Provision of Analyses of Scottish Fire and Rescue Service (SFRS) Incident Reporting System (IRS) Data in Relation to Wildfire Incidents

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Provision of Analyses of Scottish Fire and Rescue Service (SFRS) Incident Reporting System (IRS) Data in Relation to Wildfire Incidents

Report prepared for the Scottish Government

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Table of Contents

Table of Figures

Table of Tables

1 Introduction

1.1 Background

Globally, over the last 50 years, wildfires have been recorded across many countries and regions. They are particularly common in Australia and Brazil, where known incidents have occurred over extensive areas and have caused destructive environmental harm (Arnell et al, 2021a). Moreover, due to an increasing awareness of wildfire occurrence, as well as concerns about how wildfire incidents could alter the landscape and potentially damage property and infrastructure, wildfires are increasingly an important topic of discussion across the UK (Davies et al, 2008; McMorrow et al. 2006, Arnell et al, 2021a).

Wildfires are commonly classified as semi-natural hazards and, in the Scotland, they are defined as “any uncontrolled vegetation fire which requires a decision, or action, regarding suppression” (Scottish Government, 2013). Their occurrence is likely to be determined by a combination of environmental and climatic influences i.e., temperature and amount of rainfall, but are most often caused by deliberate or accidental human influences (Arnell et al, 2011a). In addition, the distribution of wildfires in Scotland is believed to be non-random in both time and space; in particular, fuel hazard in spring, with abundant dead herbaceous and aerial shrub fuels, is quite different from that in summer where most above-ground fuel is live, while grass fuels are more abundant in the north-west of Scotland (Davies and Legg, 2016).

Most wildland fires in the UK are usually small in nature - usually under a hectare in size (Arnell et al, 2021a) and are most likely to occur in arable, grassland or mountain and heath environments (de Jong et al, 2016, Gazzard et al, 2016, Forestry Commission 2019). Furthermore, wildfires also occur frequently on remote upland peatland environments (Albertson et al, 2010). Although peatlands may be rare globally, covering roughly 2–3% of the Earth’s land surface, between 9% and 15% of Europe’s peatlands are located in the UK, with 77% of those occurring in Scotland (Bain et al, 2011).

Climate change has been cited as one of the major influences in increased wildfire occurrence globally (Grau-Andres et al, 2018; Arnell et al, 2021b). Specifically for the UK, mean summer temperatures are anticipated to rise by as much as 2.5°C by 2050 increasing wildfire risk, which can be further exacerbated by potential decreases by over 15% in annual rainfall over the same period (Grau-Andres et al, 2018). Increases in the frequency of drought will most likely lead to more frequent wildfires occurring across the UK, which can be more severe in nature, occur more extensively across landscapes and exhibit more variable seasonality (Albertson et al, 2010; Davies et al, 2013).

Wildfires can be destructive for seminatural habitats (Whitehead et al, 2021); they can cause peatland degradation (Carroll et al, 2009; Bain et al, 2011) and reduction of carbon storage; the release of toxic metals into the atmosphere (Turetsky et al, 2006); and extensive damage of sensitive habitats such as *Sphagnum* vegetation communities (Grant et al, 2012). Overall, it is expected that increased occurrence of wildfires, especially on remote upland area and peatlands, will be costly to fight, cause damage to freshwater catchments and other ecosystem services and require costly restoration (Albertson et al, 2010).

1.2 Project Aims and Objectives

The overall aims of the project entitled: "Provision of Analyses of Scottish Fire And Rescue Service (SFRS) Incident Reporting System (IRS) Data In Relation To Wildfire Incidents" are to a) improve the understanding of how upland wildfires start; b) investigate if wildfire occurrence differs between geographical areas; and c) describe how wildfires exhibit seasonal and temporal trends.

In particular, the principal objectives of the project are to:

- Investigate how wildfires affecting semi-natural habitats can be extracted from SFRS incident data and how can they be best used to provide information about ignition sources (at a broad scale; accident, behavioural, intentional), locations (SFRS areas) and time of year.
- Report on any trends evident from these data.
- Make recommendations on any improvements that could be made to enhance the dataset's usefulness for these purposes.
- Compare the SFRS data to wildfire trends in Europe to examine if there are lessons that can be learnt.

1.3 Report outline

This report is organised in the following sections:

- Section 2 provides the description of the SFRS IRS dataset, including the main fields that were used in the analysis.
- Section 3 presents a brief overview of the methods used in the analysis.
- Section 4 presents the harmonisation of the fire incidents regarding fuel types, and the filtering process devised for identifying and selecting wildfires affecting seminatural habitats.
- Section 5 presents the results of the investigation of different patterns in the filtered wildfires dataset (seasonality, fuel types, motives of ignition, burnt area size and accessibility), analysed at a National and Local Authority level.
- Section 6 presents the results from the comparison of information recorded in IRS wildfires with information derived from burnt area polygons, regarding distances

between IRS locations and fire perimeters, fuel type composition and burnt area sizes.
- Section 7 presents the results of the investigation of patterns (temporal, fuel type and burnt area size) in Scotland and other Northern European countries.
- Section 8 presents the results from the Highland LA case study regarding spatial relations between wildfire locations and explanatory variables and ignition risk modelling and mapping.
- Section 9 provides recommendations for improving the IRS dataset for identifying wildfires and using wildfire incident data in wildfire operations and research.

2 Description of the SFRS IRS dataset

The dataset provided by the Scottish Fire and Rescue Service (SFRS) for the purpose of this project consists of 132,829 recorded fire incidents between April 1st 2009 to December 31st 2020. This is a subset of the Incident Reporting System (IRS) records that has been created by filtering for completed fire incident records based on thirty-one (31) Property Type Level codes/descriptions that denote an Outdoor Fire and likely Wildfire Land Type.

The IRS dataset consists of 44 fields, of which the most relevant to this project are the following:

- Incident Id, which is a unique code for each recorded fire incident.
- Eastings/Northings, which are the coordinates of the location of recorded fire incidents in the OS British Grid.
- Incident Type, which consists of three classes: Outdoor fire (*n*=87,533); Refuse (*n*=40,117) and Other Primary Fire (*n*=5,179).
- Recorded dates of fire incidents.
- Property Type codes denoting burnt vegetation or fuel type, of which information for Level 3 Property Types were mostly used in this project.
- Outdoor Damage Area, which gives an estimate of burnt area (in m^2) based on the following classes: None; Up to 5 m^2; 6 - 10 m^2; 11 - 20 m^2; 21 - 50 m^2; 51 - 100 m^2; 101 - 200 m^2; 201 - 500 m^2; 501 - 1000 m^2; 1,001 – 2,000 m^2; 2,001 – 5,000 m^2; 5,001 – 10,000 m^2 and Over 10,000 m^2. Additionally, we also considered field Outdoor Damage Large Area Size, which gives a numeric estimate of the burnt area, but this information was available for only 676 recorded fire incidents.
- Motive, which consists of three classes: Accidental (*n*=11,002); Deliberate (*n*=111,819) and Not Known (*n*=10,008). We also looked at information related to cause of ignition, ignition source and items causing ignition and fire spreading that were available for a subset of recorded fire incidents.

Visual inspection of the spatial distribution of IRS fires using the recorded coordinate information revealed the presence of strong clustering within and/or in proximity of urban areas or other settlements and around the primary and secondary road networks, as shown in Figure 2.1 for the Aberdeen City and Aberdeenshire areas.

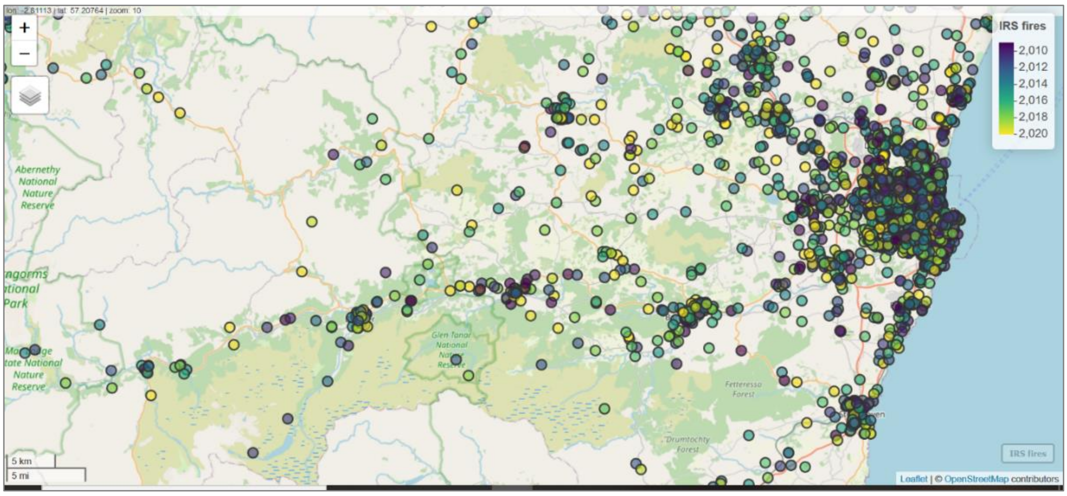


Figure 2.1 Locations of IRS fires in the Aberdeen City and Aberdeenshire areas. Legend shows years when fire incidents were recorded.

Regarding the recorded vegetation or fuel types, around 52% of the recorded fire incidents belong to the Property Type Level 2 category of "Grassland, woodland and crops" and the remaining 48% are found in the "Other outdoors (including land)" category. Table 2.1 provides the counts and overall proportions of fire incidents for each Level 3 Property Type. The greater number of recorded fire incidents (around 30%) belongs to the "Loose refuge incl. in garden" category, while another 4% is found in the "Wasteland" category; both categories are classified as "Other outdoors" fires. Most fire incidents classified as "Grassland, woodland and crops", which are more likely to relate to wildfires affecting seminatural vegetation, are found under the "Grassland, pasture, grazing etc" category (~12%), followed by fires in "Scrub land" (~11%) and in "Heathland or moorland" (~6%).

Table 2.1 Counts and proportions (in %) of fire incidents recorded in the IRS dataset Property Type Levels 2 and 3.

A/A	Property Type Level 2	Property Type Level 3	Count	Proportion (%)
1	Grasslands, woodlands, and crops	Canal/riverbank vegetation	1,910	1.44
2		Grassland, pasture, grazing etc	15,697	11.82
3		Heathland or moorland	7,417	5.58
4		Hedge	1,452	1.09
5		Nurseries, market garden	26	0.02
6		Private/Domestic garden/allotment (vegetation not equipment/building)	4,807	3.62
7		Railway trackside vegetation	836	0.63
8		Roadside vegetation	4,789	3.61
9		Scrub land	15,103	11.37
10		Stacked/baled crop (incl. manure heap)	1,010	0.76
11		Standing crop	76	0.06
12		Straw/stubble burning	1,090	0.82

A/A	Property Type Level 2	Property Type Level 3	Count	Proportion (%)
13		Tree scrub (includes single trees not in garden)	11,421	8.60
14		Woodland/forest - broadleaf/hardwood	1,798	1.35
15		Woodland/forest - conifers/softwood	2,017	1.52
16	Other outdoors (including land)	Airfield/runway	3	0.00
17		Beach	417	0.31
18		Cemetery	145	0.11
19		Cycle path/public footpath/bridleway	1,711	1.29
20		Golf Course (excluding buildings)	177	0.13
21		Highway/road surface/pavement	1,166	0.88
22		Human harm outdoors	8	0.01
23		Lake/pond/reservoir	27	0.02
24		Loose refuse (incl. in garden)	40,176	30.25
25		Other outdoor location	9,261	6.97
26		Park	3,498	2.63
27		Playground (not equipment) or Recreational area	710	0.53
28		Railway	146	0.11
29		River/canal	138	0.10
30		Sea	5	0.00
31		Wasteland	5,792	4.36

3 Methodology

3.1 Overview

The main objective of the methodological approach is to investigate how and to what extent can the Scottish Fire and Rescue Service (SFRS) Incident Reporting System (IRS) data be used to detect wildfires, which for the purpose of this project are defined as wildland fires affecting seminatural habitats in Scotland.

The analysis is based on harmonising and filtering the SFRS IRS data to identify wildfires and on devising and using methods for assessing the relation (spatial) between the location of SFRS IRS data and a) location of ignition and b) respective fuel types responsible for ignition and c) other biophysical and socioeconomical information. The methodology aims to establish these relationships with confidence to enable identifying temporal and seasonal patterns of wildfire occurrence and patterns related to fuel types, along with the investigation of patterns related to extent of burnt areas, motives for ignition and accessibility.

The methodology uses a combination of statistical and geospatial analyses of recorded information within the SFRS IRIS dataset and information derived from satellite imagery and from various spatial datasets related to wildfires available from different sources. The steps involved in the methodology are shown in Figure 3.1 and are briefly described in paragraphs

3.2 to 3.7 below. A more detailed description of the methodology is given in the Sections 4 to 9.

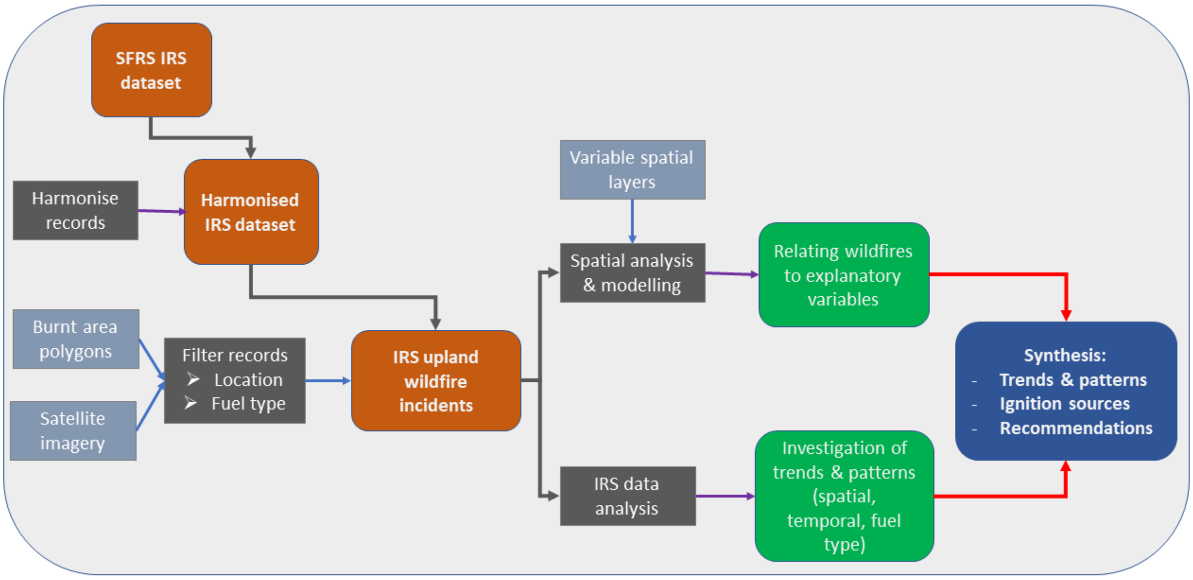


Figure 3.1 Flowchart of proposed methodology steps for the analysis of the SFRS IRS dataset.

3.2 Developing the IRS wildfires dataset

The first part of the analysis consists of the harmonisation of land use information within the IRS fire incidents dataset and the filtering procedure for identifying and selecting wildfires.

3.2.1 Harmonisation of land use information

Harmonising land use information forms the basis for developing the filtering process as land use and fuel type are the main information used to identify fires affecting seminatural vegetation. The analysis is based on devising a classification scheme at aggregated broad habitat and land use levels that is common to the IRS recorded information and to a set of available spatial layers of habitat, land use and fuel type of different scales and resolutions.

3.2.2 Identifying and selecting wildfire incidents

The purpose of the analysis is to identify IRS fires that affect seminatural habitats and to exclude urban fires (e.g., bonfires, vehicles, rubbish or unspecified) from further analysis. The process for identifying wildfires is based on the combined investigation of their recorded location, in relation to boundaries of settlements in Scotland, and vegetation/fuel type information from the relevant IRS fields and other spatial land use layers. Filtering of IRS records is based on a set of rules using the geographical and land use information and the final selection of wildfires is completed after extensive visual inspection of land use and vegetation type from satellite imagery at the locations of the filtered IRS fire incidents.

3.3 Investigation of patterns in the IRS wildfires dataset

This part of the analysis uses the information recorded in the filtered IRS wildfire dataset to identify temporal and seasonality patterns, vegetation/fuel type patterns of wildfire occurrence in Scotland and patterns related to burnt area extents, motives, and accessibility. Results are presented at a National and Local Authority level in the form of appropriate tables, figures, and maps, and are used to improve our understanding as to why these patterns emerge in certain areas, fuel types and time periods.

3.4 Comparing IRS wildfire properties using datasets of burnt areas

This part of the analysis uses available spatial datasets of burnt areas that have been produced from satellite imagery analysis, along with new burnt areas delineated in the context of this project, in order to provide an assessment of the a) The proximity of the location recorded within the IRS to the actual burnt area; b) Similarity of recorded land use/fuel type in the IRS with land use/fuel type present within the burnt area polygons; and c) Similarity between recorded burnt areas within the IRS and actual burnt area calculated from the delineated polygons. To enable this comparison, we used the date of IRS wildfires incidents and their location to identify those wildfires that corresponded to the available polygons of burnt areas.

3.5 Comparing wildfire patterns in Northern Europe

This part of the analysis aims to investigate and compare patterns of seasonality and fuel type in wildfires occurring in selected Northern European countries with similar bioclimatic conditions and land management practices to Scotland, using burnt area and fuel type information available at a European level. Countries included in this analysis were the Republic of Ireland, Northern Ireland, Scotland, Wales, England, Norway, Sweden and Finland.

3.6 Relating IRS wildfires to explanatory variables of fire occurrence

This part of the analysis aims to improve our understanding of causative factors of wildfire ignition by relating the spatial distribution of recorded IRS wildfires with information from readily available spatial layers of explanatory variables of fire occurrence (e.g., bioclimatic, topographical, land use, accessibility and socioeconomical factors). These spatial relationships between IRS wildfires and different variables are used to demonstrate how to build models of ignition risk in a test area (Highland Local Authority) that can be used for wildfire management and preparedness.

3.7 Synthesis and Recommendations

Results from the analyses conducted are used to summarise the identified patterns of wildfire occurrence in Scotland and infer assumptions about ignition sources. We also assess the usefulness of the SFRS IRS dataset for detecting wildfires affecting seminatural habitats and provide recommendations for improving the IRS dataset for this purpose.

