[12] (*Methods)*. We constrained burn depth with 112 field measurements and peat bulk density with 20 measurements from a nearby intact peatland (*Methods*). We also compared our locally-optimised bottom-up estimates to those from a global top-down fire emissions product based on observations of fire radiative power emitted from burned areas (Global Fire Assimilation System; GFAS[13]) and to a an existing UK-specific peat combustion model from Baker et al. ([12]; referred to here as the Baker Peat Combustion Model).

In this single fire, carbon emissions were 39,338 MgC (25,250 – 64,565 MgC based on the 25th and 75th quantiles of measured burn depths; Figure 2c-d, Table S2). Most emissions arose from combustion of peat (85% of total emissions, 31,294 MgC, Figure 2d, Table S2). Shrublands, which contributed the most to burned area, also contributed the most to emissions; surprisingly, a large fraction of total emissions from shrublands arose form belowground peat combustion whereas the combustion of aboveground vegetation combustion was relatively small (Figure 2d, Table S2). Bogs, which are usually too wet to burn, emitted 2,463 MgC (80% coming from burning into the peat; Figure 2d, Table S2). Combustion of peat was the predominant loss pathway in this fire and even occurred in historically wet bogs due to the low soil moisture.

Compared with our locally optimised emissions estimates, the Baker Peat Combustion Model over-estimated burn depths (predicting burn depths of ca. 6 cm vs. our observed median depths of less than 2 cm even in high severity areas, Extended Data, 8,9, Table S3). However, because the Baker Peat Combustion Model did not quantify belowground emissions from non-bog areas, the total wildfire emissions were comparable to our emissions using median field burn depths across bog as well as moorland and heathland land cover types (32,960 MgC vs. 39,338 MgC). GFAS estimated emissions based on fire radiative power were 30,000 MgC. Thus, the GFAS and peat model estimates underestimate emissions by 15% and 24%, respectively, relative to our estimates.

Many lines of evidence point to the 2025 summer climate conditions being more likely in the present climate than in a pre-industrial climate, and that conditions like this will be more common in the future, especially under higher emissions scenarios. First, human-caused climate change has increased the risk of wildfire in the UK (e.g., six-fold in 2022 ref.[11]). Second, the rising FWI, especially in the summer, appears to be a trend both locally (area around Morayshire wildfire, Extended Data 10) and regionally (Europe[14]). Even under low emission scenarios, the FWI in Europe is expected to rise by 24% by 2050[14]. Finally, the UK is projected to experience drier and hotter summers and more droughts (e.g., once every 20 years to once every three years by 2040[14]), which are conditions that lead to lower soil moisture as a pre-requisite to peat burning[2]. Consequently, fires are likely to not only grow larger but also burn more severely into peat. Both in the UK and globally, however, most fire models and fire weather indices are not tuned to peatland fires. For example, a prior analysis showed that some existing indices (e.g., the initial spread index[12]) were correlated with re-analysis soil moisture and modelled peat emissions, but the correlations were weak.

Our findings have ramifications for climate change and the policy for reducing emissions. The peat being combusted is often hundreds to thousands of years old[9], requiring equivalent or longer time to be recovered. Thus, the transition towards more C emissions from peat means that the net-emission impact of wildfires is rising. Along these lines, increasing peatland fires under dry conditions produces carbon emissions that for the purposes of climate mitigation is 'irrecoverable' because it takes centuries to reaccumulate—far exceeding the timeline of climate goals from 2050-2100. UK climate and land use policy focuses on re-wetting and restoring peatlands (e.g., investing £50M to restore 35k hectares in 2023), which in theory should help mitigate the risk of peat burning during fires. However, peatlands might remain vulnerable to extreme soil moisture deficit, necessitating policy makers to consider spatial projections in soil moisture changes when investing in restoration projects. Thus, preventing wildfires on peat should be prioritised, and factors such as projections on how soil moisture might change should be considered.

We propose that these findings highlight the UK is experiencing extreme wildfire conditions that make peatlands especially vulnerable and serves as a bellwether for how temperate and northern peatlands may change with global warming. The rising occurrence of very hot and dry summers has shattered the historically wet climate conditions of many temperate and northern peatlands[15]. This has corresponded with extensive wildfires and associated carbon emissions from these regions[16,17]. However, comparison between our field-constrained estimates and existing models for quantifying emissions demonstrated existing models underestimate carbon losses by roughly a quarter. Taken together, our findings demonstrate that as soil moisture declines, peat losses can rapidly overtake aboveground combustion as the dominant source of carbon emissions in wildfires.

Acknowledgements

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Figure 1:

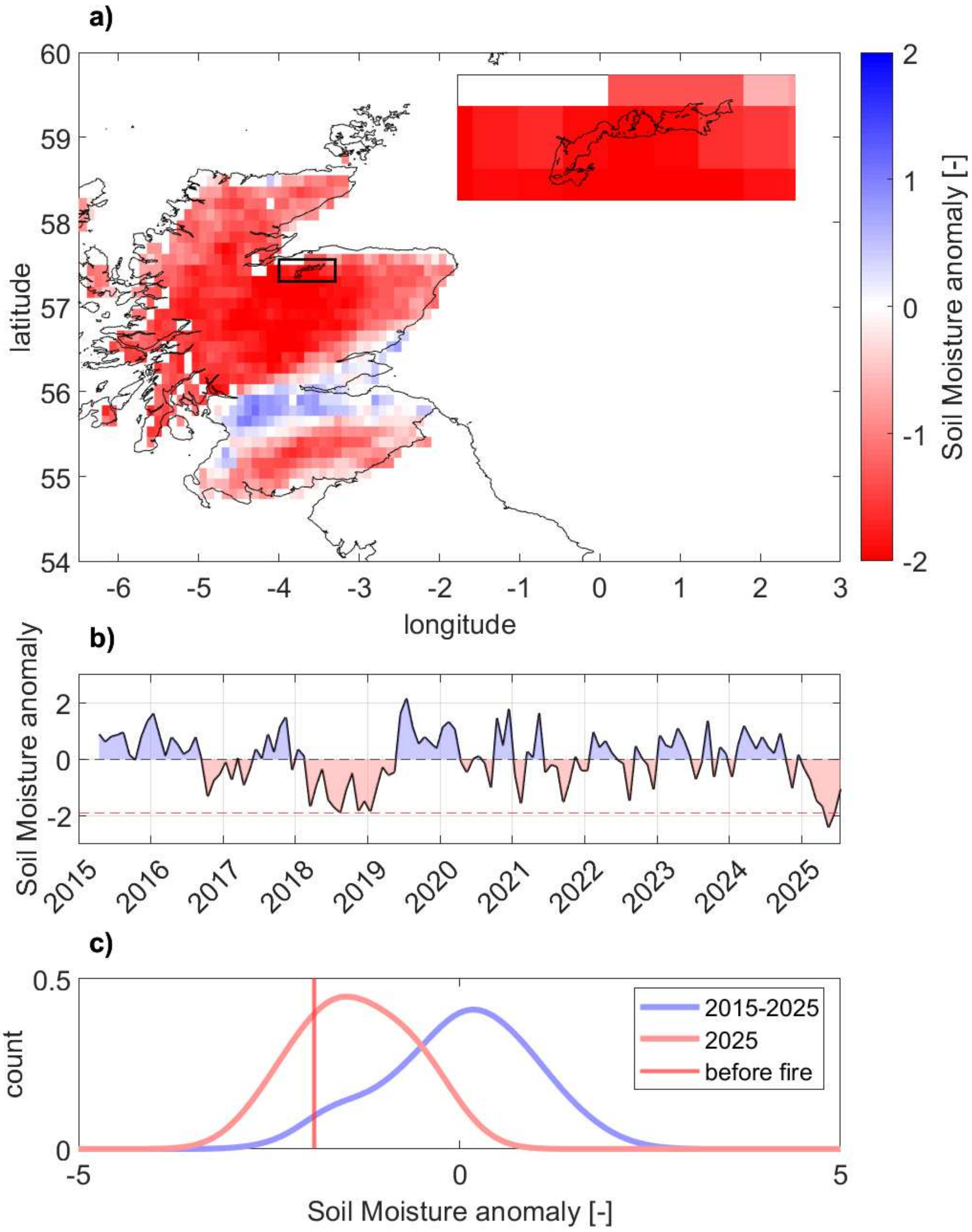


Figure 1: Exceptionally dry conditions in 2025 primed the Dava Moor fire. a) Map of the average soil moisture (SM) anomalies for June 2025, with an inlay of the Dava Moor fire perimeter. SM anomalies are calculated relative to respective monthly averages and standard deviations of the entire observational period (*Methods*). b) Time series of average monthly SM anomalies for the Dava fire area. c) Estimated SM anomaly probability density functions for all observations and 2025 observations. The average anomaly for June 2025 is displayed as a red line.

Figure 2:

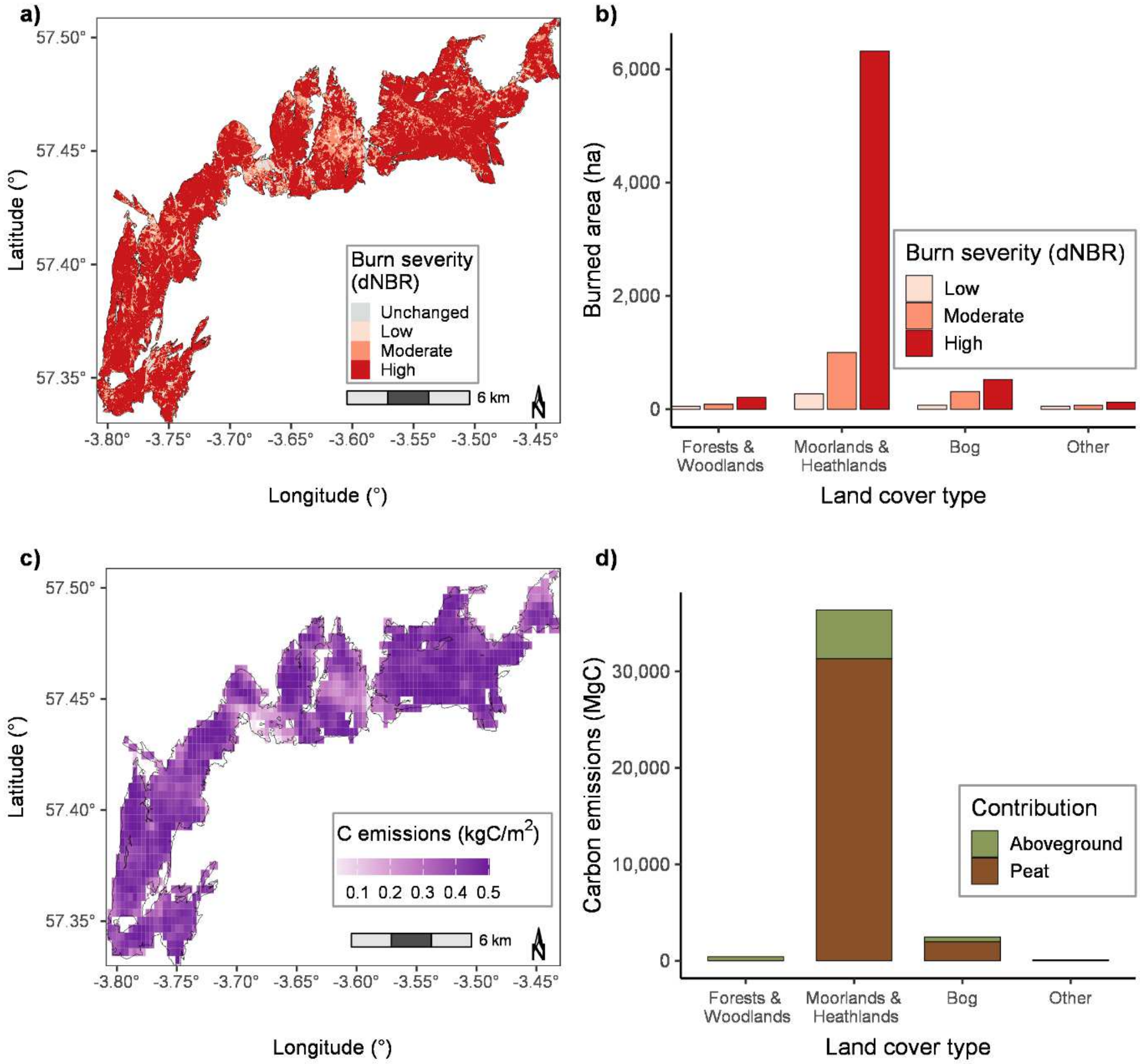


Figure 2: The wildfire was high-severity and peat combustion dominated emissions. a) fire severity calculated by the differenced Normalized Burn Ratio (dNBR) from Sentinel-2 at 20 m resolution (*Methods*). b) total burned area partitioned by land cover classes and burn severities. c) gridded carbon emissions based on the median peat burn depth in land cover classes. d) carbon emissions above- and belowground partitioned by land cover classes. All belowground emissions are combustion of peat.