4 Developing the SFRS IRS wildfires dataset

4.1 Harmonisation of land use information

Initial investigation of the IRS dataset showed that the records are complete and that there is a consistent set of categories used to describe the likely fuel types (as given in the Levels 2 and 3 Property Types). Initial investigation and findings from previous studies (Davies and Legg, 2016) have shown that, for a substantial number of the IRS records that are assumed to relate to wildfires, the location recorded is where the fire was reported from or where fire-fighting resources were marshalled rather than the core or ignition point of the fire itself. This is likely to be true for most remote wildfires with difficult access. Therefore, it was necessary to check the recorded IRS fuel type information against other available land use and fuel type information to account for the known issues related to the positional accuracy of fire incident locations. For this reason, we used the following available spatial datasets:

- EUNIS habitat classification map (20m raster) produced by Space Intelligence in partnership with NatureScot (https://www.space-intelligence.com/scotland-landcover).
- Land Cover Scotland 1988 map (LCS88) map at 1:25,000 scale (MLURI, 1993).
- Land Cover Map 2015 (LCM15, 25m raster) produced by the Centre of Ecology and Hydrology (CEH, 2017).
- European Fuel Types Map (250m raster) produced by the European Forest Fire Information System (EFFIS, 2017).

The EUNIS, LCM15 and EFFIS Fuel Type (FT) maps were available in Geotiff format and were produced using different satellite imagery products, while LCS88 was available in ESRI shapefile (polygon) format and produced with a combination of on-ground surveying and interpretation of aerial orthophoto maps. This set of maps provide a comprehensive overview of vegetation and land use patterns in Scotland at different scales, but they also use slightly different land use categories. Therefore, it was necessary to devise a common classification scheme that could cover all IRS Level 3 Property Types and harmonise them with the EUNIS, LCS88, LCM15 and EFFIS FT maps. We developed aggregated categories using our expert knowledge of Scottish vegetation types at a) Broad Habitat (BH) level and b) Land Use (LUSE) level, with BHs being finer in their classification than LUSEs. The aggregated LUSE classes were mainly used for the filtering of IRS fire incidents to identify wildfires, while BHs were mainly used to investigate patterns related to fuel type composition.

The results of this process for each of the five datasets are given in Tables 4.1 to 4.5. As expected, there was not always clear correspondence between all land use classes and vegetation types considered or there were ambiguities about the type of vegetation described in a certain IRS Property Type. Therefore, in many cases we had to resort to our judgement coupled with extensive visual inspection using the coordinates of IRS fire incident locations and Google satellite imagery loaded within the QGIS Geographical Information System (QGIS.org, 2021). For example, we used the land use datasets and visual inspection of satellite imagery to decide whether to assign the “Scrub land” category to a “Grasslands” or a “Shrubland” BH, because we were unsure as to what type of vegetation the “Scrub land” category refers to, since scrub vegetation could include a mixture of both grasses and shrubs. Similarly, visual inspection at the locations of fire incidents belonging to the quite extensive category of “Loose Refuse” revealed that these fires could potentially occur in seminatural, cultivated or urban areas. Therefore, we took the decision to give this category an initial LUSE class of BOTH (i.e., both cultivated and seminatural) and devise different filtering rules at the next stage depending on whether these fire incidents were inside or outside built-up areas. The same applied for the “Grassland, pasture, grazing etc” category which was given a BOTH LUSE class since it includes both managed and seminatural grasslands.

Overall, the harmonisation process highlighted two main issues in relation to identifying wildfires:

- There is no IRS Level 3 Property Type specific to Bogs and/or peatlands, which are mapped as a separate class in the EUNIS, LCS88, LCM15 and EFFIS FT datasets.
- There is no clear distinction in the IRS Level 3 Property Type between seminatural grasslands and grazed pastures, while the EUNIS, LCS88 and LCM15 maps provide the distinction between the different types of seminatural and improved grassland.

Table 4.1 Classification of IRS Level 3 Property Types into Broad Habitats (BH) and Land Use (LUSE) classes. For LUSE classes: CULT=Cultivated land; SEMI=Seminatural vegetation; BOTH=Could be both cultivated land and seminatural vegetation.

Property Type Level 3	BH	LUSE
Airfield/runway	Built-up	URBAN
Animal harm outdoors	None	NONE
Beach	Other	OTHER
Canal/riverbank vegetation	Grasslands	BOTH
Cemetery	Built-up	URBAN
Cycle path/public footpath/bridleway	Linear features	URBAN
Golf Course (excluding buildings)	Built-up	URBAN
Grassland, pasture, grazing etc	Grasslands	BOTH
Heathland or moorland	Shrubland	SEMI
Hedge	Grasslands	SEMI
Highway/road surface/pavement	Linear features	URBAN
Human harm outdoors	None	NONE
Lake/pond/reservoir	Freshwater	WATER
Loose refuse (incl. in garden)	Refuse	BOTH
Nurseries, market garden	Grasslands	CULT
Other outdoor location	Other	OTHER
Park	Built-up	URBAN

Property Type Level 3	BH	LUSE
Playground (not equipment) or Recreational area	Built-up	URBAN
Private/Domestic garden/allotment (vegetation not equipment/building)	Grasslands	URBAN
Railway	Linear features	NONE
Railway trackside vegetation	Linear features	BOTH
River/canal	Freshwater	WATER
Roadside vegetation	Linear features	BOTH
Scrub land	Grasslands	SEMI
Sea	Freshwater	WATER
Stacked/baled crop (incl manure heap)	Arable	CULT
Standing crop	Arable	CULT
Straw/stubble burning	Arable	CULT
Tree scrub (includes single trees not in garden)	Broadleaves	SEMI
Wasteland	Refuse	BOTH
Woodland/forest - broadleaf/hardwood	Broadleaves	SEMI
Woodland/forest - conifers/softwood	Conifers	SEMI

Table 4.2 Classification of EUNIS habitat classes into Broad Habitats (BH) and Land Use (LUSE) classes.

EUNIS habitat classes	BH	LUSE
C Surface standing and running waters	Freshwater	WATER
D1 Raised and blanket bogs	Bogs & peatlands	SEMI
D2 Valley mires, poor fens and transition mires	Bogs & peatlands	SEMI
D4 Base-rich fens and calcareous spring mires	Bogs & peatlands	SEMI
E1 Dry grasslands	Grasslands	SEMI
E2 Mesic grassland	Grasslands	BOTH
E3 Seasonally wet and wet grasslands	Grasslands	SEMI
E4 Alpine and subalpine grasslands	Montane	SEMI
E5 Woodland fringes and clearings and tall forb stands	Linear features	SEMI
F2 Arctic, alpine and subalpine scrub	Montane	SEMI
F3 Temperate and mediterranean-montane scrub	Montane	SEMI
F4 Temperate shrub heathland	Shrubland	SEMI
F9 Riverine and fen scrubs	Riparian	SEMI
G1 Broadleaved deciduous woodland	Broadleaves	SEMI
G3 Coniferous woodland	Conifers	SEMI
G4 Mixed deciduous and coniferous woodland	Mixed woodland	SEMI
G5 Lines of trees, small anthropogenic woodlands, early-stage woodland and coppice	Linear features	SEMI
H2 Screes	Screes	SEMI
H3 Cliffs and rock pavements	Cliffs	SEMI
I1 Arable land and market gardens	Arable	CULT
J Built-up	Built-up	URBAN
O Bare field	Bare	CULT

Table 4.3 Classification of Land Cover Scotland (LCS88) classes into Broad Habitats (BH) and Land Use (LUSE) classes.

LCS88	BH	LUSE
Arable	Arable	CULT
Blanket bog & peatlands	Bogs & peatlands	SEMI
Bracken	Grasslands	SEMI
Broadleaved woodland	Broadleaves	SEMI
Cliffs	Cliffs	SEMI
Coarse & smooth grassland	Grasslands	SEMI
Coniferous plantation	Conifers	SEMI
Factories & urban	Built-up	URBAN
Heather moor	Shrubland	SEMI
Improved grassland	Grasslands	CULT
Low scrub	Grasslands	SEMI
Mixed woodland	Mixed woodland	SEMI
Montane vegetation	Montane	SEMI
Open canopy young plantation	Conifers	SEMI
Recreational land	Built-up	URBAN
Ripping	Conifers	SEMI
Water	Freshwater	WATER
Wetland	Bogs & peatlands	SEMI

Table 4.4 Classification of Land Cover Map 2015 (LCM15) classes into Broad Habitats (BH) and Land Use (LUSE) classes.

LCM15 classes	BH	LUSE
Broadleaved Woodland	Broadleaves	SEMI
Coniferous Woodland	Conifers	SEMI
Arable and Horticulture	Arable	CULT
Improved Grassland	Grasslands	CULT
Neutral Grassland	Grasslands	SEMI
Calcareous Grassland	Grasslands	SEMI
Acid Grassland	Grasslands	SEMI
Fen, Marsh and Swamp	Grasslands	SEMI
Heather	Shrubland	SEMI
Heather grassland	Shrubland	SEMI
Bog	Bogs & peatlands	SEMI
Inland Rock	Screes	SEMI
Saltwater	Other	OTHER
Freshwater	Freshwater	WATER
Supra-littoral Rock	Other	OTHER
Supra-littoral Sediment	Other	OTHER
Littoral Rock	Other	OTHER
Littoral Sediment	Other	OTHER
Saltmarsh	Other	OTHER
Urban/Suburban	Built-up	URBAN

Table 4.5 Classification of EFFIS Fuel Type groups into Broad Habitats (BH) and Land Use (LUSE) classes.

EFFIS FT group	BH4	LUSE4
Agroforestry	Grasslands	SEMI
Broadleaved forests	Broadleaves	SEMI
Conifer forests	Conifers	SEMI
Mixed forests	Mixed woodland	SEMI
No Data	No data	NONE
Not fuel	Arable	CULT
Not fuel	Built-up	URBAN
Not wildland fuels	Arable	CULT
Pastures	Grasslands	SEMI
Peat bogs	Bogs & peatlands	SEMI
Riparian and aquatic vegetation	Riparian	SEMI
Shrublands	Shrubland	SEMI
Transition shrubland-forest	Shrubland	SEMI

4.2 Identifying wildfires affecting seminatural habitats

4.2.1 Devising the filtering process

The filtering process for identifying wildfires in the IRS dataset is based on a) their location in relation to whether they fall inside or outside built-up areas; and b) their fuel type information. Built-up areas were defined using the National Records of Scotland (NRS) Settlements 2016 map (in ESRI shapefile format downloaded from https://spatialdata.gov.scot), which gives built-up areas with a population of 500 people or more. Fuel type was defined using aggregated Broad Habitat (BH) and Land Use (LUSE) classes classified from the recorded IRS Level 3 Property Types and from the EUNIS, LCS88, LCM15 and EFFIS FT habitat and land use maps. The IRS fires incidents were imported into QGIS using their coordinate information, along with the NRS Settlements and different habitat type and land use maps (all in ESRI shapefile format). We applied a 100m buffer to the settlement boundaries as suggested previously by Davies and Legg (2016) to account for uncertainties in locational accuracy.

We intersected the IRS fire incidents with the NRS settlement buffered boundaries and habitat type and land use maps and extracted their values at the IRS incident locations. We coded IRS fire incidents as “inside or outside of settlements” and harmonised the BH and LUSE class information for each IRS fire incident using the classification scheme of Tables 4.2 to 4.5. The most frequent LUSE class was calculated for each IRS fire incident using the EUNIS, LCS88 and LCM15 map for the fire incidents located within settlement boundaries, plus the EFFIS FT map for those fire incidents outside settlement boundaries. We didn’t use the EFFIS FT map within settlements because its resolution was too coarse and hence not appropriate for this purpose. The classification and harmonisation processes were implemented in the R statistical software (R Core Team, 2020).

As expected, almost all 63,380 fire incidents (92%) belonging to the “Other outdoors (including land)” category, which were more likely to be urban fires, were located inside settlement boundaries. At the same time, the majority of the 69,449 fire incidents (75%) under the “Grassland, woodland and crops”, which were likely to include almost all existing wildfires, were also located within settlement boundaries. This was expected since the NRS dataset does not only include large urban areas but also small settlements in rural areas and around small settlements where wildfires are more likely to occur.

We used the IRS fire incidents with the extracted settlement and land use type information to devise a set of rules to filter the dataset and identify those fire incidents more likely to relate to wildfires affecting seminatural habitats. We need to stress that devising these rules was an iterative process based on extensive trial and testing using visual inspection of satellite imagery provided from Google and loaded within QGIS. The filtering process was semi-automated and was implemented using scripts written and executed within R coupled with visual inspection in QGIS. It is highly likely that the filtering process did not necessarily identify all fire incidents likely to be wildfires, but we are highly confident that those fires selected are actual wildfires.

The rules and criteria used for the filtering process are given in Table 4.6. Rules were devised for each of the individual Level 3 Property Types based on their LUSE classification as given in Table 4.1. As expected, there were differences between BHs and LUSE classified using the IRS Level 3 Property Types (Table 4.1) and BHs and LUSE classified using the land use datasets (Tables 4.2 to 4.5); these were attributed to issues related to different classification schemes and the difficulty to harmonise all datasets, to different spatial accuracies of the layers used that led to spatial inconsistencies between datasets and inherent ambiguities regarding how fuel type is recorded within the IRS. For example, of the 7,417 IRS fire incidents under the “Heathland and moorland” Property Type, which were assigned a “Shrubland” BH (Table 4.1), only 302 fire incidents also had a “Shrubland” BH based on the EUNIS Habitat Types map, but another 996 and 196 fire incidents had a “Bogs & peatlands” and “Montane” BH, respectively, while a further 1,632 fire incidents were classified as “Grasslands” and 1,329 as “Built-up”.

Table 4.6 Matrix showing the process filtering the IRS fire incidents and selecting wildfires. Counts of fire incidents for LUSE classes based on IRS Property Types given in brackets.

IRS Property Type Level 3 LUSE	Inside settlements	Most frequent LUSE	Process
SEMI (*n=39,208*)	Yes	SEMI	Check for seminatural BHs & visual inspection
		Other than SEMI	Check for seminatural BHs & visual inspection
	No	SEMI	Visual inspection
		CULT	Check for seminatural BHs & visual inspection
		BOTH	Check for seminatural BHs & visual inspection
		Rest LUSEs	Check for seminatural BHs & visual inspection
CULT (*n=2,202*)	Yes	SEMI	Check for seminatural BHs & visual inspection
		Other than SEMI	Remove fire incident
	No	SEMI	Visual inspection
		SEMI at least once	Check for seminatural BHs & visual inspection
		Other than SEMI	Remove fire incident
BOTH (*n=69,200*)	Yes	SEMI	Check for seminatural BHs & visual inspection
		Other than SEMI	Remove fire incident
	No	SEMI	Visual inspection
		SEMI at least once	Check for seminatural BHs & visual inspection
		Other than SEMI	Remove fire incident
URBAN (*n=12,217*)	Yes	SEMI	Check for seminatural BHs & visual inspection
		Other than SEMI	Remove fire incident
	No	SEMI or SEMI at least one	Check for seminatural BHs & visual inspection
		Other than SEMI	Remove fire incident
OTHER (*n=9,678*)	Yes	SEMI	Check for seminatural BHs & visual inspection
		Other than SEMI	Remove fire incident
	No	SEMI or SEMI at least one	Check for seminatural BHs & visual inspection
		Other than SEMI	Remove fire incident
WATER (*n=170*)	Yes	SEMI	Check for seminatural BHs & visual inspection
		Other than SEMI	Remove fire incident
	No	SEMI or SEMI at least one	Visual inspection
		Other than SEMI	Remove fire incident
NONE (*n=154*)	Yes	SEMI	Check for seminatural BHs & visual inspection
		Other than SEMI	Remove fire incident
	No	SEMI or SEMI at least one	Visual inspection
		Other than SEMI	Remove fire incident

Below, we provide a brief description of the rules and process shown in Table 4.6 that was used to filter the IRS dataset for identifying wildfires:

- Fire incidents with a seminatural (SEMI) IRS LUSE falling within settlement boundaries were selected as wildfires when their BHs (mainly from the EUNIS dataset that is the most recent one and has the better spatial resolution) were of seminatural vegetation (mainly bogs and peatlands, shrublands and montane vegetation) and after verifying via visual inspection. In many cases SEMI was referring to trees or woodlands in recreational areas and in urban areas (e.g., parks); these fire incidents were excluded from the dataset. On the other hand, this approach ensured that fires in seminatural areas within urban centre boundaries (e.g., known fire incidents in Arthur's Seat in Edinburgh) were identified and kept in the dataset.

- All fire incidents located outside settlements with a SEMI IRS LUSE class were either selected based on visual inspection (if most frequent LUSE was also SEMI) or based on the combination of visual inspection and checking for the presence of seminatural BHs.
- Fire incidents with a cultivated (CULT) IRS LUSE class but with SEMI as the most frequent LUSE class or with at least one SEMI LUSE class present were selected based on the combination of visual inspection and checking for the presence of seminatural BHs, regardless of whether they were inside or outside settlement boundaries. This was done to ensure that fire incidents in cultivated land in the vicinity of seminatural vegetation were identified, since they were likely to affect seminatural habitats. A similar approach was also used for fire incidents with a BOTH (both seminatural and cultivated) IRS LUSE class.
- Fire incidents with an URBAN (i.e., likely to be located within built-up areas) IRS LUSE class but with a SEMI most frequent LUSE class (for fire incidents within settlement boundaries) or at least one SEMI LUSE (for fire incidents outside settlement boundaries) were checked for the presence of seminatural BHs and/or visual inspected. All remaining URBAN LUSE IRS fire incidents, with LUSE other than SEMI, were removed from further analysis. The same rules were also applied to the fire incidents of the remaining IRS LUSE classes (OTHER, WATER and NONE).

4.2.2 Filtered dataset of IRS wildfires

The result of the filtering process resulted in the selection of 9,725 IRS fire incidents as the most likely to be wildfires. Around 85% of identified wildfires (8,271 fire incidents) were located outside the buffered settlement boundaries, with the remaining 1,454 fire incidents falling within the settlement boundaries (Table 4.7). The spatial distribution of the identified IRS wildfires is shown in Figure 4.1.

Table 4.7 Counts and respective proportions (in %) of IRS fire incidents falling outside and within the boundaries of settlements in Scotland.

Property Type Level 3	Count		Proportion (%)	
	Outside	Within	Outside	Within
Beach	26	3	*90*	*10*
Canal/riverbank vegetation	106	0	*100*	*0*
Cemetery	3	0	*100*	*0*
Cycle path/public footpath/bridleway	54	0	*100*	*0*
Golf Course (excluding buildings)	4	0	*100*	*0*
Grassland, pasture, grazing etc	1301	578	*69*	*31*
Heathland or moorland	2431	259	*90*	*10*
Hedge	29	2	*94*	*6*
Highway/road surface/pavement	18	0	*100*	*0*
Human harm outdoors	1	0	*100*	*0*
Lake/pond/reservoir	7	0	*100*	*0*
Loose refuse (incl in garden)	652	11	*98*	*2*
Nurseries, market garden	0	1	*0*	*100*
Other outdoor location	382	3	*99*	*1*
Park	56	2	*97*	*3*
Playground (not equipment) or Recreational area	2	3	*40*	*60*
Private/Domestic garden/allotment (vegetation not equipment/building)	24	4	*86*	*14*
Railway	13	0	*100*	*0*
Railway trackside vegetation	52	0	*100*	*0*
River/canal	7	0	*100*	*0*
Roadside vegetation	284	4	*99*	*1*
Scrub land	988	529	*65*	*35*
Stacked/baled crop (incl manure heap)	48	0	*100*	*0*
Standing crop	2	0	*100*	*0*
Straw/stubble burning	52	1	*98*	*2*
Tree scrub (includes single trees not in garden)	902	45	*95*	*5*
Wasteland	124	0	*100*	*0*
Woodland/forest - broadleaf/hardwood	219	0	*100*	*0*
Woodland/forest - conifers/softwood	484	9	*98*	*2*

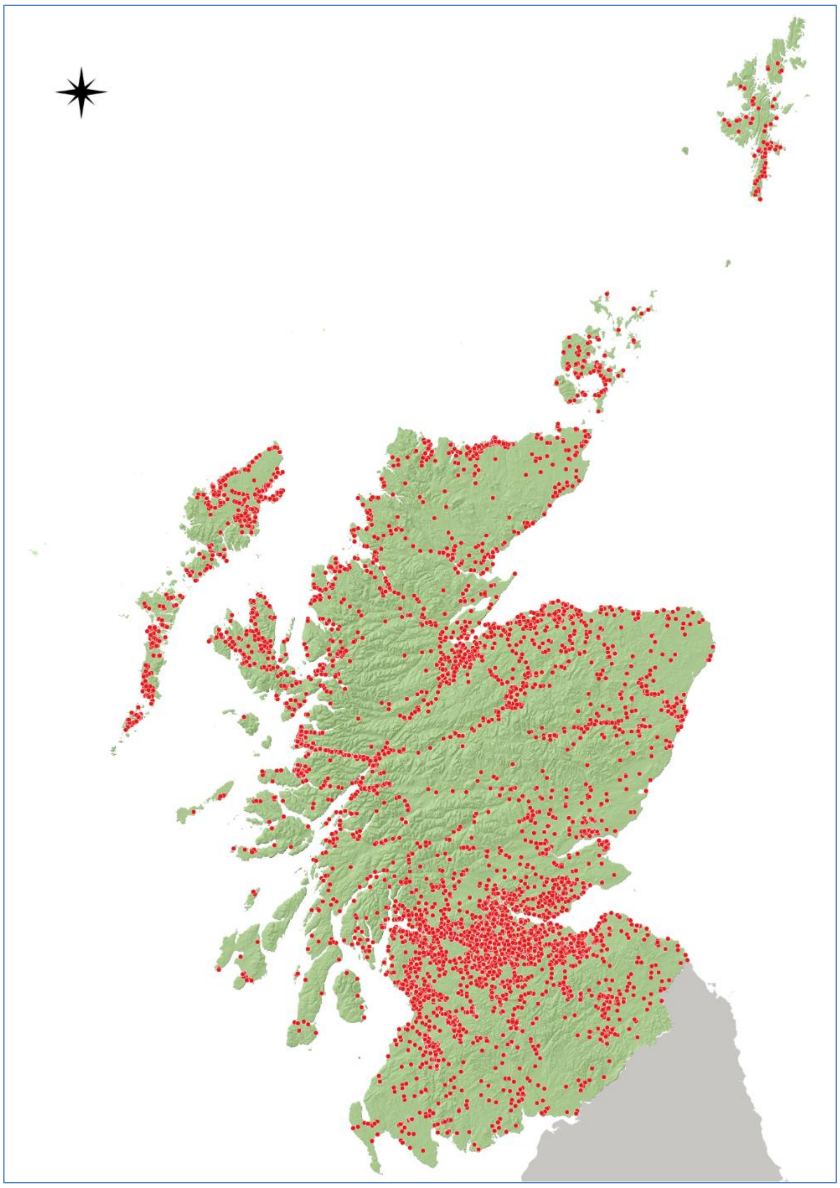


Figure 4.1 Locations of the filtered IRS dataset of wildfires

The filtering process revealed significant disparities between fuel type information recorded in the IRS and respective information extracted from the different land use maps at the locations of the fire incidents. For this reason, we built confusion matrices and checked the agreement at a Broad Habitat (BH) level between IRS recorded fuel type information and extracted information from the land use maps. The results of this analysis for individual BHs and for overall agreement are given in Table 4.8. As expected, there was no agreement for the Bogs & peatlands category as this is not included in the IRS property types. Agreement at BH level and overall for all BHs was lowest for the EFFIS FT, probably due to the coarser resolution of this dataset. Agreement for woodlands (broadleaves and conifers) were similar but low for the EUNIS, LCS88 and LCM15 maps. Agreement was higher for grasslands, almost 60% for the EUNIS map and 54% for the LCS88 map. This was because most fire incidents in the “Scrub land” IRS Property Type were located in grassland areas in the EUNIS and LCS88 maps. The LCS88 map gave the closest match with the IRS records for Shrubland

(75%), followed by the EUNIS (69%) and LCM15 (65%) maps, while LCS88 gave the greater overall accuracy. Based on these results, we decided to use fuel type information in our investigation of patterns in the IRS wildfires dataset (Section 5) from both the IRS Property Types and from information extracted from the LCS88 map. Additionally, using the LCS88 maps enabled us to include the Bogs and peatlands BH in the analysis and to distinguish between seminatural and managed grasslands, which is quite useful for detecting patterns of wildfire occurrence in seminatural habitats in Scotland.

Table 4.8 Agreement (%) of individual Broad Habitat (BH) classifications between BHs for the IRS Level 3 Property Types and respective BHs for the EUNIS habitat types, Land Cover Scotland 1988 (LCS88) classes, Land Cover Map 2015 (LCM15) classes and European Fuel Types Map (EFFIS FT), and overall agreement for all BHs for each dataset.

Property Type Level 3	EUNIS	LCS88	LCM15	EFFIS FT
Arable	0	4	2	2
Bare	0	-	-	-
Bogs & peatlands	0	0	0	0
Broadleaves	27	27	25	26
Built-up	0	0	2	4
Cliffs	0	-	-	-
Conifers	24	22	20	12
Freshwater	2	0	5	
Grasslands	59	54	47	44
Linear features	6	-	-	-
Mixed woodland	0	0		0
Montane	0	0	-	-
Riparian	0	-	-	0
Other	-	-	23	-
Screes	0	-	0	-
Shrubland	69	75	65	42
Overall agreement	*33*	*36*	*32*	*25*

5 Investigation of patterns in the IRS wildfires dataset

5.1 Overview

We used the information recorded in the filtered IRS wildfire dataset to identify patterns of wildfire occurrence related to a) time and seasonality; b) vegetation and fuel types; c) size of burnt areas; d) motives of ignition along with causes of ignition, ignition source and items causing ignition and spreading fire (where available) and e) accessibility and proximity to urban areas. For the latter we used the Scottish Government Urban Rural Classification (downloaded in ESRI shapefile format from https://spatialdata.gov.scot) which provides a consistent way of defining urban and rural areas across Scotland and is based upon two main criteria: a) population as defined by National Records of Scotland (NRS), and b) accessibility based on drive time analysis to differentiate between accessible and remote areas in Scotland.

For this analysis, we used the full dataset of identified wildfires (*n*=9,725) and a subset of wildfire incidents with damage area greater than 1,000 m^2 (*n*=1,325); we used this threshold in consultation with the SFRS to select fire incidents most likely to be bigger wildfires with significant impacts on seminatural habitats and filter out those wildfires that are more likely to be small incidents driven mainly by anti-social behaviour or relatively trivial cases of negligence with fire. Results of this analysis are presented in a consistent way at a) National level and b) Local Authority (LA) level to enable project results to be communicated to local staff in the SFRS and NatureScot. To facilitate an easier comparison of wildfire occurrence patterns in different LAs, we used cluster analysis to group LAs based on similar wildfire characteristics and presented respective patterns for the LA groupings identified by the analysis. More details on this are given in Section 5.4.

5.2 Patterns at National Level

5.2.1 Temporal – Seasonality

5.2.1.1 Annual

The number of yearly wildfire incidents (with complete records) in the full dataset ranged from 584 incidents in 2014 to 1,184 incidents in 2013 (Figure 5.1a). Overall, there are no indications of the presence of an increasing or decreasing trend over time in the number of wildfires occurring in Scotland based on the IRS records.

Regarding the subset of bigger wildfires, yearly fire incidents ranged from 50 incidents in 2020 to 134 incidents in 2010 (Figure 5.1b), with the exception of 2013 (Figure 5.1b) when 268 wildfires were recorded, most in the Highland and Na h-Eileanan Siar areas (125 and 83 fire incidents, respectively). This spike of wildfire activity was followed by three years of lower wildfire frequency up to 2016, while wildfire numbers increased again between 2017 to 2019 before dipping again in 2020 to just 50 big wildfires.

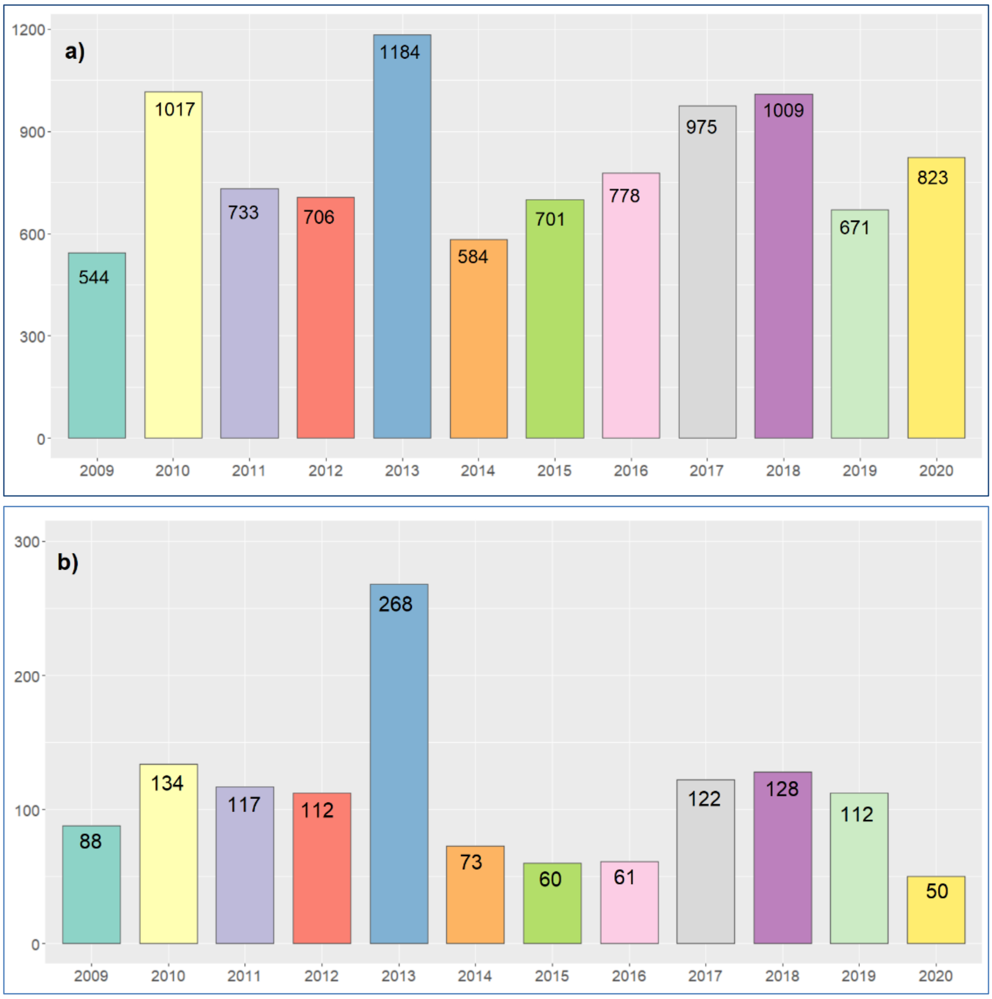


Figure 5.1 Yearly counts of IRS wildfires from 2009 to 2020 for a) complete wildfires dataset and b) wildfires with damage area greater than 1,000 m^2. Records for 2009 start from April 1^{st} 2009.

5.2.1.2 Monthly

Looking at seasonality at a monthly basis for all years, it is evident that most wildfires occur during the spring season: almost 29% of all wildfires occur in April, followed by 20% of wildfires in May and 15% in March (Figure 5.2a). A further 28% of wildfires occur in the summer season and in September, with small numbers occurring in late autumn and in the winter season. Occurrence of spring wildfires is much more dominant in the subset of bigger wildfires with around 81% of wildfires occurring in April (40.4%), March (22.3%) and May (20.3%) (Figure 5.2a). Moreover, a smaller proportion of bigger wildfires was recorded in summer months, especially in July and August when only 4.8% and 0.6%, respectively, of all bigger wildfires occurred compared to 9.7% in July and 4.2% in August of wildfires from the full dataset.

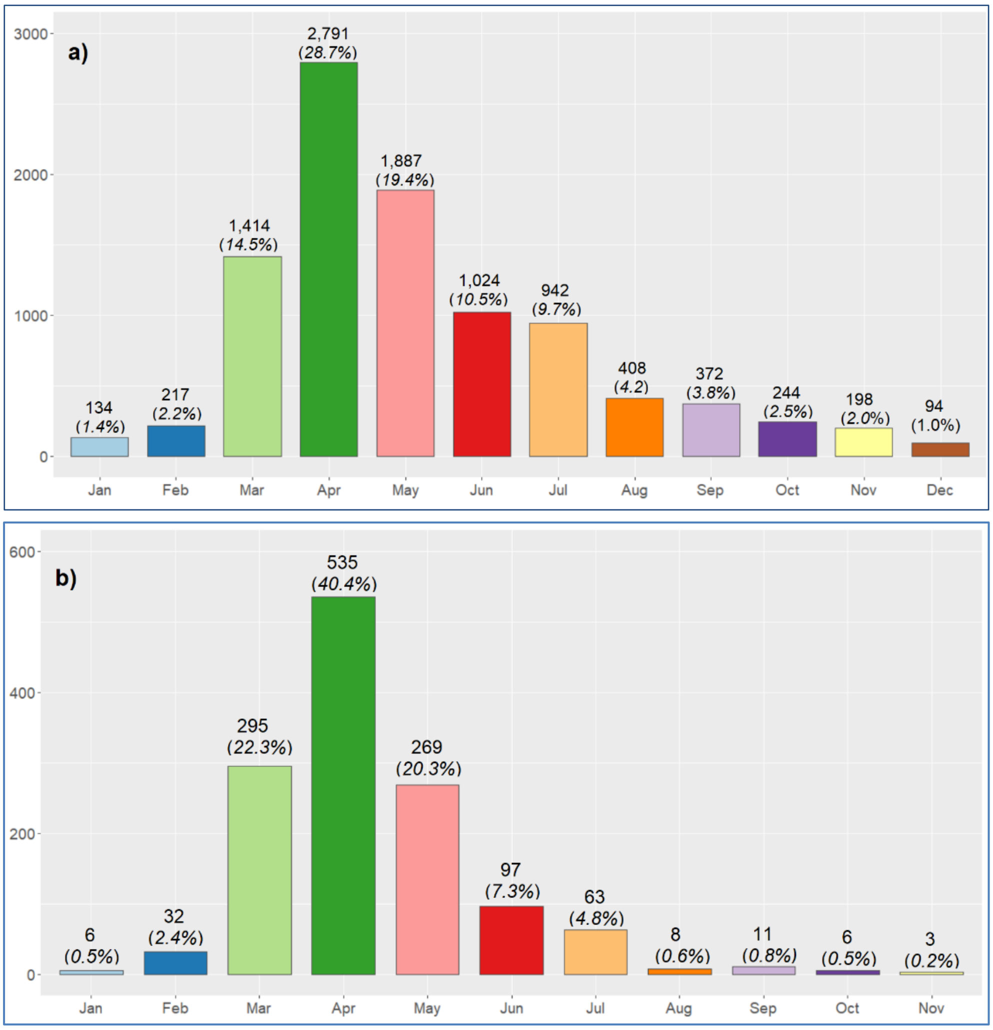


Figure 5.2 Monthly counts and proportions (in %) of IRS wildfires for the 2009-2020 period for a) complete wildfires dataset and b) wildfires with damage area greater than 1,000 m^2.

The same seasonal patterns emerge for the wildfires from the full dataset when looking at each year individually (Table 5.1). Most wildfires occur in the spring season, either in April or May. The only exception is year 2018 where most fires occurred in July and the second most fires in May; this could be explained by the prolonged period of above average temperature and below average precipitation that Scotland experienced from late spring to mid-summer that year, which could have caused an increased number of ignitions during this period.

Similarly for the subset of bigger wildfires, most wildfires occurred in April followed by wildfires occurring in May (Table 5.2). Looking at bigger wildfires occurring in the summer months, these accounted for just 2% of bigger fire incidents recorded in 2017 to 27% of fire incidents recorded in 2014.

Table 5.1 Yearly counts and monthly proportions of IRS wildfires for years 2009 to 2020.

Year	Sum	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2009	544	0	0	0	39	16	16	11	6	4	4	3	1
2010	1017	1	2	12	33	21	17	6	3	3	1	2	0
2011	733	1	1	18	35	21	6	8	2	1	2	3	1
2012	706	1	2	42	11	20	11	3	4	3	1	2	1
2013	1184	1	3	21	35	8	8	14	4	4	1	1	1
2014	584	3	1	12	28	10	10	14	5	9	5	3	1
2015	701	1	4	11	39	11	10	4	5	7	5	2	0
2016	778	0	1	17	21	28	15	3	4	2	4	2	1
2017	975	2	3	14	25	38	6	3	3	2	2	2	1
2018	1009	1	2	10	9	19	11	29	6	4	3	2	2
2019	671	4	6	7	47	14	5	6	3	3	3	1	1
2020	823	2	1	7	29	22	13	8	6	6	2	2	1

Table 5.2 Yearly counts and monthly proportions of IRS wildfires with damage area greater than 1,000 m^2 for years 2009 to 2020.

Year	Sum	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2009	88	0	0	0	58	16	19	5	2	0	0	0	0
2010	134	0	4	13	51	21	7	1	1	1	1	0	0
2011	117	0	0	15	50	28	3	4	0	0	0	0	0
2012	112	0	1	52	7	21	14	3	1	1	0	0	0
2013	268	0	2	36	43	4	7	6	1	1	0	0	0
2014	73	0	0	16	42	11	8	18	1	0	0	3	0
2015	60	0	0	15	60	12	8	0	0	0	5	0	0
2016	61	0	0	16	39	30	11	0	2	0	2	0	0
2017	122	0	10	22	12	53	2	0	0	0	0	0	0
2018	128	0	2	30	21	22	6	16	0	2	1	1	0
2019	112	4	6	4	73	10	1	1	0	0	0	0	0
2020	50	0	0	8	38	42	6	0	0	6	0	0	0

5.2.2 Fuel types

5.2.2.1 Annual

Tables 5.3 and 5.4 give fire incident counts at Broad Habitat (BH) level classified from Level 3 Property Types for the full wildfire dataset and the subset of bigger fires, respectively, for years 2009 to 2020, while Tables 5.5 and 5.6 provide the same information for BHs classified from LCS88 classes. In addition, Figures 5.3 and 5.4 give the stacked proportions of individual BHs classified from Level 3 Property Types and LCS88 classes, for each year and wildfire dataset.