Methods summary

Climate conditions and fuel load

To assess the climatic and environmental conditions around the Dava Moor fire we use soil moisture and vegetation optical depth (VOD) from NASA's Soil Moisture Active Passive (SMAP) mission, which uses on observations in the microwave spectrum to track water in soils and vegetation. SMAP soil moisture has been successfully used to predict burned area in peatlands and to track fire across ecosystems[4,18]. VOD is strongly related to vegetation water content and can give information on fuel load and fuel moisture[19]. Here we use SMAP soil moisture from the baseline single channel algorithm (SMAP-SCA), while VOD is taken from the dual channel algorithm (DCA), both of which are included in the SMAP Enhanced L2 Radiometer Half-Orbit 9 km EASE-Grid Soil Moisture product, version 6 (O'Neill et al. 2023). Soil moisture and VOD are mapped at least every 3 days and at a 9 km spatial resolution. For our analyses, we convert soil moisture and VOD to monthly anomalies relative to the 2015-2025 long-term average for each pixel. To further assess the dry conditions underlying the fire, we also use monthly precipitation estimates from the Met Office's HadUK-Grid[20] gridded and regional average climate observations dataset at 1 km resolution, which we also converted to monthly anomalies (accessed 9/19/2025).

The Fire Weather Index we analysed here is the Canadian Forest Service Fire Weather Index Rating System[10], which was downloaded from https://ewds.climate.copernicus.eu/datasets/cems-fire-historical-v1?tab=download.

Characterizing fire behaviour and severity

Using fire radiative power (VIIRS, 375m resolution, and MODIS, 500m resolution), we found that the fire front evolved within the southern and northeastern area, tending to transition from high intensity to low intensity at the timescale of days.

We further mapped the fire extent and severity with Sentinel-2 (20 m resolution). We found good agreement with the MODIS-based fire perimeter, and consistent spatial patterns for both dNBR and RdNBR (two alternative burn severity metrics). dNBR was calculated using a cloud-free median composite of 24 pre-fire images (May 15th-June 24th, 2025) and 10 post-fire images (July 25th-August 10th, 2025). Severity categories using categories in ref [21]: unchanged (<0.100), low (0.100-0.269), moderate (0.270-0.439) and high (>0.439).

We classified burned area into different land cover classes using land cover data came from the UK Centre for Ecology and Hydrology (2023 data, 10m pixels) and grouped them into

'Bogs', 'Moorlands and Heathlands', 'Forests and Woodlands', and 'Other Natural'. We assigned carbon stock values based on ecosystem type. These data were plugged into our emissions model (described below).

We conducted a field sampling campaign to measure peat burn depth across the wildfire. This helped constrain estimates of burn depths because of the high uncertainties in modelled data. At 107 locations within the burn scar (on a 200 m evenly spaced point-grid), we measured maximum and minimum burn depth in a 1 m^2 quadrat and assigned the mean of both measurements as the peat burn depth at that point. Burn depths were determined by comparing the base and roots of intact vegetation indicator species with the location of the residual peat (Extended Data 7,8).

Quantifying carbon emissions

For each burned grid cell, we apportioned carbon stocks based on the cover of different vegetation types and mean carbon stocks of those vegetation types[12]. Aboveground emissions were then calculated for each vegetation class within each burned pixel by multiplying the burned fraction, the available biomass carbon, the combustion completeness of different fuel types and the fraction of carbon (assumed to be 50%) in different fuel types.

For belowground emissions, we used two approaches to calculate our own bottom-up estimates. The first used burn depths constrained by field data. Specifically, we used the 25^{th}, 50^{th}, and 75^{th} quantiles of field-measured burn depths within burn severity classes (low, moderate, high) in the 'Bog' as well as 'Moorlands and Heathlands' land cover classes. Given that soil moisture measured via SMAP is at a very coarse scale relative to the finer-scale mosaic of bogs interspersed throughout the landscape, the field sampling is an approach that allows for microclimate or microtopography influences on burn depths. We did not account for potential compression in bulk density, but we did only assume 50% of combustion completeness. The mean bulk density of 58.2 ± 38.75 Mg m^{-3} used in these belowground emission calculations was determined from 20 measurements in a nearby intact heathland.

The second approach used a UK-wide model that estimates peat combustion based on a soil moisture scaler. This model also only considers peat combustion in the fraction of each burned area pixel where landcover is denoted as 'Bog'. We estimated peat stocks within bogs using a gridded peat map of Scotland[15]. For the bog pixels, the peat burn depth was estimated using soil moisture extracted from SMAP (top 7 cm of soil). The soil moisture was taken for the day of the fire.

Peat burn depth was calculated using:

$$SOC\ burn\ depth\ (cm) = 13.88 * soil\ dryness - 3.024.$$

Carbon emissions from belowground burning were then calculated as:

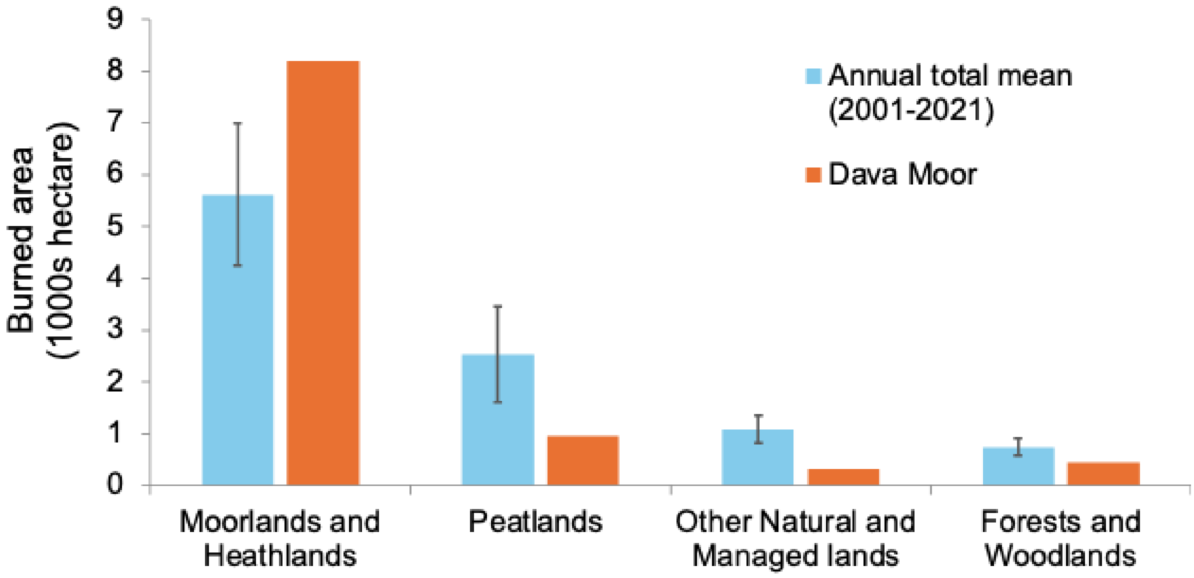
Carbon emitted from SOC burning = depth of burn (based on soil moisture) ∗ peat carbon bulk density (for Scotland) ∗ peatland fraction burned ∗ Combustion Completeness (0.5 for dry peat). A nation specific bulk density for Scotland of 68.64 Mg m^{-3} was used for the model.

Total fire carbon emissions is the sum of above- and belowground losses.

We also compared our estimates with reported values from GFAS. GFAS is based on applying emission coefficients relative to fire radiative power for specific land cover types.

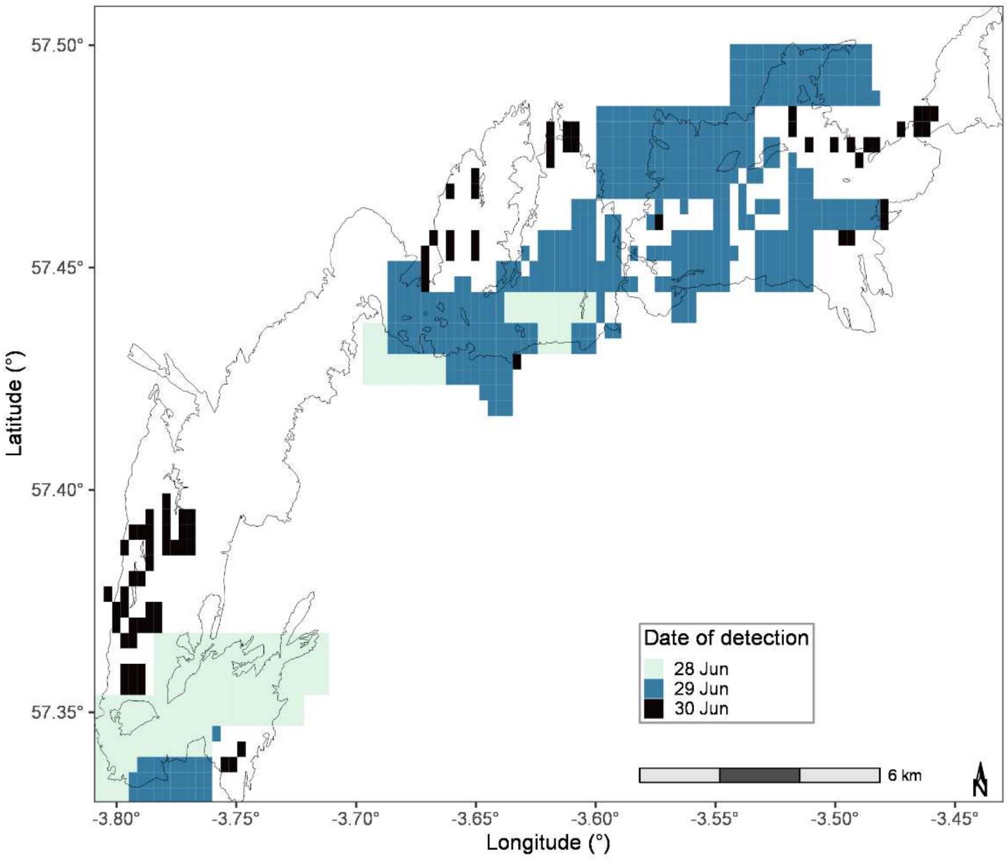
Supplemental Information

Extended Data 1:



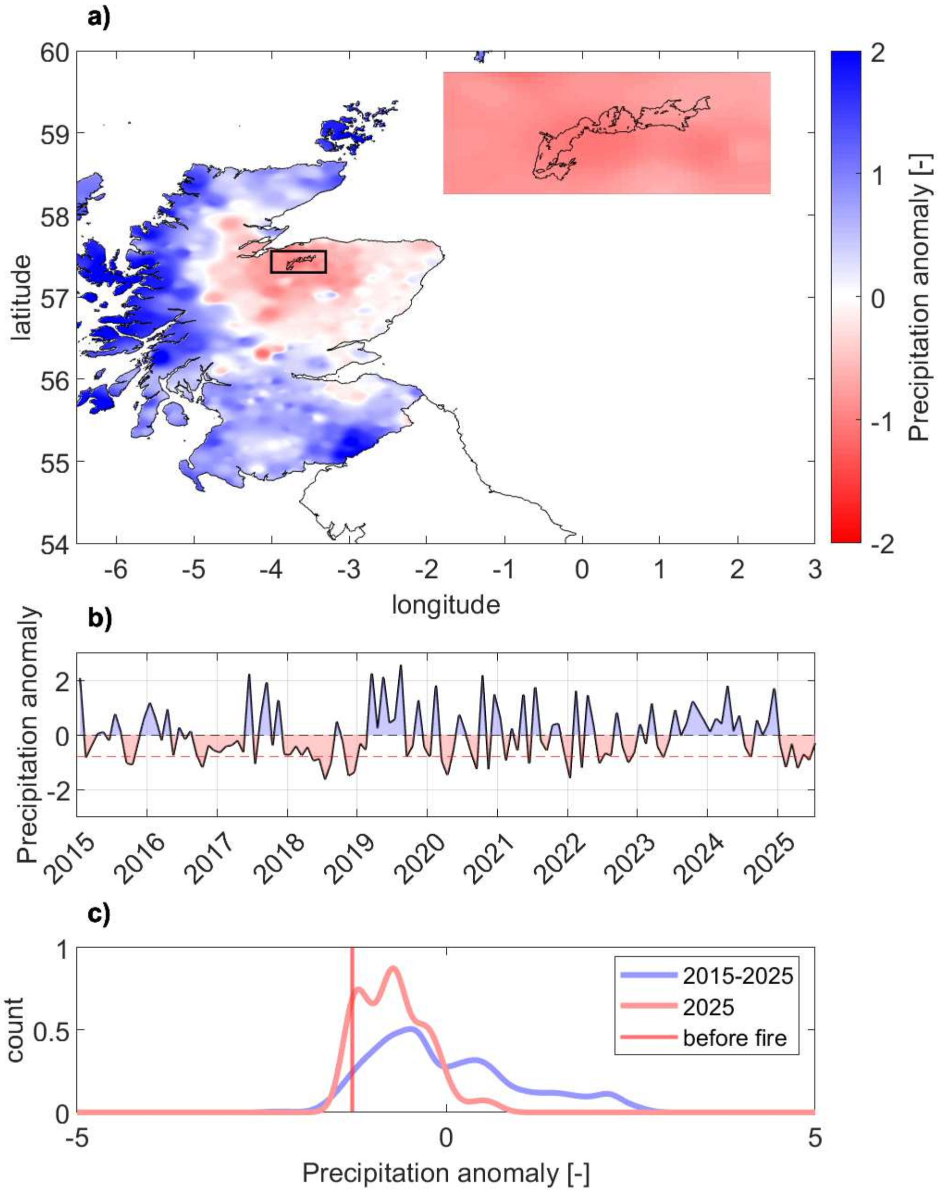
Extended Data 1: Comparison of Dava Moor with annual total burned area in the UK (averaged across 2001-2021, with standard errors). Vegetation type categories and burned areas from 2001-2021 are taken from ref.[22].