Investigation of Table 5.3 and Figure 5.3a. shows that there is limited inter-annual variability in the fuel time composition based on BHs classified from Level 3 Property Types. Wildfires burning grasslands are the most frequent for most years, followed by wildfires burning heathlands/shrubland. On the other hand, bigger wildfires burning heathland and grassland, based on Level 3 Property types, are the most frequent for all years and the proportion of fires on shrubland in relation to all recorded wildfires is greater than fires on grassland for all years (Table 5.4 and Figure 5.3b).

Table 5.3 Counts of IRS wildfires at Broad Habitat (BH) level classified from Level 3 Property Types for years 2009 to 2020.

Year	Shrub land	Grass lands	Broad leaves	Conifers	Arable	Fresh water	Linear features	Built-up	Refuse	Other	None
2009	138	214	71	14	5	2	22	1	55	22	0
2010	275	377	135	50	11	1	52	11	75	30	0
2011	202	231	121	36	8	1	27	3	70	34	0
2012	222	239	76	25	11	0	33	5	57	38	0
2013	383	498	88	30	7	2	49	11	79	37	0
2014	164	194	64	35	6	1	22	2	61	35	0
2015	168	296	68	31	8	2	32	7	53	36	0
2016	200	340	76	30	14	0	34	11	51	22	0
2017	254	354	134	66	4	3	52	8	65	35	0
2018	284	351	119	74	8	0	40	6	75	52	0
2019	243	195	76	26	10	0	26	1	60	34	0
2020	157	273	138	76	11	2	36	4	86	39	1
Sum	*2,690*	*3,562*	*1,166*	*493*	*103*	*14*	*425*	*70*	*787*	*414*	*1*

Table 5.4 Counts of IRS wildfires with damage area greater than 1,000 m^2 at Broad Habitat (BH) level classified from Level 3 Property Types for years 2009 to 2020.

Year	Shrubland	Grasslands	Broadleaves	Conifers	Arable	Linear features	Refuse	Other
2009	41	35	6	5	0	0	0	1
2010	86	32	3	10	0	2	0	1
2011	76	22	7	7	1	0	2	2
2012	75	22	4	8	0	2	0	1
2013	169	71	10	10	2	3	2	1
2014	50	17	1	5	0	0	0	0
2015	35	19	3	3	0	0	0	0
2016	37	19	1	3	0	1	0	0
2017	78	29	7	7	0	1	0	0
2018	87	26	2	11	0	0	1	1
2019	93	13	0	6	0	0	0	0
2020	26	12	4	8	0	0	0	0
Sum	*853*	*317*	*48*	*83*	*3*	*9*	*5*	*7*

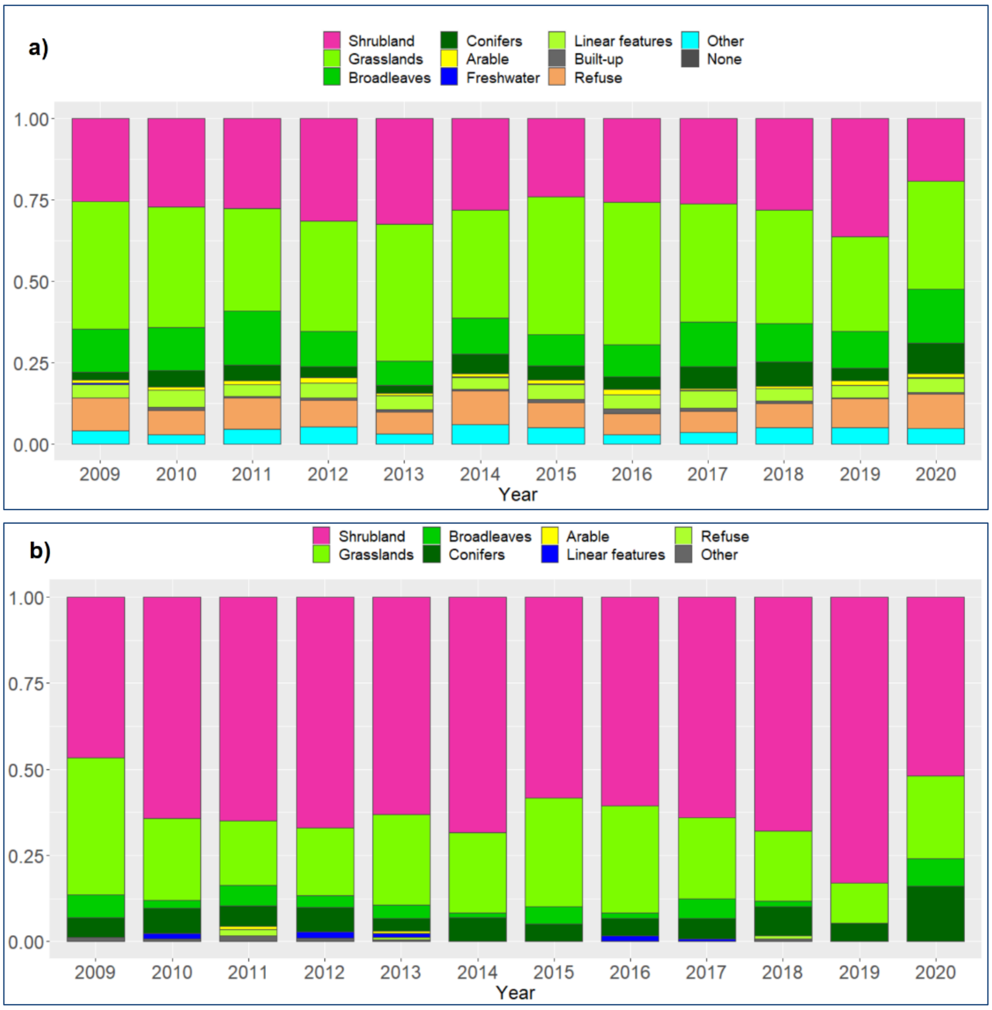


Figure 5.3 Stacked proportions of Broad Habitats (BHs) classified from Level 3 Property Types for years 2009 to 2020 for a) all IRS wildfires and b) IRS wildfires with damage area greater than 1,000 m^2.

The picture is similar for fuel type composition when LCS88 classes are used to classify BHs (Table 5.5 and Figure 5.4a, full dataset), with grassland fires being the most frequent. But there is slightly more variability in fuel type composition regarding wildfires burning peatlands and bogs and heathland/shrubland in some years compared to BHs classified from Level 3 Property Types. Nevertheless, there is no evident trend in fuel type composition over the 2009 to 2020 period for the full wildfire dataset.

Regarding the subset of bigger wildfires, fires on shrubland are the most frequent for all years based on LCS88 classes (Table 5.6 and Figure 5.4b), but to a lesser degree than when BHs classified from Level 3 Property Types were used. When combined, wildfires on bogs and peatland and on shrubland outnumbered all grassland fires (on both seminatural and improved grass) from 2010 to 2014 and from 2017 to 2020, the opposite was observed in 2015, 2016 and 2020, while the same number of fires on bogs/peatlands and shrubland and on grasslands was recorded in 2009.

Table 5.5 Counts of IRS wildfires Broad Habitats (BH) classified from LCS88 classes for years 2009 to 2020.

Year	Bogs & peatlands	Shrub land	Monta ne	Cliffs	Grass lands	Impr grass	Broad leaves	Mixed wood	Conifers	Arable	Fresh water	Built-up	No Data
2009	35	46	0	0	103	120	33	42	92	32	1	31	9
2010	74	92	1	0	198	239	38	84	149	52	2	76	12
2011	43	80	0	0	179	161	30	67	97	31	5	28	12
2012	67	89	0	2	143	173	42	66	75	14	1	28	6
2013	95	159	0	0	240	289	41	101	152	28	5	63	11
2014	40	76	0	2	101	137	18	42	107	23	1	31	6
2015	24	47	0	0	181	157	22	66	120	35	2	41	6
2016	41	52	0	0	190	193	26	79	104	23	2	55	13
2017	50	87	1	0	228	163	50	127	166	39	1	49	14
2018	47	113	0	1	187	217	48	92	211	39	2	42	10
2019	54	85	1	0	120	156	34	79	83	22	0	30	7
2020	34	47	0	1	136	183	35	105	193	30	2	39	18
Sum	*604*	*973*	*3*	*6*	*2,006*	*2188*	*417*	*950*	*1,549*	*368*	*24*	*513*	*124*

Table 5.6 Counts of IRS wildfires with damage area greater than 1,000 m^2 at Broad Habitats (BH) level classified from LCS88 classes for years 2009 to 2020.

Year	Bogs & peatlands	Shrub land	Monta ne	Cliffs	Grass lands	Impr grass	Broad leaves	Mixed wood	Conifers	Arable	Fresh water	Built-up	No Data
2009	12	23	0	0	12	23	10	2	4	0	0	0	2
2010	22	40	0	0	29	18	8	2	10	0	0	2	3
2011	14	36	0	0	28	20	7	3	7	0	0	2	0
2012	22	40	0	1	11	20	8	2	7	1	0	0	0
2013	46	88	0	0	47	53	6	8	14	0	2	2	2
2014	15	26	0	0	14	8	2	1	6	0	0	0	1
2015	10	13	0	0	18	13	0	1	5	0	0	0	0
2016	12	10	0	0	9	21	3	0	3	0	0	3	0
2017	20	32	0	0	25	15	8	7	14	1	0	0	0
2018	16	40	0	0	16	27	3	3	18	1	0	3	1
2019	20	39	1	0	15	21	5	3	7	0	0	1	0
2020	4	10	0	0	9	8	2	2	14	0	0	0	1
Sum	*213*	*397*	*1*	*1*	*233*	*247*	*62*	*34*	*109*	*3*	*2*	*13*	*10*

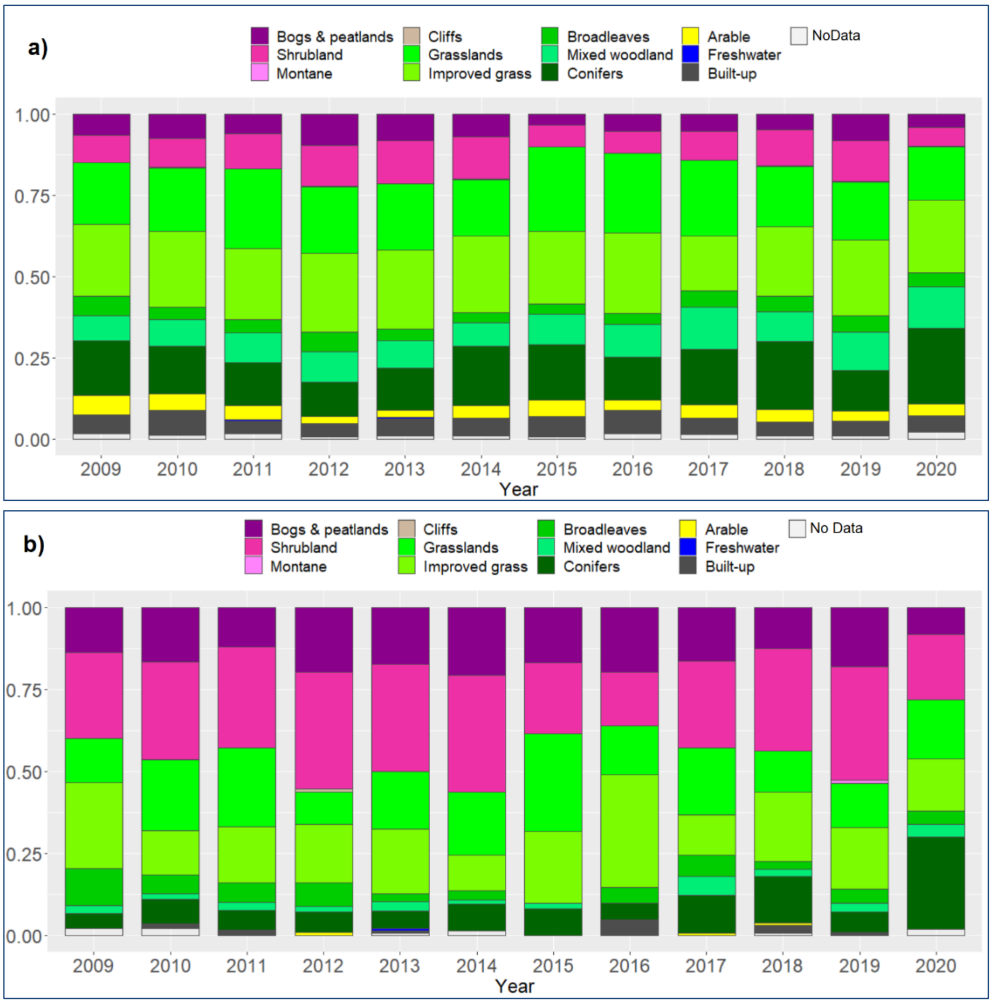


Figure 5.4 Stacked proportions of Broad Habitats (BHs) classified from LCS88 classes for years 2009 to 2020 for a) all IRS wildfires and b) IRS wildfires with damage area greater than 1,000 m^2.

5.2.2.2 Monthly

Regarding fuel type composition at a monthly basis for the whole 2009-2020 period and based on BHs classified from IRS Level 3 Property Types (Table 5.7 and Figure 5.5a), most wildfires burning heathlands/shrubland and grasslands (both managed and seminatural) occurred in April (36% and 33% respectively), while most wildfires on broadleaves and conifers occurred in May (21% and 24%, respectively). Overall, 70-80% of all wildfires on shrubland and grasslands occurred in the spring season, while around 80% of wildfires on woodlands (broadleaves and conifers) occurred from late spring to the end of the summer season. On the other hand, wildfires from loose refuse and on wasteland show smaller seasonal variability with monthly proportions ranging from 7.5% to 15% for almost all months in the spring, summer, and autumn seasons.

Table 5.7 Monthly proportions (in %) of IRS wildfires per Broad Habitat (BH) classified from Level 3 Property Types for the 2009-2020 period.

BH	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Shrubland	0.8	2.4	19.7	36.3	19.7	8.4	6.8	1.4	1.9	1.4	1.0	0.2
Grasslands	1.0	1.6	17.0	33.4	19.3	9.3	8.5	3.7	2.9	1.6	1.1	0.5
Broadleaves	1.1	1.8	6.9	18.8	21.3	16.6	14.6	7.1	6.3	3.0	1.8	0.8
Conifers	0.8	1.6	4.3	18.3	23.9	13.8	19.5	6.7	6.5	2.8	0.8	1.0
Arable	2.9	1.9	10.7	20.4	16.5	7.8	10.7	5.8	9.7	7.8	4.9	1.0
Freshwater	0.0	7.1	7.1	14.3	21.4	14.3	7.1	0.0	14.3	7.1	7.1	0.0
Linear features	1.2	4.0	11.8	24.2	20.5	12.9	8.2	5.2	4.0	4.0	1.9	2.1
Built-up	2.9	2.9	10.0	14.3	20.0	11.4	10.0	10.0	10.0	5.7	2.9	0.0
Refuse	4.4	3.4	9.5	15.1	15.2	10.2	10.3	7.9	7.5	5.3	7.4	3.7
Other	3.6	4.6	7.5	15.0	14.7	12.3	13.5	5.3	4.3	7.0	8.0	4.1
None	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0

Table 5.8 Monthly proportions (in %) of IRS wildfires with damage area greater than 1,000 m^2 per Broad Habitat (BH) classified from Level 3 Property Types for the 2009-2020 period.

BH	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Shrubland	0.7	2.6	25.1	41.6	18.9	6.0	3.3	0.5	0.6	0.5	0.4	0.0
Grasslands	0.0	2.5	21.5	41.3	20.8	7.9	4.1	0.9	0.3	0.6	0.0	0.0
Broadleaves	0.0	0.0	14.6	29.2	25.0	16.7	12.5	2.1	0.0	0.0	0.0	0.0
Conifers	0.0	2.4	4.8	30.1	28.9	12.0	15.7	0.0	6.0	0.0	0.0	0.0
Arable	0.0	0.0	0.0	33.3	33.3	0.0	33.3	0.0	0.0	0.0	0.0	0.0
Linear features	0.0	0.0	22.2	11.1	33.3	22.2	11.1	0.0	0.0	0.0	0.0	0.0
Refuse	0.0	0.0	0.0	60.0	20.0	0.0	20.0	0.0	0.0	0.0	0.0	0.0
Other	0.0	0.0	0.0	71.4	14.3	14.3	0.0	0.0	0.0	0.0	0.0	0.0

Regarding fuel type composition at a monthly basis for the subset of bigger wildfires and based on BHs classified from IRS Level 3 Property Types (Table 5.8 and Figure 5.5b), again most wildfires burning heathlands/shrubland and grasslands occurred in April (42% and 41% respectively), but this was also the case for woodland/forest fires as most wildfires on broadleaves and conifers also occurred in April (29% and 30%, respectively). Overall, around 85% of all wildfires on shrubland and grasslands occurred in the spring season, while around 65% to 70% of wildfires on woodlands (broadleaves and conifers) occurred in the spring season and around 30% during summer months. There were only 24 bigger incidents with BHs other than shrubland, grasslands and woodlands, with most also occurring in the spring season.

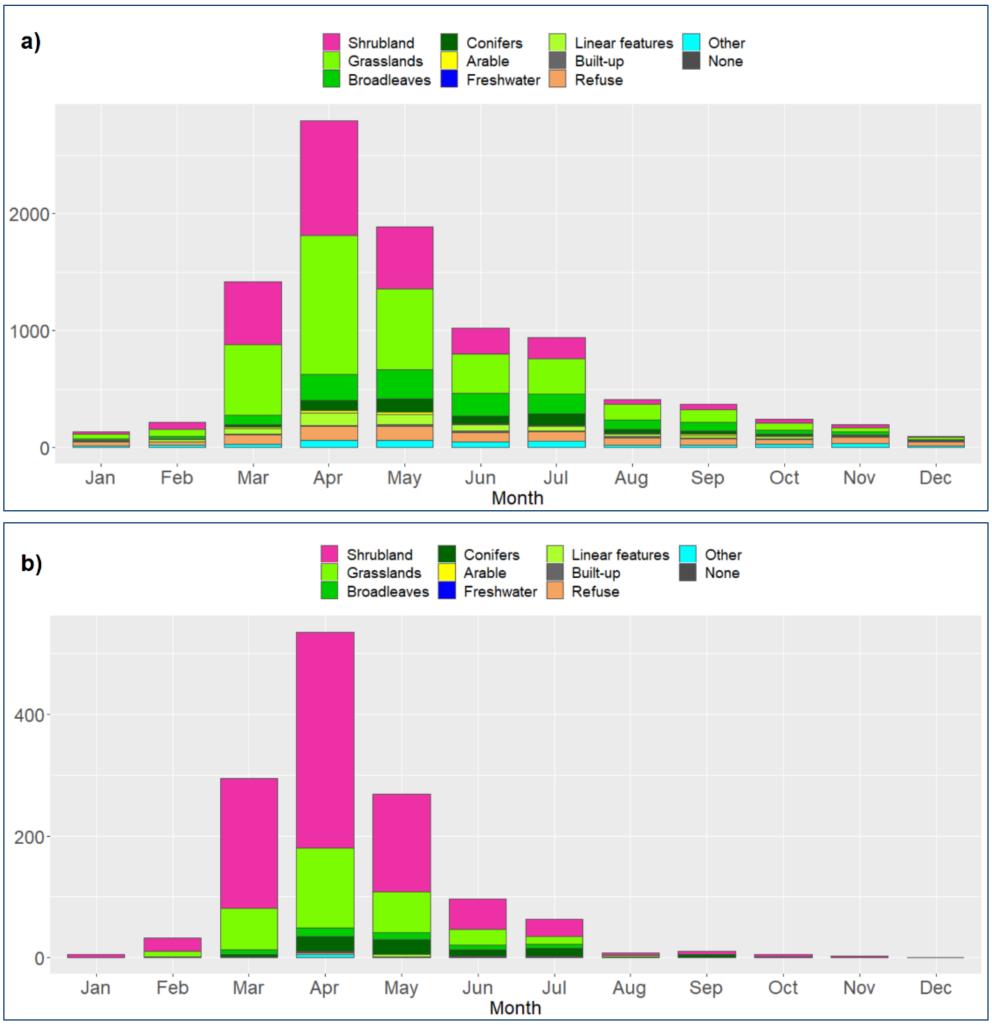


Figure 5.5 Monthly counts of IRS wildfires per Broad Habitat (BH) classified from Level 3 Property Types for the 2009-2020 period for a) all IRS wildfires and b) IRS wildfires with damage area greater than 1,000 m^2.