Extended Data 2:



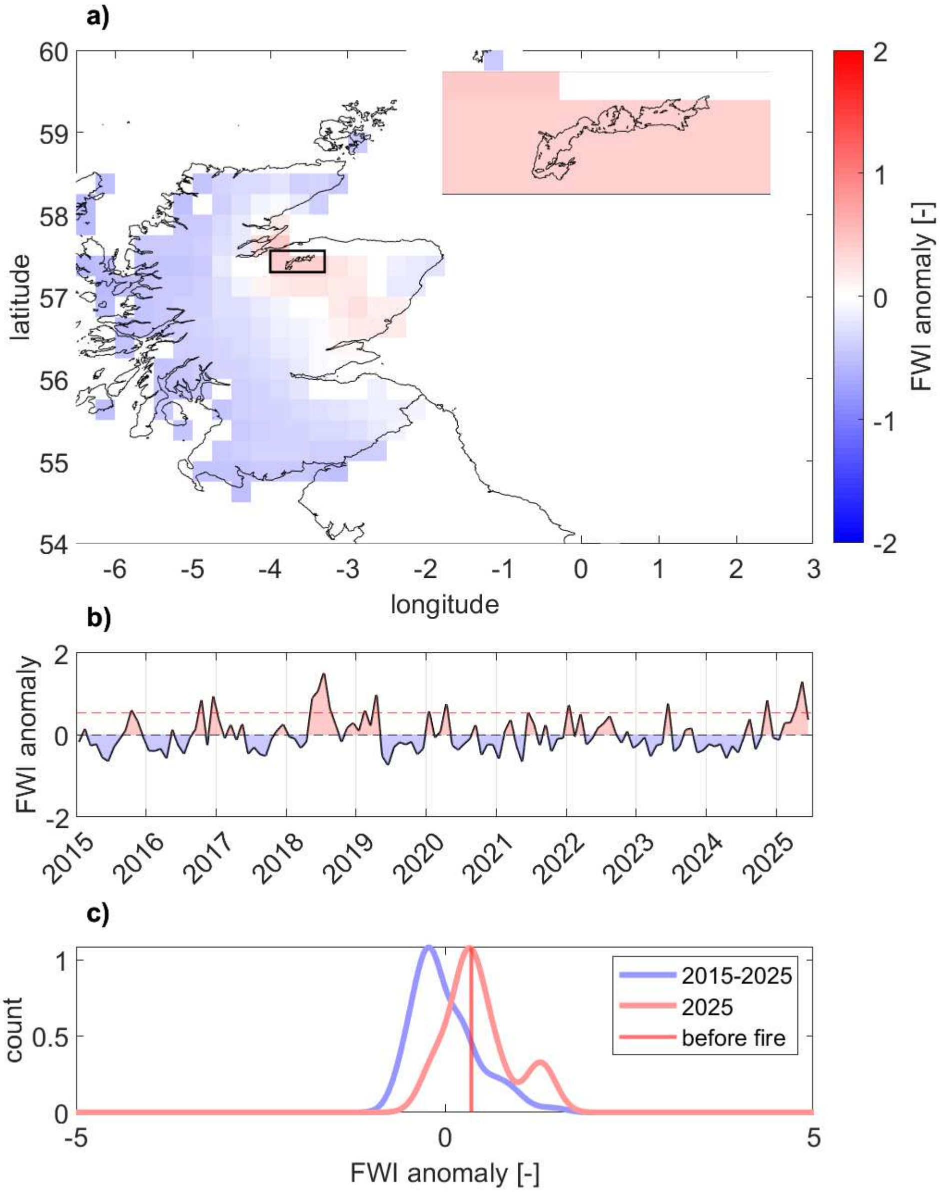
Extended Data 2: Fire spread. Active fire detections through time compositing Visible Infrared Imaging Radiometer Suite (VIIRS; 375m spatial resolution) and Moderate Resolution Imaging Spectroradiometer (MODIS; 1000m spatial resolution) thermal anomaly products. All dates are from 2025.

Extended Data 3:



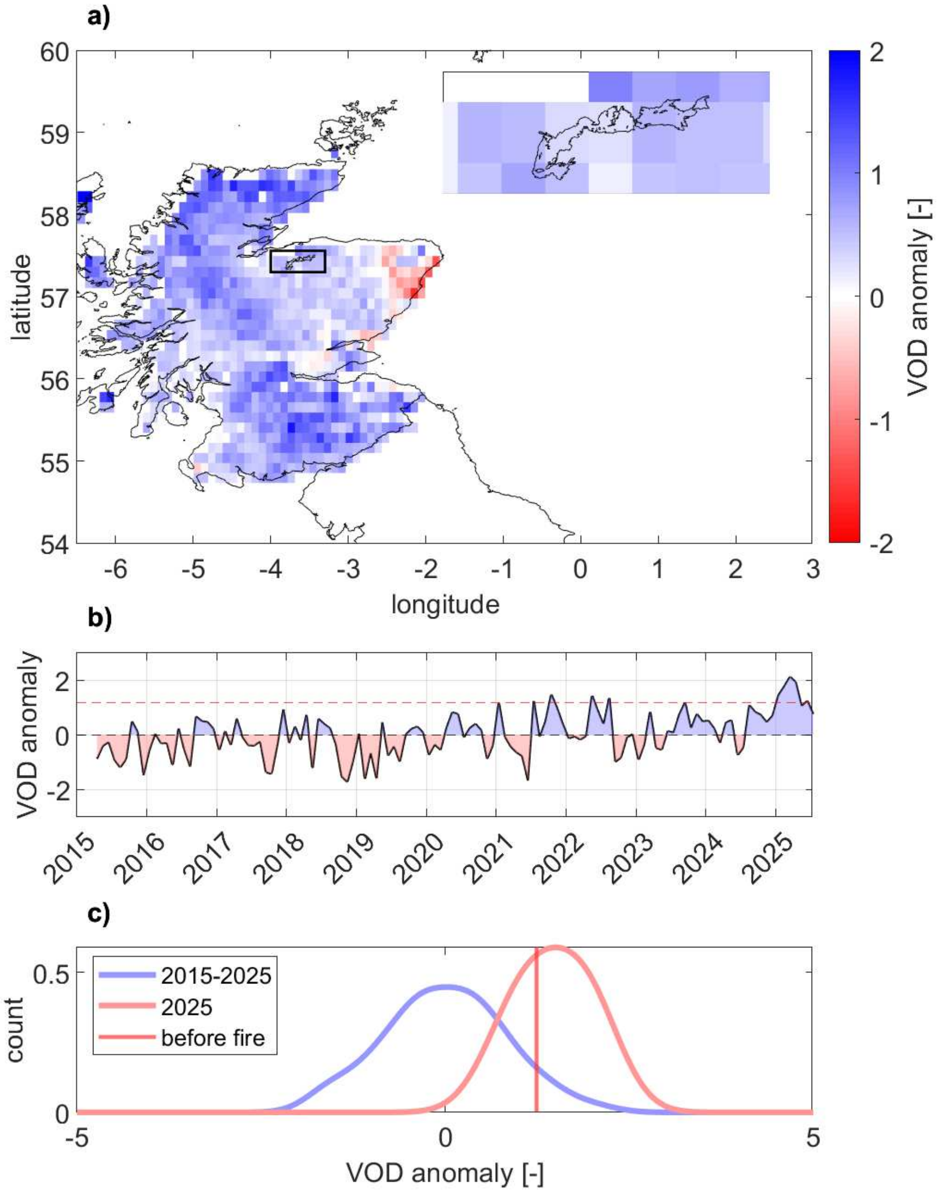
Extended Data 3: a) Map of the average precipitation anomalies for June 2025, with an inlay of the Dava Moor fire perimeter. Precipitation anomalies are calculated relative to respective monthly averages and standard deviations of the entire observational period (*Methods*). b) Time series of average monthly precipitation anomalies for the Dava fire area. c) Estimated precipitation anomaly probability density functions for all observations and 2025 observations. The average anomaly for June 2025 is displayed as a red line.

Extended Data 4:



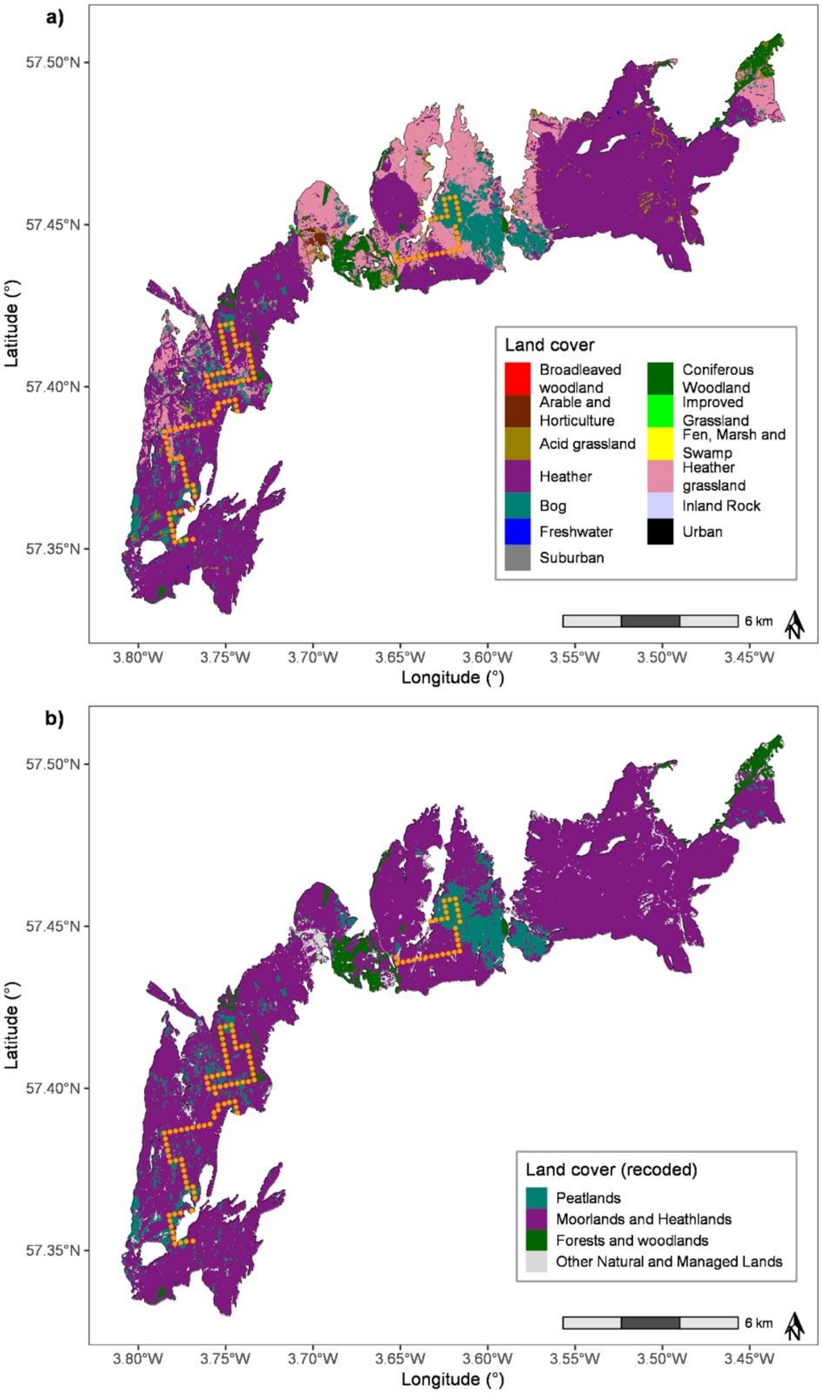
Extended Data 4: a) Map of the average Fire Weather Index (FWI) anomalies for June 2025, with an inlay of the Dava Moor fire perimeter. FWI anomalies are calculated relative to respective monthly averages and standard deviations of the entire observational period (*Methods*). b) Time series of average monthly FWI anomalies for the Dava fire area. c) Estimated FWI anomaly probability density functions for all observations and 2025 observations. The average anomaly for June 2025 is displayed as a red line.

Extended Data 5:



Extended Data 5: a) Map of the average vegetation optical depth (VOD) anomalies for June 2025, with an inlay of the Dava Moor fire perimeter. VOD anomalies are calculated relative to respective monthly averages and standard deviations of the entire observational period (*Methods*). b) Time series of average monthly VOD anomalies for the Dava fire area. c) Estimated VOD anomaly probability density functions for all observations and 2025 observations. The average anomaly for June 2025 is displayed as a red line.

Extended Data 6:

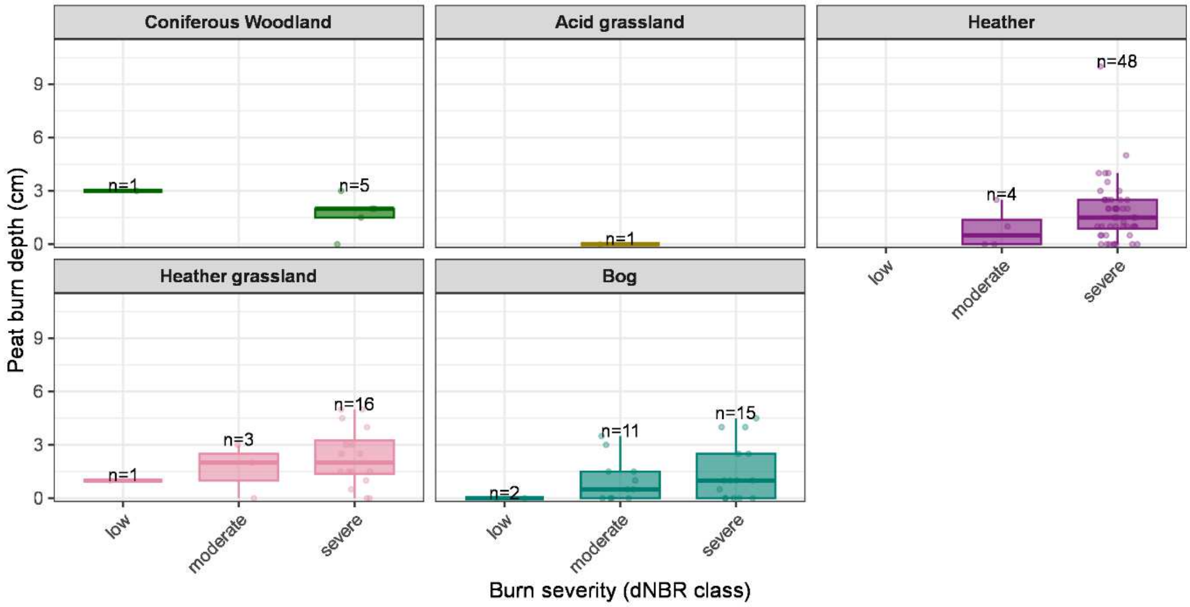


Extended Data 6: a) 2023 land cover classification at 10 m spatial resolution from the NERC EDS Environmental Information Data Centre (*Methods*). b) Grouped land cover classes used for emissions calculations. In both maps, locations of field-sampled burn depths are marked in orange.

Extended Data 7:

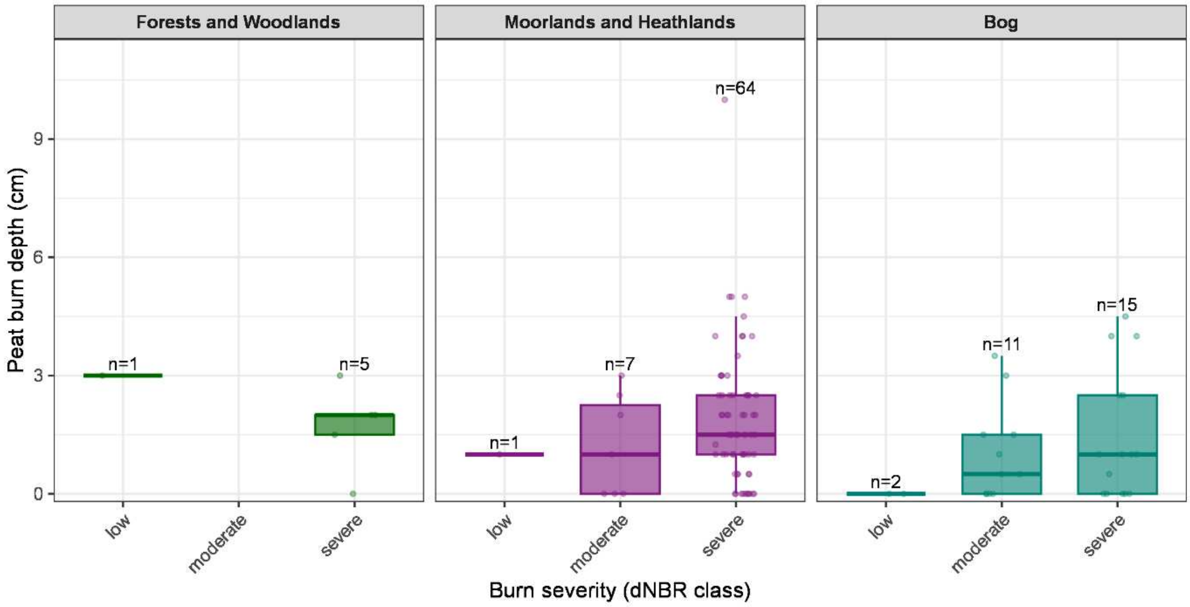
Extended Data 7: Landscape of the Dava Moor fire a month after the fire with an example of measuring burn depths and combustion of peat.