Similar to BHs based on Level 3 Property Type, most wildfires burning on bogs and peatlands, heathlands/shrubland and seminatural grasslands for the 2009-2020 period, based on BHs classified from LCS88 classes, occurred in April and around 70%-75% of all wildfires for those fuel types occurred in the spring season (Table 5.9 and Figure 5.6a). The picture is also similar for wildfires on improved grasslands. For wildfires on woodlands (broadleaves, conifers and mixed), most wildfires (67%-75%) occurred from April to end of July. Looking at the subset of bigger wildfire incidents (Table 5.10 and Figure 5.6b), most wildfires burning on bogs and peatlands, heathlands/shrubland, seminatural and improved grasslands, broadleaves and mixed woodland occurred in April and around 76%-87% of all wildfires for those fuel types occurred in the spring season. Most conifer wildfires were recorded in May and a greater number of bigger wildfires on conifers occurred during the summer season (30% of all conifer fires) compared to wildfires on mixed woodland (24%) and on broadleaves (16%), indicating that there might be a greater risk of conifer forest fires in the summer compared to other woodland types.

Table 5.9 Monthly proportions (in %) of IRS wildfires per Broad Habitat (BH) classified from LCS88 classes for the 2009-2020 period.

BH	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bogs & peatlands	1.0	1.8	20.5	36.8	19.4	10.6	6.0	1.0	1.0	0.7	1.0	0.3
Shrubland	1.0	2.9	22.1	35.1	15.9	8.6	7.9	2.1	1.2	1.3	1.5	0.2
Montane	0.0	0.0	33.3	33.3	33.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cliffs	0.0	16.7	50.0	0.0	0.0	0.0	33.3	0.0	0.0	0.0	0.0	0.0
Grasslands	1.5	2.1	16.7	31.7	20.8	8.6	6.8	4.0	3.2	2.0	1.8	0.8
Improved grass	1.6	3.1	16.2	29.4	19.1	9.4	7.5	3.9	3.1	2.7	3.0	1.2
Broadleaves	1.0	1.4	9.8	27.8	25.2	12.2	9.4	4.3	3.1	3.6	0.7	1.4
Mixed woodland	1.7	1.9	10.4	22.0	20.7	12.3	12.4	5.4	5.7	2.9	2.7	1.8
Conifers	1.2	1.4	5.0	19.9	19.1	15.2	17.9	6.9	7.5	3.3	1.7	0.8
Arable	2.4	2.7	14.1	25.5	18.2	8.7	11.7	2.7	6.3	3.8	2.4	1.4
Freshwater	0.0	0.0	8.3	33.3	12.5	12.5	8.3	12.5	0.0	8.3	4.2	0.0
Built-up	0.8	1.9	17.3	35.1	16.4	9.6	6.6	4.3	2.7	2.3	1.8	1.2
NoData	0.8	2.4	17.7	24.2	22.6	8.9	9.7	4.8	1.6	5.6	1.6	0.0

Table 5.10 Monthly proportions (in %) of IRS wildfires with damage area greater than 1,000 m^2 per Broad Habitat (BH) classified from LCS88 classes for the 2009-2020 period.

BH	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bogs & peatlands	0.5	2.8	27.7	43.2	15.5	6.6	2.3	0.9	0.5	0.0	0.0	0.0
Shrubland	0.0	2.3	25.4	41.8	16.6	7.8	4.0	0.8	0.5	0.3	0.5	0.0
Montane	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cliffs	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grasslands	1.7	1.7	20.2	40.8	24.0	3.9	5.2	0.9	0.9	0.9	0.0	0.0
Improved grass	0.4	4.0	25.9	42.9	18.6	4.5	2.8	0.0	0.0	0.8	0.0	0.0
Broadleaves	0.0	1.6	9.7	43.5	29.0	12.9	3.2	0.0	0.0	0.0	0.0	0.0
Mixed woodland	0.0	0.0	8.8	35.3	32.4	8.8	11.8	2.9	0.0	0.0	0.0	0.0
Conifers	0.0	1.8	7.3	24.8	30.3	16.5	13.8	0.0	5.5	0.0	0.0	0.0
Arable	0.0	0.0	33.3	0.0	33.3	0.0	33.3	0.0	0.0	0.0	0.0	0.0
Freshwater	0.0	0.0	50.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Built-up	0.0	0.0	23.1	38.5	7.7	15.4	7.7	0.0	0.0	7.7	0.0	0.0
No Data	0.0	0.0	10.0	40.0	30.0	10.0	0.0	0.0	0.0	0.0	10.0	0.0

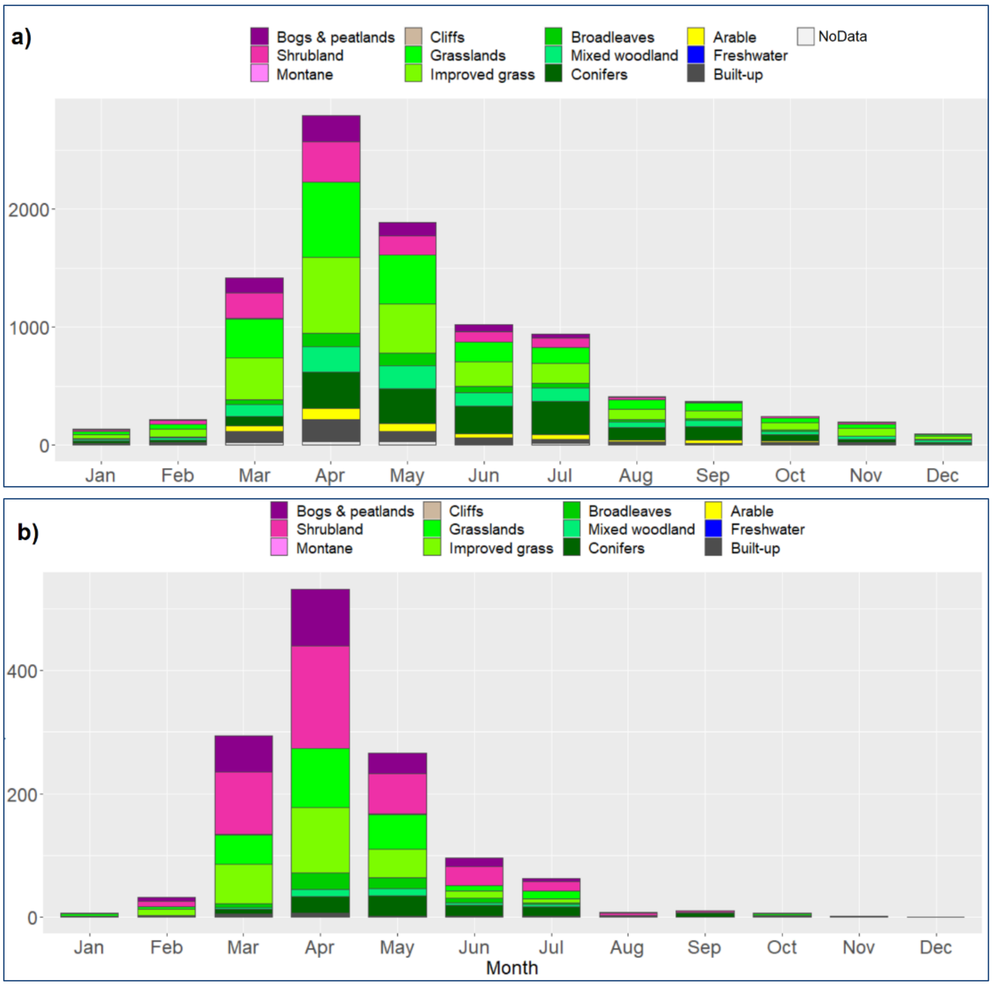


Figure 5.6 Monthly counts of IRS wildfires per Broad Habitat (BH) classified from LCS88 classes for the 2009-2020 period for a) all IRS wildfires and b) IRS wildfires with damage area greater than 1,000 m^2.

5.2.2.3 Daily

Tables 5.11 and 5.12 give the daily total counts for the 2009-2020 period of wildfires from the full dataset per Broad Habitats (BH) classified from Level 3 Property Types and LCS88 classes, respectively, while Tables 5.12 and 5.13 give the same information as above for bigger wildfires with damage area greater than 1,000 m^2 per. Data for the full wildfire dataset show that more wildfires occurred during weekends (1,641 on Saturdays and 1,517 on Sundays) and on Mondays (1,472), compared to the rest of the weekdays which had a similar number of recorded wildfires (1,256 – 1,311). However, there does not seem to be a strong pattern regarding fuel type composition in relation to the day of wildfire occurrence. Using both BH classifications for wildfires from the full dataset, there is an indication that wildfires on woodlands are generally more frequent during weekends, and this also applies for bogs and peatlands, shrublands and grasslands, but to a smaller extent. But overall, 60% to 70% of wildfires for the main fuel types (bogs, shrublands, grasslands and woodlands) occurred during weekdays, so there is no strong indication of an increased ignition risk during weekends due to, for example, recreational effects.

Table 5.11 Daily counts of IRS wildfires per Broad Habitat (BH) classified from Level 3 Property Types for the 2009-2020 period.

BH	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Shrubland	428	375	366	359	349	430	383
Grasslands	552	477	470	449	468	585	561
Broadleaves	165	134	157	153	176	189	192
Conifers	68	62	50	48	80	90	95
Arable	19	9	16	11	14	12	22
Freshwater	1	1	2	2	2	5	1
Linear features	69	48	43	53	53	84	75
Built-up	15	7	6	12	4	13	13
Refuse	108	99	103	106	107	151	113
Other	47	44	56	66	58	81	62
None	0	0	0	0	0	1	0
Sum	*1,472*	*1,256*	*1,269*	*1,259*	*1,311*	*1,641*	*1,517*

Table 5.12 Daily counts of IRS wildfires per Broad Habitat (BH) classified from LCS88 classes for the 2009-2020 period.

BH	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Bogs & peatlands	115	87	76	64	66	104	92
Shrubland	165	141	130	129	144	149	115
Montane	0	1	1	0	0	0	1
Cliffs	1	0	0	0	4	1	0
Grasslands	297	288	252	259	250	329	331
Improved grass	361	271	283	312	289	388	284
Broadleaves	53	45	68	51	56	67	77
Mixed woodland	143	112	128	131	116	175	145
Conifers	206	179	189	184	240	267	284
Arable	41	40	59	42	66	65	55
Freshwater	0	7	4	4	4	1	4
Built-up	76	66	63	66	61	81	100
NoData	14	19	16	17	15	14	29
Count	*1,472*	*1,256*	*1,269*	*1,259*	*1,311*	*1,641*	*1,517*

Results from the subset of bigger wildfires show a different picture than those from the full dataset, as more bigger wildfires occurred on Mondays (248) compared to weekends (205 on Saturdays and 153 on Sundays), while fire incident numbers ranged from 168 to 203 for the rest of the weekdays (Tables 5.13 and 5.14). Looking at results using BHs based on Level 3 Property types (Table 5.13), there does not seem to be a strong pattern regarding fuel type composition in relation to the day of wildfire occurrence. Using BHs classified using LCS88 classes, there is an indication that wildfires on bogs and peatlands and on conifer forests are slightly more frequent during weekends than compared to wildfires on heath and on grass, but overall and for both BH classifications 63% to 77% of bigger wildfires for the main fuel types (bogs, shrublands, grasslands and woodlands) occurred during weekdays.

Table 5.13 Daily counts of IRS wildfires with damage area greater than 1,000 m^2 per Broad Habitat (BH) classified from Level 3 Property Types for the 2009-2020 period.

BH	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Shrubland	172	135	127	111	99	120	89
Grasslands	49	53	34	38	43	58	42
Broadleaves	12	3	3	6	10	8	6
Conifers	12	8	9	12	11	17	14
Arable	1	1	0	0	0	0	1
Linear features	1	2	1	3	1	1	0
Refuse	0	1	0	1	2	1	0
Other	1	0	0	3	2	0	1
Sum	*248*	*203*	*174*	*174*	*168*	*205*	*153*

Table 5.14 Daily counts of IRS wildfires with damage area greater than 1,000 m^2 per Broad Habitat (BH) classified from LCS88 classes for the 2009-2020 period.

BH	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Bogs & peatlands	33	37	26	20	23	42	32
Shrubland	81	57	56	55	58	53	37
Montane	0	0	1	0	0	0	0
Cliffs	0	0	0	0	0	1	0
Grasslands	46	37	24	37	21	43	25
Improved grass	50	45	37	30	26	39	20
Broadleaves	8	8	14	7	9	6	10
Mixed woodland	11	0	4	8	5	1	5
Conifers	18	13	11	14	19	17	17
Arable	0	1	1	0	1	0	0
Freshwater	0	2	0	0	0	0	0
Built-up	1	1	0	3	2	3	3
No Data	0	2	0	0	4	0	4
Sum	*248*	*203*	*174*	*174*	*168*	*205*	*153*

5.2.3 Ignition motives

Based on IRS recorded information on ignition motives, most wildfires in the full dataset were caused by a deliberate ignition (*n*=5,560) compared to an accidental ignition (*n*=2,506) and unknown motive (*n*=1,659). On the other hand, most of the bigger wildfires were caused by accidental ignitions (*n*=615), followed by an unknown ignition motive (*n*=441) and deliberate ignitions (*n*=269).

Regarding temporal patterns, the proportions of wildfires for each ignition motive type recorded in the IRS (accidental, deliberate, and not known) appear to be quite similar for each day for both the full wildfire dataset (Table 5.15) and the subset of bigger wildfires (Table 5.16). Accidental wildfires from the full dataset accounted for 23% to 29% of daily fire incidents, while deliberate wildfires accounted for 55% to 60% of daily wildfires.

On the other hand, for bigger wildfires, accidental fire incidents were the most frequent for all days and accounted for 42% to 51% of daily fire incidents, while deliberate wildfires accounted for 17% to 24% of daily wildfires. Therefore, there does not seem to be a clear indication of an emerging daily pattern regarding the different motive types for wildfire ignition for both the full wildfire dataset and the subset of bigger wildfires.

Table 5.15 Daily counts and proportions (in %, brackets) of IRS wildfires per recorded motive.

Motive	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Accidental	387 (*26%*)	353 (*28%*)	329 (*26%*)	312 (*25%*)	374 (*29%*)	396 (*24%*)	355 (*23%*)
Deliberate	823 (*56%*)	685 (*55%*)	741 (*58%*)	731 (*58%*)	723 (*55%*)	950 (*58%*)	907 (*60%*)
Not known	262 (*18%*)	218 (*17%*)	199 (*16%*)	216 (*17%*)	214 (*16%*)	295 (*18%*)	255 (*17%*)
Sum	*1,472*	*1,256*	*1,269*	*1,259*	*1,311*	*1,641*	*1,517*

Table 5.16 Daily counts and proportions (in %, brackets) of IRS wildfires with damage area greater than 1,000 m^2per recorded motive.

Motive	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Accidental	113 (*46%*)	99 (*49%*)	85 (*49%*)	73 (*42%*)	86 (*51%*)	89 (*43%*)	70 (*46%*)
Deliberate	54 (*22%*)	35 (*17%*)	31 (*18%*)	41 (*24%*)	31 (*18%*)	46 (*22%*)	31 (*20%*)
Not known	81 (*33%*)	69 (*34%*)	58 (*33%*)	60 (*34%*)	51 (*30%*)	70 (*34%*)	52 (*34%*)
Sum	*248*	*203*	*174*	*174*	*168*	*205*	*153*

However, there are indications of patterns related to fuel type composition and ignition motive types. In particular, a greater proportion of wildfires from the full dataset on bogs and peatlands and shrublands was caused by accidental ignitions compared to deliberate ignitions (Tables 5.7a and 5.8a). On the other hand, deliberate ignitions were more frequent for seminatural and improved grasslands than accidental ones. At the same time, most of the wildfires with an unknown motive of ignition occurred on shrublands based on BHs classified using the Level 3 Property Types (Figure 5.7a). However, looking at BHs classified using the LCS88 classes (Figure 5.7b) shows that roughly the same numbers of fires on bogs and peatlands and shrublands and fires on grasslands (seminatural and improved) had an unknown ignition motive. In addition, most wildfires on loose refuse and wasteland had a deliberate ignition motive.

Similarly, looking at BHs of bigger wildfires based on Level 3 Property types, a greater proportion of shrubland fires had an accidental ignition motive than a deliberate one, while most of the wildfires with an unknown motive of ignition occurred on shrublands (Figure 5.7b). A clearer pattern emerges when looking at BHs based on LCS88 classes (Figure 5.8b); it is evident that more bigger wildfires on bogs and peatlands and on heathland/shrubland were caused by accidental than deliberate ignitions, while wildfires on grassland accounted for most fire incidents with deliberate ignitions.

Overall, these results indicate that wildfires on more remote or less accessible seminatural habitats, such as peatlands and heathlands, are more likely to be caused by accidental ignitions, compared to wildfires occurring in more accessible and/or managed land where they are more likely to be caused by deliberate ignitions.