Extended Data 8:



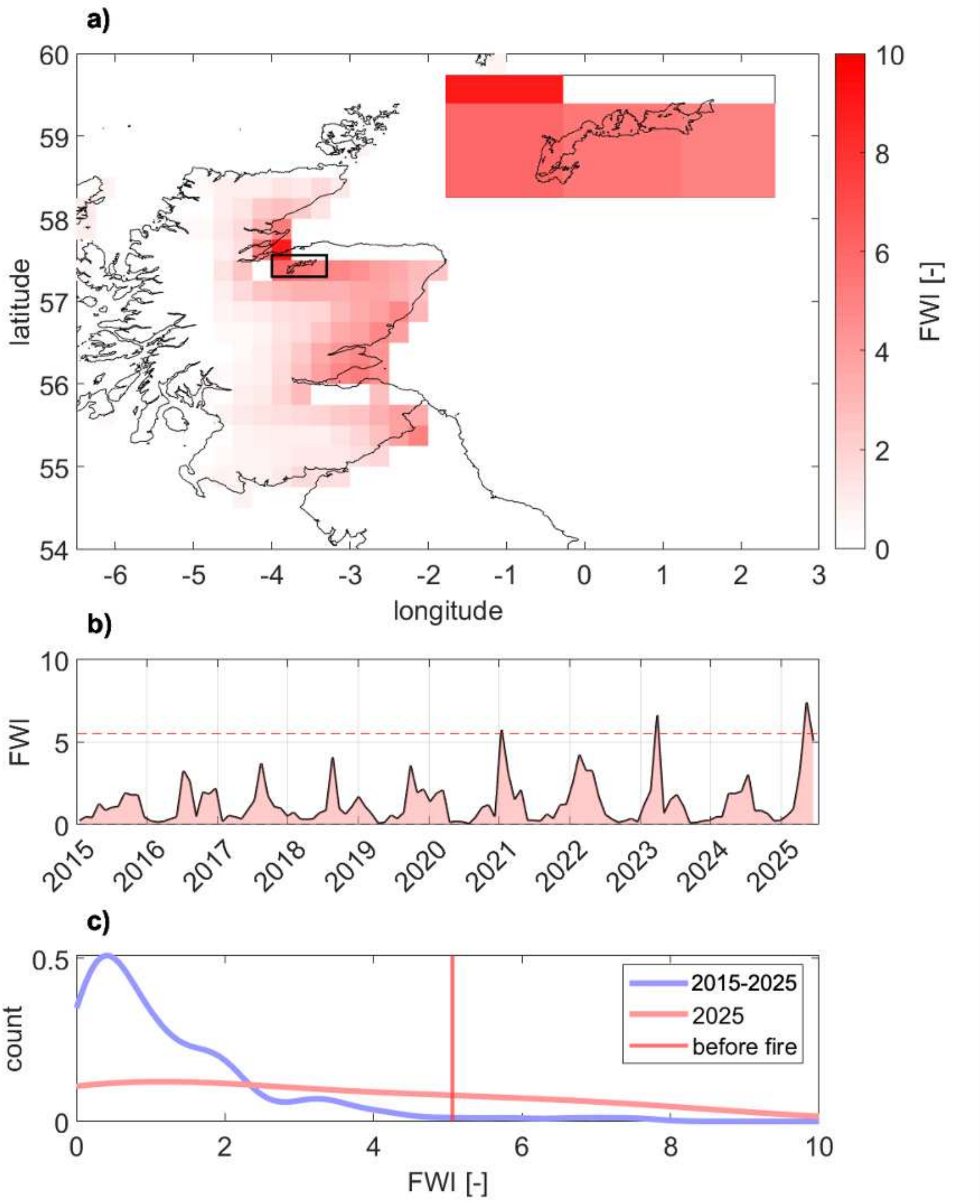
Extended Data 8: Field survey of burn depths across ecosystems from land cover classification in Extended Data 6a.

Extended Data 9:



Extended Data 9: Field-measured peat burn depths (cm; n=106) within the grouped vegetation types used for emissions calculations (Extended Data 6b), by burn severity class (based on dNBR).

Extended Data 10:



Extended Data 10: a) Map of the average Fire Weather Index (FWI) for June 2025, with an inlay of the Dava Moor fire perimeter. b) Time series of average monthly FWI for the Dava fire area. c) Estimated FWI probability density functions for all observations and 2025 observations. The average for June 2025 is displayed as a red line.

Table S1: Burned area by severity and land cover type

Land cover type	Low severity area (ha)	Moderate severity area (ha)	High severity area (ha)	Total area (ha)	Percent low severity	Percent moderate severity	Percent high severity
Forests and Woodlands	52.8	88.0	209.3	350.1	15.1%	25.1%	59.8%
Moorlands and Heathlands	271.9	1001.7	6320.2	7593.9	3.6%	13.2%	83.2%
Bog	72.5	312.3	523.2	907.9	8.0%	34.4%	57.6%
Other	54.8	70.8	123.3	248.8	22.0%	28.4%	49.5%
All categories	452.0	1472.7	7176.0	9100.8	5.0%	16.2%	78.9%

Table S2: Carbon (C) emissions by land cover type, using median field-measured burn depths.

Land cover type	Aboveground C emissions (MgC)	Belowground C emissions (MgC)	Total (MgC)	Percent aboveground	Percent belowground
Forests and Woodlands	421.1	0.0	421.1	100.0%	0.0%
Moorlands and Heathlands	5,064.6	31,294.1	36,358.6	13.9%	86.1%
Bog	486.1	1,976.9	2,463.0	19.7%	80.3%
Other	94.8	0.0	94.8	100.0%	0.0%
All categories	6,066.6	33,270.9	39,337.5	15.4%	84.6%

Table S3: Field-measured peat burn depths (cm) by landcover type and burn severity class (dNBR)

Landcover	Severity class	n	mean	Q25	median	Q75
Peatland	low	2	0.00	0.00	0.00	0.00
Peatland	moderate	11	1.05	0.00	0.50	1.50
Peatland	severe	15	1.47	0.00	1.00	2.50
Moorlands and heathland	low	1	1.00	1.00	1.00	1.00
Moorlands and heathland	moderate	7	1.21	0.00	1.00	2.25
Moorlands and heathland	severe	64	1.92	1.00	1.50	2.50
Coniferous woodland	low	1	3.00	3.00	3.00	3.00
Coniferous woodland	moderate	-	-	-	-	-
Coniferous woodland	severe	5	1.70	1.50	2.00	2.00