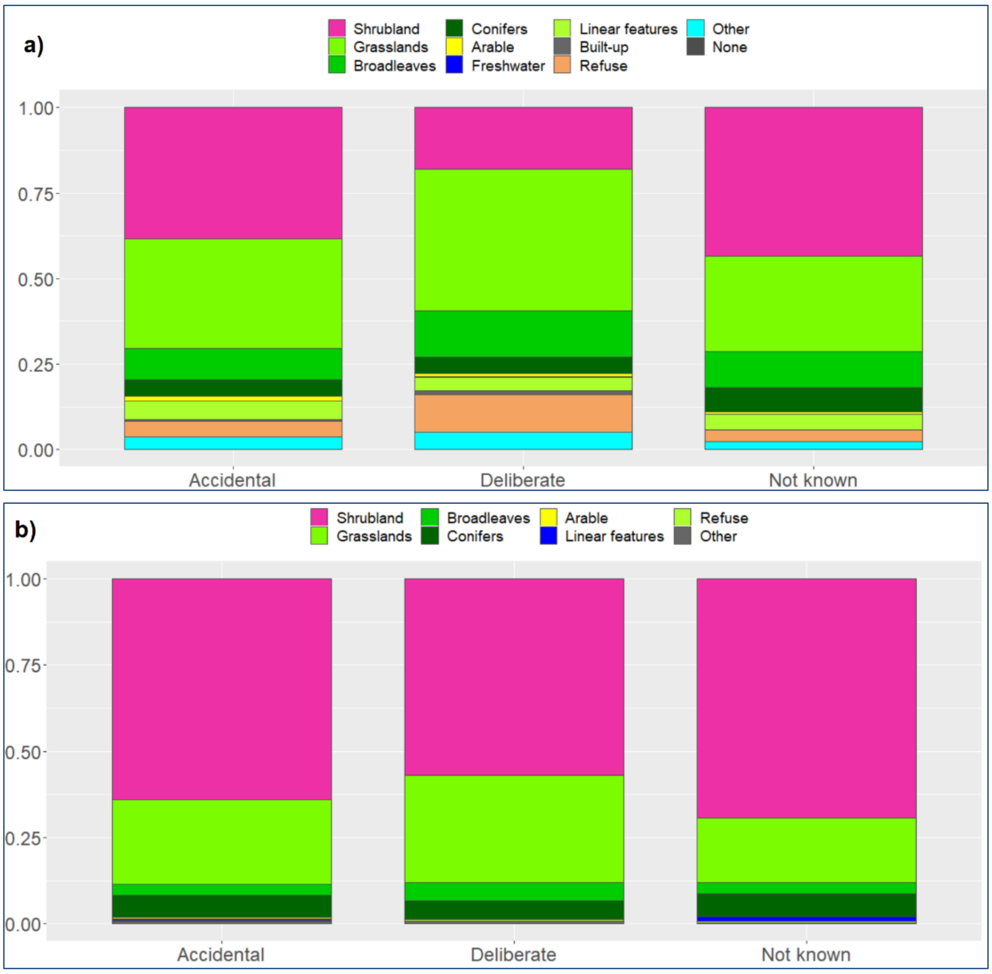


Figure 5.7 Stacked proportions of Broad Habitats (BHs) classified from Level 3 Property Types per recorded motive for years 2009 to 2020 for a) all IRS wildfires and b) wildfires with damage area greater than 1,000 m^2.

In addition, we investigated patterns of causes of ignition, ignition sources, first items ignited and items causing spread in relation to ignition motive (Tables 5.17-5.24). This information was available for 919 wildfire incidents from the full dataset and 232 fire incidents from the subset of bigger wildfires. Regarding the cause of ignition, bringing together a heat source and combustibles was almost exclusively the cause of deliberate ignitions (>90%), for all fire incidents irrespective of damage area size (Tables 5.17 and 5.18). On the other hand, most accidental wildfires were caused by bonfires or some other form of intentional burn that got out of control; 24% and 27% of wildfires from the full dataset and 26% and 33% of the bigger wildfires, respectively. Regarding wildfires of unknown motive, most had an ignition cause of "Other", followed by overheating of unknown cause and some form of intentional burn that got out of control (Tables 5.17 and 5.18).

There was limited information to extract regarding ignition sources, since an unknown ignition source was recorded for most fire incidents from the full dataset and the subset of bigger wildfires, regardless of ignition motive (Tables 5.19 and 5.20). Other recorded ignition sources included match and candles, naked flame and smoking-related ignitions, that each accounted from 12%-24% of wildfires from the full dataset and 9% to 19% of the bigger wildfires. Interestingly, 3%-4% of wildfires (from the subset and full dataset, respectively) were attributed to natural occurrence; however no further information was provided for those fire incidents.

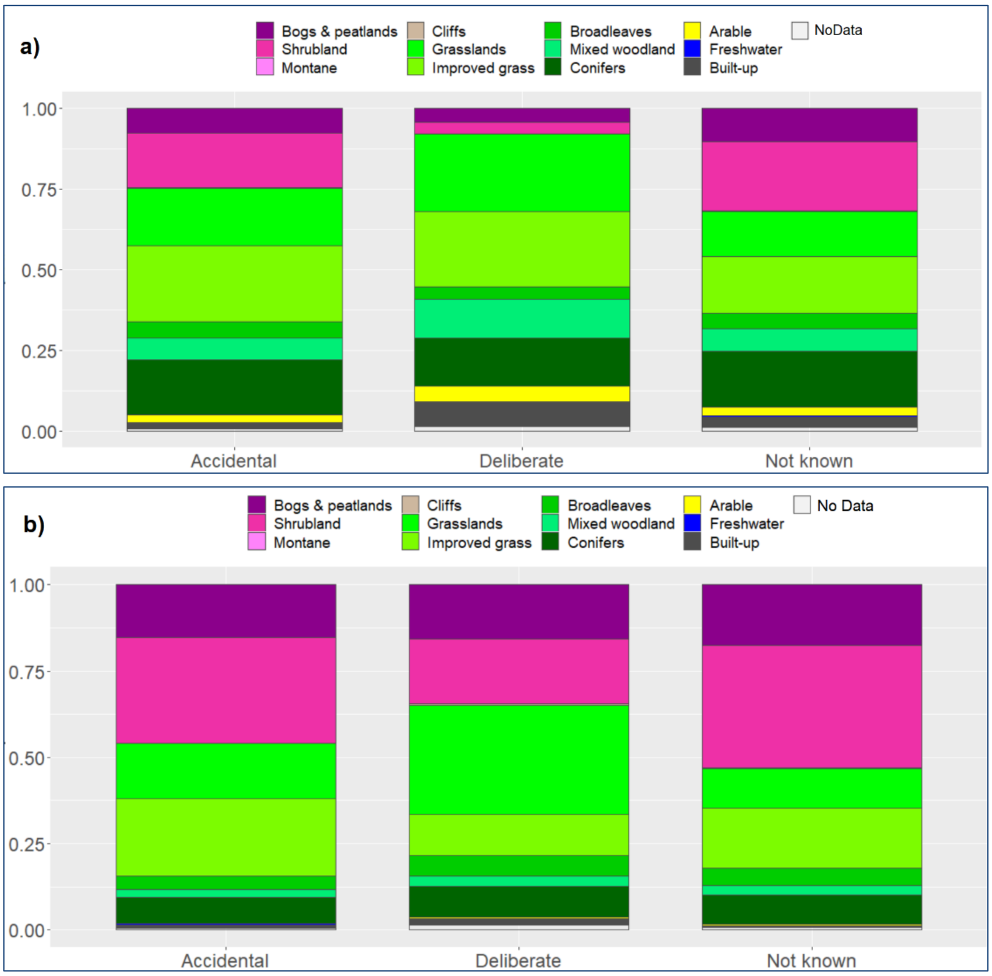


Figure 5.8 Stacked proportions of Broad Habitats (BHs) classified from LCS88 classes per recorded motive for years 2009 to 2020 for a) all IRS wildfires and b) wildfires with damage area greater than 1,000 m^2.

Vegetation was recorded as the item or material first ignited for 709 of the 919 wildfires from the full dataset and 204 of the 232 bigger wildfires (Tables 5.21 and 5.22). Looking at the main types of vegetation recorded (given in field "ItemFirstIgnitedSubtype") for the wildfires from the full dataset, there were 383 records for grassland, heath and scrub, 199 records for trees, 49 records for leaves and 34 records for straw/stubble, while grassland, heath and scrub dominated the subset of bigger wildfires (178 records), followed by 20 records for trees. More wildfires from the full dataset with grass, heath or scrub as the recorded vegetation type of ignition were caused by an accident (153 records) than by deliberate action (125 records) or unknown motive (105 records), whilst most wildfires with trees and straw/stubble as recorded ignition materials were caused by deliberate action (118 and 21 records, respectively) than by accident (35 and 9 records, respectively). On the other hand for bigger wildfires, accidental ignitions greatly outnumbered deliberate ignitions for fire incidents with grass, heath or scrub as the recorded vegetation type of ignition (94 records for accidental ignitions compared to 23 records for deliberate ignitions).

Vegetation was also recorded as the most frequent item or material causing fire spread for 731 of the 919 wildfires from the full dataset and 222 of the 232 bigger wildfires (Tables 5.23 and 5.24). Again, investigating the main types of vegetation recorded (given in field "ItemCausingSpreadSubtype") for the wildfires from the full dataset showed that there were 404 records for grassland, heath and scrub, 209 records for trees and 33 records for straw/stubble, while grassland, heath and scrub dominated the subset of bigger wildfires (192 records), followed by 25 records for trees. Looking different vegetation types causing spread in relation to ignition motives revealed the same patters as in the case of items causing ignition. More wildfires from the full dataset with grass, heath or scrub as the recorded vegetation type causing spread had an accidental ignition motive (162 records) compared to a deliberate motive (127 records) or unknown motive (115 records), whilst most wildfires with trees and straw/stubble as recorded materials responsible for fire spread were caused by deliberate action (127 and 23 records, respectively) than by accident (37 and 7 records, respectively). As expected for bigger wildfires, accidental ignitions greatly outnumbered deliberate ignitions for fire incidents with grass, heath or scrub as the recorded vegetation type of ignition (101 records for accidental ignitions compared to 64 records for deliberate ignitions).

Although results given in Tables 5.17 to 5.24 are based on the analysis of a limited number of wildfire incidents, they give a clear indication that types of seminatural vegetation (grass, heath, scrub) are more likely to be responsible for ignition and fire spread in fires caused by accident, especially in the bigger wildfires where almost all records had grass, heath, and scrub as the vegetation types responsible for ignition and fire spread. On the other hand, trees and to a lesser degree straw/stubble are more likely to be the most frequent vegetation type responsible for ignition and fire spread in, mainly smaller and less trivial, fires caused by deliberate ignitions.

Table 5.17 Total counts and proportions of cause of ignition per motive of IRS wildfires.

Motive	Sum	Accumulation flammable material	Bonfire out of control	Careless handling-careless disposal	Combustible articles close to heat source	Coo king	Faulty fuel supplies-Gas/ Electricity/ Petrol	Heat source + combustibles brought together	Natural occurrence	Negligent use of equipment	Other	Other intentional burn, out of control	Over heating, unknown cause	Playing with fire (or heat source)
Accidental	248	2	24	13	3	1	0	0	6	3	14	27	5	2
Deliberate	454	0	0	0	0	0	0	96	0	0	4	0	0	0
Not known	217	3	7	2	6	1	0	0	11	0	35	15	17	3

Table 5.18 Total counts and proportions of cause of ignition per motive of IRS wildfires with damage area greater than 1,000 m^2.

Motive	Sum	Accumulation flammable material	Bonfire out of control	Careless handling-careless disposal	Combustible articles close to heat source	Coo king	Faulty fuel supplies-Gas/ Electricity/ Petrol	Heat source + combustibles brought together	Natural occurrence	Negligent use of equipment	Other	Other intentional burn, out of control	Over heating unknown cause	Playing with fire (or heat source)
Accidental	117	1	26	11	3	1	1	0	4	1	15	33	4	0
Deliberate	37	0	0	0	0	0	0	92	0	0	8	0	0	0
Not known	78	0	4	1	5	3	0	0	9	0	41	15	21	1

Table 5.19 Total counts and proportions of ignition sources per motive of IRS wildfires.

Motive	Sum	Bombs and explosives	Cooking appliance	Electricity supply	Fuel/ chemical related	Industrial Equipment	Matches and candles	Naked flame	Natural Occurrence	Not known	Other	Smoking Related	Spread from secondary fire	Vehicles only	Wet hay
Accidental	250	2	5	1	0	0	14	12	4	29	8	12	10	2	1
Deliberate	456	0	0	0	2	0	26	18	0	40	0	14	0	0	0
Not known	221	0	1	0	0	0	8	2	5	77	4	3	0	0	0

Table 5.20 Total counts and proportions of ignition sources per motive of IRS wildfires with damage area greater than 1,000 m^2.

Motive	Sum	Bombs and explosives	Cooking appliance	Electricity supply	Industrial equipment	Matches and candles	Naked flame	Natural occurrence	Not known	Other	Smoking Related	Spread from secondary fire	Vehicles only
Accidental	118	4	2	1	2	19	13	3	32	10	9	5	0
Deliberate	38	0	0	0	0	29	26	0	42	0	3	0	0
Not known	78	0	4	0	0	5	1	3	79	3	4	0	1

Table 5.21 Total counts and proportions of first item ignited per motive of IRS wildfires.

Motive	Sum	None	Not known	Other	Paper/Cardboard	Rubbish/Waste/Recycling	Vegetation	Wood
Accidental	250	2	7	1	0	2	86	2
Deliberate	456	3	14	0	5	4	70	4
Not known	221	1	16	0	0	0	79	4

Table 5.22 Total counts and proportions of first item ignited per motive of IRS wildfires with damage area greater than 1,000 m^2.

Motive	Sum	Not known	Other	Paper/Cardboard	Rubbish/Waste/Recycling	Vegetation	Wood
Accidental	118	8	1	0	3	87	1
Deliberate	38	11	0	3	0	86	0
Not known	78	13	0	0	1	86	0

Table 5.23 Total counts and proportions of items causing fire spread per motive of IRS wildfires.

Motive	Sum	Foam, rubber, plastic	None	Not known	Other	Paper/ Cardboard	Rubbish/ Waste/Recycling	Vegetation	Wood
Accidental	250	0	6	2	2	0	0	89	1
Deliberate	456	1	12	6	0	1	2	72	6
Not known	221	0	9	6	0	0	0	83	2

Table 5.24 Daily counts and proportions of items causing spread per motive of IRS wildfires with damage area greater than 1,000 m^2.

Motive	Sum	None	Not known	Vegetation
Accidental	118	2	3	95
Deliberate	38	3	5	92
Not known	78	1	3	96

5.2.4 Burnt area size

The purpose of this analysis was to investigate patterns of burnt area size related to fuel type composition, i.e., investigate whether certain fuel types cause more burnt areas and greater wildfires than others. For this reason, we aggregated the thirteen (13) classes of the Outdoor Damage Area field recorded in the IRS (see Section 2) into four (4) classes:

a) None: Wildfires with no burn area estimates
b) DA0_100: Wildfires with burnt areas of 0-100 m^2;
c) DA0100_1000: Wildfires with burnt areas of 100-1,000 m^2; and
d) DA>1000: Wildfires with burnt areas >1,000 m^2 (this is the same as the subset of bigger wildfires described in previous Sections).

Overall, most wildfires (67%) were small wildfires with estimated burnt areas less than 100 m^2, while wildfires of moderate size (100 – 1,000 m^2) and bigger wildfires (>1,000 m^2) accounted for 15% and 14% of all wildfires, respectively. Regarding fuel types, wildfires in almost all Broad Habitats (BH) are small with estimated burnt areas less than 100 m^2, with the clear exception of bogs and peatlands and shrubland. Based on Broad Habitats BHs classified from IRS Level 3 Property Types, small wildfires with less than 100 m^2 burnt areas accounted for around 60% to 90% of all wildfires for each BH, with small wildfires being the most frequent for shrubland (43%) but to a smaller extent compared to the other BHs, while bigger wildfires accounted for 32% of shrubland wildfires (Table 5.25 and Figure 5.9a).

Table 5.25 Counts of IRS wildfire Broad Habitats (BHs) classified from Level 3 Property Types per recorded Damage Area (DA) group: None; 0-100 m^2; 100-1,000 m^2 and >1,000 m^2.

BH	None	DA0_100	DA100_1000	DA>1000
Shrubland	57	1158	622	853
Grasslands	145	2522	578	317
Broadleaves	49	971	98	48
Conifers	11	329	70	83
Arable	7	86	7	3
Freshwater	1	13	0	0
Linear features	25	355	36	9
Built-up	10	57	3	0
Refuse	83	681	18	5
Other	67	320	20	7
None	0	1	0	0

Regarding wildfire BHs classified from LCS88 classes, bigger wildfires (burnt area >1,000 m^2) accounted for 35% of wildfires on bogs and peatlands and 41% of shrubland wildfires, compared to small wildfires (burnt area <100 m^2) that accounted for 41% and 34% of all wildfires, respectively (Table 5.26 and Figure 5.9b). Bigger wildfires accounted for only 11%-12% of wildfires on seminatural and improved grasslands, while most broadleaved, mixed and conifer woodland fires were small wildfires (68%, 82% and 77%, respectively).

Table 5.26 Counts of IRS wildfire Broad Habitats (BHs) classified from LCS88 classes per recorded Damage Area (DA): 0-100 m^2; 100-1,000 m^2 and >1,000 m^2.

BH	None	DA0_100	DA100_1000	DA>1000
Bogs & peatlands	16	248	127	213
Shrubland	22	329	225	397
Montane	0	1	1	1
Cliffs	1	1	3	1
Grasslands	80	1321	372	233
Improved grass	140	1504	297	247
Broadleaves	25	282	48	62
Mixed woodland	51	780	85	34
Conifers	64	1188	188	109
Arable	16	311	38	3
Freshwater	2	14	6	2
Built-up	32	427	41	13
No Data	6	87	21	10

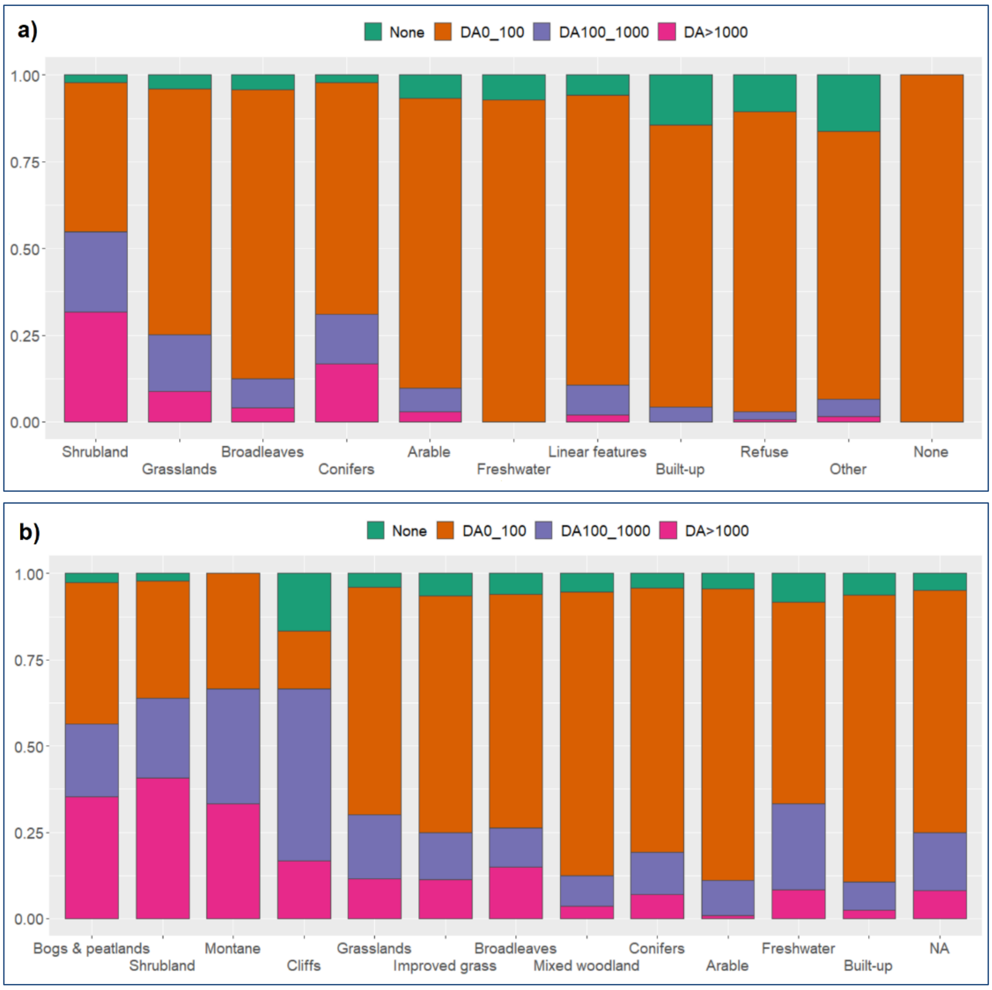


Figure 5.9 Stacked proportions of IRS wildfire Broad Habitats (BH) classified from a) Level 3 Property Types and b) LCS88 classes per Damage Area (DA) group: 0-100 m^2; 100-1,000 m^2 and >1,000 m^2.

Overall, these results indicate that wildfires on peatlands and heathlands tend to be larger in burnt area size and cause greater damage (based on recorded damage area estimates) than wildfires in other seminatural vegetation such as grasslands and woodlands, which are more likely to be small fires causing limited damage.

5.2.5 Urban-Rural classification

Accessibility and population density and proximity to populated areas are established factors influencing wildfire ignitions and wildfire risk. For this reason, we used the 8-fold Scottish Government Urban Rural (UR) Classification (Table 5.27) to investigate, in an integrated way, patterns of wildfire occurrence related to accessibility and population numbers.

Table 5.27 Description of the 8-fold Urban Rural (UR) classification system.

UR Folds	Description	UR Folds	Description
Fold01	Large Urban Areas	Fold05	Very Remote Small Towns
Fold02	Other Urban Areas	Fold06	Accessible Rural
Fold03	Accessible Small Towns	Fold07	Remote Rural
Fold04	Remote Small Towns	Fold08	Very Remote Rural

Figure 5.10a shows that most IRS wildfires occurred within accessible rural areas (57%), followed by wildfires in very remote rural areas (22%) and in remote rural areas (14%). Only 5% of wildfires occurred within large urban and other urban areas (477 wildfire incidents in total). In contrast, most of the 1,325 bigger wildfires occurred in very remote rural areas (58%) and then in accessible rural areas (24%) and remote rural areas (15%), while only six (6) bigger wildfires were recorded in urban areas (Folds 1 and 2) and just nine (9) wildfires in small towns (one (1) in accessible small towns and eight (8) in very remote small towns) (Figure 5.10b).

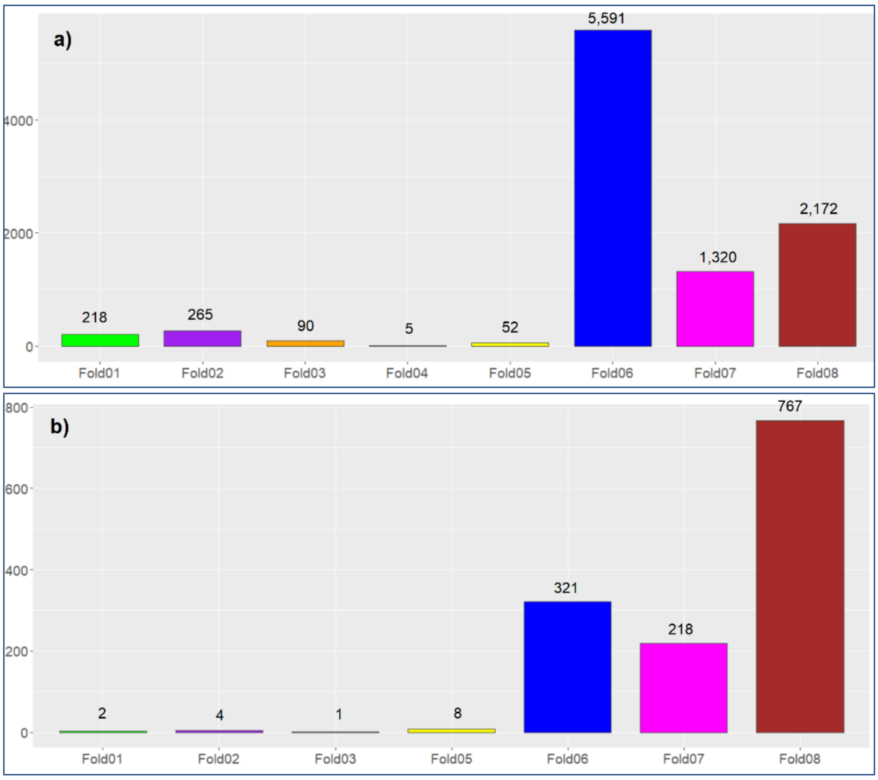
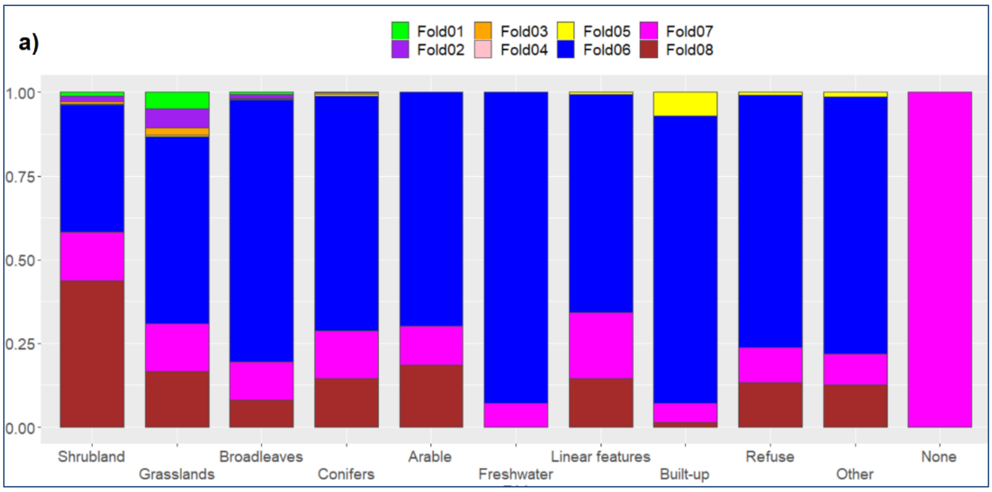


Figure 5.10 Counts of a) IRS wildfires and b) wildfires with damage area greater than 1,000 m^2 for the 8-fold Urban Rural (UR) classification system.

Regarding fuel type composition, most grassland and woodland wildfires occurred in accessible rural areas for Broad Habitats (BH) classified from both the IRS Level 3 Property Types (Figure 5.11a) and LCS88 classes (Figure 5.12a). However, most wildfires on bogs and peatlands and heathlands/shrubland occurred in very remote rural areas, which shows a clear indication that these wildfires that tend to be larger in burnt area size and of accidental motive are more likely to occur in areas with very low population density and with very limited accessibility.

This is further supported when looking at the subset of bigger wildfires, where a greater proportion of wildfires on bogs and peatlands and on heathlands occurred in very remote areas compared to when all wildfires where investigated (Figures 5.11b and 5.12b). In addition, a greater proportion of bigger grassland wildfires occurred in very remote areas than accessible rural areas when BHs based on Level 3 Property types were used (Figure 11b); this is also true for bigger wildfires on managed or improved grasslands using BHs based on LCS88 classes (Figure 12b).



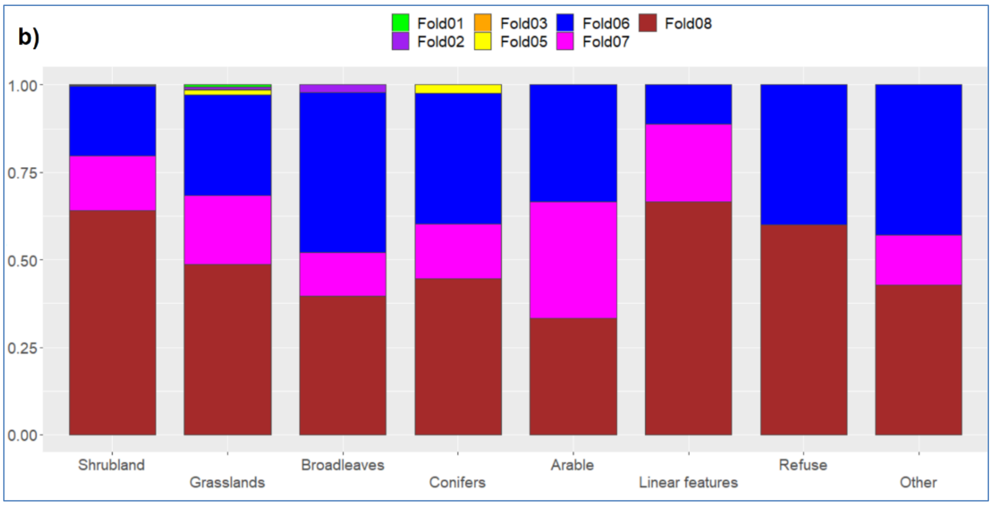


Figure 5.11 Stacked proportions of Broad Habitats (BH) classified from Level 3 Property Types per Urban Rural (UR) 8-folds for a) all IRS wildfires and b) wildfires with damage area greater than 1,000 m^2.

Looking at bigger woodland fires based on LCS88 classes (Figure 12b), it is evident that most wildfires on broadleaf woodlands occurred in remote rural areas (61%) with only 10% of wildfires on broadleaves occurring in accessible rural areas. On the other hand, most wildfires on mixed woodland occurred in very remote areas (53%) and in accessible rural areas (32%). Finally, most bigger conifer forest fires occurred in accessible rural areas, with an almost even number of conifer forest fires occurring in remote and very remote rural areas (21% and 19%, respectively). These results indicate that bigger wildfires on broadleaves and mixed woodland are more likely to occur in remote and very remote rural areas compared to wildfires of smaller damage area size on the same vegetation/fuel types that are more likely to occur in more accessible rural areas.

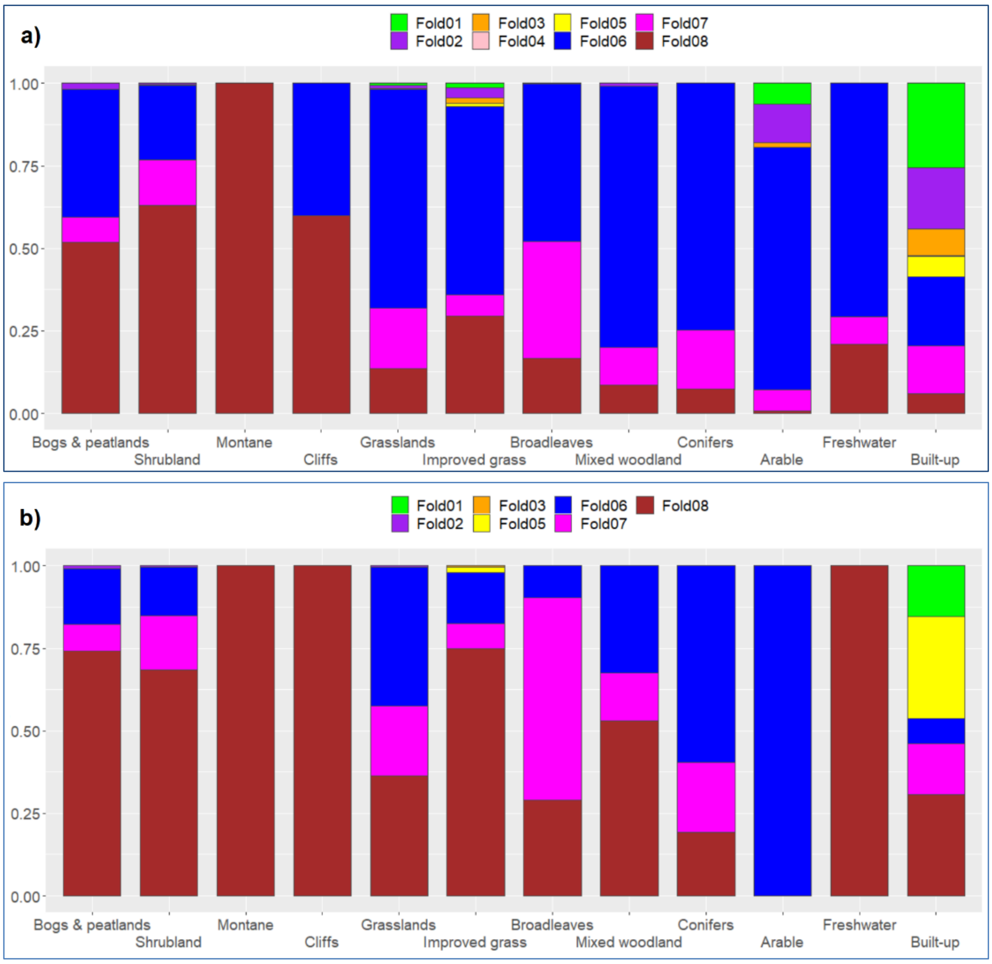


Figure 5.12 Stacked proportions of Broad Habitats (BH) classified from LCS88 classes per Urban Rural (UR) 8-folds for a) all IRS wildfires and b) wildfires with damage area greater than 1,000 m^2.

5.3 Patterns per Local Authorities

5.3.1 Overview

Wildfire data from both the full wildfire dataset and the subset of bigger wildfires are presented for each Local Authority (LA) using tables of the total count of wildfires per LA along with the proportions of those wildfire counts falling into the different time periods (years, months, days), fuel types, ignition motive types and burnt area sizes. Results at LA level are presented using tables because the large number of LAs made generated figures difficult to read and interpret (LA *n*=32 for the full wildfire dataset and *n*=31 for the bigger wildfires; no bigger wildfire incident recorded in East Renfrewshire).

5.3.2 Temporal - Seasonality

5.3.2.1 Annual

Most wildfires from the full dataset occurred in the Highland area (1,852), followed by the North Lanarkshire (690) and West Lothian (684) areas, while Clackmannanshire, Angus and East Renfrewshire areas had the least recorded wildfires (79, 54, 35 incidents, respectively)

(Table 5.28). For most LAs, the greater annual number of wildfires within their areas occurred during the 2016 to 2020 period, but there was no clear indication of any trend of inter-annual wildfire occurrence.

Table 5.28 Total counts and yearly proportions (in %) of IRS wildfires per Local Authority (LA) for the 2009-2020 period.

LA	Sum	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Aberdeen City	125	6	6	10	4	6	2	7	2	10	21	11	14
Aberdeenshire	281	5	6	9	5	10	6	9	5	9	11	11	16
Angus	54	7	7	11	2	7	7	6	6	13	7	9	17
Argyll & Bute	355	5	19	9	9	14	3	5	8	7	7	10	5
Clackmannanshire	79	9	8	3	8	11	9	17	3	24	6	0	4
Dumfries & Galloway	177	6	19	14	6	9	3	5	6	9	10	3	12
Dundee City	150	1	5	9	4	4	5	13	11	16	17	6	9
East Ayrshire	609	3	15	5	6	17	4	8	10	14	8	4	5
East Dunbartonshire	81	4	9	9	6	7	9	16	5	11	9	5	11
East Lothian	154	4	9	8	3	7	2	12	6	18	11	12	8
East Renfrewshire	35	3	3	3	17	26	3	3	11	11	6	9	6
Edinburgh City	200	10	13	7	7	13	6	10	7	6	12	5	8
Falkirk	357	5	15	6	3	9	9	6	13	12	9	3	10
Fife	414	13	12	7	6	9	5	10	8	7	13	4	8
Glasgow City	198	3	7	9	4	11	10	13	15	11	5	9	4
Highland	1852	7	10	8	9	15	7	5	5	8	12	9	7
Inverclyde	245	0	2	6	9	9	5	9	25	18	7	4	7
Midlothian	202	10	8	9	6	7	5	7	6	16	5	10	11
Moray	323	6	7	8	6	7	7	6	7	4	19	10	13
Na h-Eileanan Siar	644	3	7	6	15	23	6	5	6	6	14	5	5
North Ayrshire	187	2	6	6	10	9	4	8	9	17	16	10	5
North Lanarkshire	690	4	8	9	8	14	7	10	11	9	6	7	8
Orkney Islands	101	11	11	5	5	13	6	5	7	6	16	9	7
Perth & Kinross	182	9	13	6	7	9	9	7	10	13	9	4	7
Renfrewshire	195	4	3	9	7	10	7	11	14	14	9	3	10
Scottish Borders	257	7	15	11	4	7	6	6	4	16	8	8	8
Shetland Islands	83	6	18	6	6	8	4	5	4	6	21	2	15
South Ayrshire	87	2	17	8	9	5	8	6	6	8	16	3	12
South Lanarkshire	368	7	9	8	4	9	7	10	12	10	4	8	12
Stirling	211	10	13	7	3	5	3	7	6	11	13	7	17
West Dunbartonshire	145	2	8	8	2	21	8	8	12	13	6	4	6
West Lothian	684	6	16	6	7	9	6	6	6	9	11	8	11

Most bigger wildfires occurred in the Highland and Na h-Eileanan Siar areas (656 and 251 fire incidents, respectively) (Table 5.29). There is an indication that a greater proportion of bigger wildfires occurred in 2013 when most fire incidents were recorded for the Na h-Eileanan Siar (33%) and Highland (19%) LAs, which combined accounted for 208 of the 268 wildfires recorded in 2013.

Table 5.29 Total counts and yearly proportions (in %) of IRS wildfires with damage area greater than 1,000 m^2 per Local Authority (LA) for the 2009-2020 period.

LA	Sum	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Aberdeen City	3	0	0	33	0	0	0	0	0	0	67	0	0
Aberdeenshire	27	4	4	7	15	19	11	0	4	7	11	7	11
Angus	4	0	0	0	0	0	0	0	0	25	0	50	25
Argyll & Bute	59	0	27	19	5	17	2	3	2	10	5	8	2
Clackmannanshire	7	0	14	14	14	0	0	43	0	15	0	0	0
Dumfries & Galloway	33	9	21	21	15	9	0	6	9	3	0	0	6
Dundee City	2	0	0	0	0	50	0	0	0	0	50	0	0
East Ayrshire	30	0	4	13	0	33	7	0	3	33	0	7	0
East Dunbartonshire	4	0	25	0	0	0	25	50	0	0	0	0	0
East Lothian	5	0	0	0	0	0	0	0	0	0	0	100	0
Edinburgh City	2	0	0	0	0	0	0	0	0	0	50	0	50
Falkirk	7	0	14	0	0	0	29	0	0	14	14	0	29
Fife	17	6	0	6	6	29	0	6	6	6	12	12	12
Glasgow City	2	0	0	50	0	0	0	0	0	0	0	50	0
Highland	656	9	10	8	9	19	6	3	4	9	10	10	3
Inverclyde	8	0	0	13	0	0	0	13	25	38	0	0	13
Midlothian	4	25	0	25	25	0	0	25	0	0	0	0	0
Moray	25	0	4	0	12	8	8	4	0	8	12	24	20
Na h-Eileanan Siar	251	4	7	6	11	33	5	4	4	5	13	7	1
North Ayrshire	2	0	0	0	0	0	0	0	0	0	100	0	0
North Lanarkshire	26	0	4	12	0	12	0	19	4	23	8	4	15
Orkney Islands	11	9	27	0	0	45	0	0	9	0	9	0	0
Perth & Kinross	13	8	23	8	15	15	8	0	8	15	0	0	0
Renfrewshire	3	0	0	0	0	0	0	0	67	33	0	0	0
Scottish Borders	22	9	23	23	9	5	0	0	0	5	14	14	0
Shetland Islands	11	0	9	9	0	45	0	0	9	9	18	0	0
South Ayrshire	7	0	14	14	14	0	0	0	0	14	14	0	29
South Lanarkshire	16	0	13	6	6	6	6	13	13	6	0	13	19
Stirling	15	13	13	7	0	7	13	20	0	20	0	0	7
West Dunbartonshire	14	0	0	14	0	14	14	0	29	21	0	7	0
West Lothian	39	13	8	5	10	10	10	15	10	5	5	0	8

5.3.2.2 Monthly

The greater monthly counts of wildfires for the 2009-2020 period and for all LAs were recorded in one of the spring months, with the only exception of Moray where more wildfires were recorded for July than in other months (Table 5.30). April was the month with the most recorded wildfires for most LAs, followed by May. Overall, spring wildfires outnumbered summer wildfires in all LAs, apart from in the Moray and Falkirk areas, while an almost equal number of spring and summer wildfires was recorded in the Shetlands Islands.

Table 5.30 Total counts and monthly proportions (%) of IRS wildfires per Local Authority (LA) for the 2009-2020 period.

LA	Sum	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Aberdeen City	125	5	7	6	12	18	12	14	6	12	2	4	1
Aberdeenshire	281	2	2	13	20	17	10	12	9	9	3	2	2
Angus	54	2	6	11	7	26	9	6	9	6	2	13	4
Argyll & Bute	355	1	2	17	34	25	8	7	1	2	1	1	1
Clackmannanshire	79	0	3	8	22	29	8	13	8	11	0	0	0
Dumfries & Galloway	177	1	2	14	31	22	10	6	4	2	5	2	2
Dundee City	150	3	2	25	27	17	13	7	1	1	3	0	1
East Ayrshire	609	1	1	18	39	18	7	6	2	2	1	2	1
East Dunbartonshire	81	4	1	9	33	23	7	7	2	4	2	5	1
East Lothian	154	6	6	8	23	17	14	10	3	2	5	1	4
East Renfrewshire	35	0	3	11	26	34	6	9	0	0	6	3	3
Edinburgh City	200	0	4	8	22	16	9	22	4	7	5	4	3
Falkirk	357	1	1	6	18	19	18	16	9	6	4	2	0
Fife	414	1	2	8	23	16	17	15	6	5	5	2	0
Glasgow City	198	1	2	17	46	17	5	4	2	4	2	2	0
Highland	1852	1	2	17	33	17	10	10	4	3	2	1	0
Inverclyde	245	0	0	16	34	31	11	4	0	1	1	1	0
Midlothian	202	2	3	10	23	24	7	8	4	10	2	3	1
Moray	323	1	2	5	16	14	14	22	8	11	5	2	1
Na h-Eileanan Siar	644	1	3	30	30	13	10	6	2	1	1	2	0
North Ayrshire	187	1	4	9	25	22	11	14	6	3	2	3	1
North Lanarkshire	690	1	2	20	37	19	7	7	2	2	2	1	1
Orkney Islands	101	1	2	13	26	20	6	10	8	2	4	5	4
Perth & Kinross	182	2	3	8	27	21	13	10	5	7	2	2	2
Renfrewshire	195	1	5	13	24	27	6	8	2	5	4	3	3
Scottish Borders	257	2	2	10	21	18	15	9	9	7	2	4	2
Shetland Islands	83	0	5	20	13	7	23	7	10	4	2	4	5
South Ayrshire	87	2	2	11	13	24	16	9	5	7	5	3	2
South Lanarkshire	368	3	3	11	26	21	12	7	5	4	4	4	1
Stirling	211	1	1	8	30	22	11	13	5	2	3	2	1
West Dunbartonshire	145	1	1	15	34	19	13	6	5	3	2	1	1
West Lothian	684	2	1	11	28	26	10	10	4	3	2	2	1

Regarding the subset of bigger wildfires, greater monthly counts of wildfires for most LAs were recorded in one of the spring months (Table 5.31). For example, 43% and 39% of wildfires recorded for the Highland and Na h-Eileanan Siar areas, respectively, occurred in April, while April was the month with the most recorded wildfires for most LAs, followed by May. Overall, bigger spring wildfires outnumbered summer wildfires in almost all LAs and in those LAs with the greatest numbers of wildfire occurrence.

Table 5.31 Total counts and monthly proportions (in %) of IRS wildfires with damage area greater than 1,000 m^2 per Local Authority (LA) for the 2009-2020 period.

LA	Sum	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Aberdeen City	3	0	0	0	0	33	0	33	0	33	0	0	0
Aberdeenshire	27	0	0	26	19	15	15	19	4	4	0	0	0
Angus	4	0	0	25	25	50	0	0	0	0	0	0	0
Argyll & Bute	59	0	2	29	37	29	3	0	0	0	0	0	0
Clackmannanshire	7	0	0	29	57	14	0	0	0	0	0	0	0
Dumfries & Galloway	33	0	3	21	52	18	6	0	0	0	0	0	0
Dundee City	2	0	0	0	50	0	0	50	0	0	0	0	0
East Ayrshire	30	0	0	13	50	30	7	0	0	0	0	0	0
East Dunbartonshire	4	0	0	0	50	50	0	0	0	0	0	0	0
East Lothian	5	80	20	0	0	0	0	0	0	0	0	0	0
Edinburgh City	2	0	0	0	50	0	0	50	0	0	0	0	0
Falkirk	7	0	0	0	29	43	0	29	0	0	0	0	0
Fife	17	0	6	12	24	18	18	18	0	0	6	0	0
Glasgow City	2	0	0	0	50	0	0	50	0	0	0	0	0
Highland	656	0	2	20	43	20	8	4	1	1	0	0	0
Inverclyde	8	0	0	0	38	63	0	0	0	0	0	0	0
Midlothian	4	0	0	25	25	25	25	0	0	0	0	0	0
Moray	25	0	0	8	20	28	20	12	0	12	0	0	0
Na h-Eileanan Siar	251	0	5	35	39	11	6	3	1	0	0	0	0
North Ayrshire	2	0	0	0	0	0	0	100	0	0	0	0	0
North Lanarkshire	26	0	0	4	38	54	4	0	0	0	0	0	0
Orkney Islands	11	0	0	9	55	18	0	9	0	0	9	0	0
Perth & Kinross	13	0	0	15	38	31	0	8	0	8	0	0	0
Renfrewshire	3	0	0	0	33	67	0	0	0	0	0	0	0
Scottish Borders	22	0	5	36	32	18	0	5	5	0	0	0	0
Shetland Islands	11	0	0	64	27	9	0	0	0	0	0	0	0
South Ayrshire	7	0	0	43	14	43	0	0	0	0	0	0	0
South Lanarkshire	16	0	0	13	44	25	19	0	0	0	0	0	0
Stirling	15	0	0	0	60	33	7	0	0	0	0	0	0
West Dunbartonshire	14	0	0	14	57	14	7	7	0	0	0	0	0
West Lothian	39	0	0	18	33	31	10	8	0	0	0	0	0

5.3.2.3 Daily

The greater daily counts of wildfires for the 2009-2020 period and for all LAs were recorded during weekends (either on a Saturday or a Sunday) (Table 5.32). However, in most cases the differences between daily wildfire counts were small. Overall, total wildfires occurring during weekdays outnumbered wildfires occurring at the weekend in all LAs. The greater numbers of weekday wildfires were recorded in the Dundee City, Aberdeen City and Na h-Eileanan Siar areas, where weekday wildfires accounted for 80%, 73% and 72% of the total number of wildfires. On the other hand, weekday wildfires accounted for 59% and 58% in the Shetlands and Orkney Islands, respectively, but accounted for 60% and more of total wildfires in all other LAs.

Table 5.32 Total counts and daily proportions of IRS wildfires per Local Authority (LA) for the 2009-2020 period.

LA	Sum	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Aberdeen City	125	13	13	16	17	14	17	10
Aberdeenshire	281	16	12	12	11	12	19	17
Angus	54	9	24	15	7	13	17	15
Argyll & Bute	355	19	12	12	13	14	14	15
Clackmannanshire	79	14	14	11	15	10	14	22
Dumfries & Galloway	177	17	10	12	14	14	14	20
Dundee City	150	17	13	21	15	13	11	9
East Ayrshire	609	13	14	14	13	13	18	16
East Dunbartonshire	81	14	14	10	9	21	21	12
East Lothian	154	12	16	15	13	12	19	14
East Renfrewshire	35	20	20	6	6	17	11	20
Edinburgh City	200	15	12	13	9	11	21	20
Falkirk	357	16	16	11	13	12	16	16
Fife	414	15	11	13	14	12	16	19
Glasgow City	198	13	11	14	11	16	16	20
Highland	1852	14	14	14	14	15	17	12
Inverclyde	245	12	12	16	17	13	14	16
Midlothian	202	14	7	12	14	17	17	18
Moray	323	14	14	11	13	16	14	18
Na h-Eileanan Siar	644	19	16	12	13	11	17	11
North Ayrshire	187	16	12	11	12	11	23	15
North Lanarkshire	690	17	11	12	13	11	18	17
Orkney Islands	101	12	8	15	14	10	18	24
Perth & Kinross	182	14	10	17	5	14	23	16
Renfrewshire	195	16	13	14	12	17	15	13
Scottish Borders	257	11	14	11	12	18	16	19
Shetland Islands	83	12	8	10	11	18	20	20
South Ayrshire	87	17	2	16	17	7	21	20
South Lanarkshire	368	15	13	14	15	12	17	16
Stirling	211	16	13	11	15	9	19	17
West Dunbartonshire	145	12	12	16	14	10	16	20
West Lothian	684	16	14	11	12	14	16	17

Regarding bigger wildfires, fire incidents occurring during weekdays outnumbered wildfires occurring at the weekend in 25 of the 31 LAs, with three (3) LAs having the same wildfire occurrence between weekdays and weekends and another three (3) LAs having more wildfires recorded in weekends than during the week (Table 5.32). However, these six (6) LAs where weekend wildfires were the same or outnumbered fires during weekdays had only 26 (out of a total 1,325 fires) incidents of bigger wildfires. Overall, weekday wildfires accounted for 60% and more of total wildfires in most LAs. Looking at LAs with the greater numbers of bigger wildfires (>30 incidents), weekday wildfires accounted for 80%, 75% and 75% of the total number of bigger wildfires in the Argyll and Bute, Highland and Na h-Eileanan Siar areas, respectively.

Table 5.33 Total counts and daily proportions (in %) of IRS wildfires with damage area greater than 1,000 m^2 per Local Authority (LA) for the 2009-2020 period.

LA	Sum	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Aberdeen City	3	0	0	33	33	0	33	0
Aberdeenshire	27	22	11	19	15	4	22	7
Angus	4	25	0	0	0	50	0	25
Argyll & Bute	59	24	15	12	10	19	10	10
Clackmannanshire	7	29	29	14	14	0	14	0
Dumfries & Galloway	33	24	12	12	9	6	15	21
Dundee City	2	0	0	0	0	50	0	50
East Ayrshire	30	13	23	7	0	17	23	17
East Dunbartonshire	4	25	0	25	0	50	0	0
East Lothian	5	0	0	40	20	0	20	20
Edinburgh City	2	0	0	0	50	0	0	50
Falkirk	7	57	0	0	0	14	29	0
Fife	17	12	0	12	29	12	18	18
Glasgow City	2	0	0	0	0	0	50	50
Highland	656	17	16	14	13	14	15	11
Inverclyde	8	38	13	13	13	13	13	0
Midlothian	4	0	0	25	50	0	25	0
Moray	25	24	4	8	24	12	12	16
Na h-Eileanan Siar	251	22	19	14	8	12	14	11
North Ayrshire	2	0	0	0	50	0	50	0
North Lanarkshire	26	19	12	8	12	4	31	15
Orkney Islands	11	18	9	18	0	0	18	36
Perth & Kinross	13	23	15	0	23	15	8	15
Renfrewshire	3	0	33	0	67	0	0	0
Scottish Borders	22	23	9	5	32	14	18	0
Shetland Islands	11	0	18	18	18	0	36	9
South Ayrshire	7	14	14	14	0	0	29	29
South Lanarkshire	16	19	6	13	31	13	6	13
Stirling	15	33	13	0	7	7	20	20
West Dunbartonshire	14	14	14	7	29	21	0	14
West Lothian	39	18	10	8	15	10	26	13

5.3.3 Fuel type

Broad Habitats (BH) classified from IRS Level 3 Property Types (Table 5.34) for wildfires from the full dataset show that grasslands were the most frequent fuel type in almost all LAs, where they ranged from 24% to 79% of total number of wildfires in the Angus and Dundee City, respectively. The main exceptions were in the Highland and Na h-Eileanan Siar areas where wildfires on heathlands/shrubland accounted for 56% and 50% of total wildfires, respectively. Wildfires on broadleaved and conifer woodlands accounted for 50% of all wildfires that occurred in the Falkirk area and for 44% of all wildfires in the Scottish Borders, while woodland/forest fires accounted for only 1% of total numbers of wildfires in the Shetland Islands and Glasgow City areas. In addition, wildfires on loose refuse were most frequent in the Orkney Islands, where they accounted for 25% of all recorded fires, and in the Midlothian and Angus areas (19% of all wildfires for both areas). Regarding BHs classified from LCS88 classes (Table 5.35), seminatural or improved grasslands were also the most frequent fuel types in most LAs, but there was several LAs where wildfires on either mixed or conifer forest were the most frequent (Aberdeenshire, Clackmannanshire, East Lothian, Falkirk, Fife, Midlothian, Moray, Scottish Borders), while wildfires on shrublands were the most frequent in the Highland area.

On the other hand, analysis of the subset of bigger wildfires using BHs classified from IRS Level 3 Property Types (Table 5.36) showed that shrublands were the most frequent fuel type for 22 LAs, with grasslands being the most frequent fuel type in another eight (8) LAs and conifers in one LA (Moray). Looking at BHs based on LCS88 classes (Table 5.37), bigger wildfires on grasslands (either seminatural or improved) outnumbered wildfires on bogs and peatlands and shrubland combined and woodland fires (broadleaves, mixed and conifers) in 18 LAs. Wildfires on bogs and peatland and on shrubland were more frequent in the Angus, Highland and Na h-Eileanan Siar LAs (75%, 56% and 53% of all wildfires, respectively), while combined woodland fires were more frequent in Falkirk, Moray and Midlothian LAs (71%, 68% and 50% of all wildfires, respectively).

Table 5.34 Total count of IRS wildfires and proportions (in %) of Broad Habitat (BH) types classified from Level 3 Property Types per Local Authority (LA).

LA	Sum	Shrubland	Grasslands	Broadleaves	Conifers	Arable	Freshwater	Linear features	Built-up	Refuse	Other
Aberdeen City	125	26	38	18	3	1	1	0	0	13	0
Aberdeenshire	281	22	31	19	6	1	0	4	0	14	3
Angus	54	20	24	17	2	0	0	11	2	19	6
Argyll & Bute	355	35	36	8	4	1	0	4	0	3	8
Clackmannanshire	79	14	41	33	1	5	0	1	1	4	0
Dumfries & Galloway	177	28	29	10	7	2	0	12	0	9	3
Dundee City	150	7	79	7	1	0	0	0	2	5	0
East Ayrshire	609	14	57	7	3	0	0	4	0	9	6
East Dunbartonshire	81	21	30	11	2	1	0	5	0	12	17
East Lothian	154	11	34	21	8	1	0	6	1	6	12
East Renfrewshire	35	11	51	6	3	6	0	0	0	9	14
Edinburgh City	200	22	32	19	7	2	2	6	4	6	3
Falkirk	357	7	29	35	15	1	0	4	2	5	3
Fife	414	11	37	21	10	2	0	3	1	12	2
Glasgow City	198	10	75	1	0	1	1	2	0	8	4
Highland	1852	56	23	7	4	1	0	5	0	3	2
Inverclyde	245	40	46	4	1	0	0	2	0	4	4
Midlothian	202	10	27	24	6	1	0	8	3	19	1
Moray	323	9	41	21	8	1	0	9	0	10	1
Na h-Eileanan Siar	644	50	35	4	2	1	0	1	0	5	1
North Ayrshire	187	13	43	2	2	2	0	10	1	9	20
North Lanarkshire	690	21	52	6	1	1	0	4	1	11	3
Orkney Islands	101	17	37	1	2	4	0	7	2	25	6
Perth & Kinross	182	16	32	23	4	4	1	7	1	7	7
Renfrewshire	195	10	46	13	3	2	1	4	1	14	8
Scottish Borders	257	20	16	28	16	2	0	6	1	6	5
Shetland Islands	83	29	35	0	1	0	0	8	2	17	7

LA	Sum	Shrubland	Grasslands	Broadleaves	Conifers	Arable	Freshwater	Linear features	Built-up	Refuse	Other
South Ayrshire	87	8	32	15	6	2	0	3	0	7	26
South Lanarkshire	368	14	37	10	3	1	0	5	0	18	12
Stirling	211	26	28	23	9	1	1	1	1	7	1
West Dunbartonshire	145	23	52	9	2	0	0	1	3	4	6
West Lothian	684	24	36	13	10	0	0	4	2	10	3

Table 5.35 Total count of IRS wildfires and proportions (in %) of Broad Habitat (BH) types classified from LCS88 classes per Local Authority (LA).

LA	Sum	Bogs & peatlands	Shrubland	Montane	Cliffs	Grasslands	Improved grass	Broadleaves	Mixed woodland	Conifers	Arable	Fresh water	Built-up	No Data
Aberdeen City	125	0	3	0	0	54	11	2	2	16	5	0	2	5
Aberdeenshire	281	2	7	0	0	16	5	8	13	37	10	0	0	0
Angus	54	0	13	0	0	35	9	2	17	11	2	0	7	4
Argyll & Bute	355	10	14	0	0	31	17	8	8	12	0	0	1	0
Clackmannanshire	79	0	0	0	0	18	6	8	42	10	11	0	5	0
Dumfries & Galloway	177	8	3	0	0	37	12	10	8	17	3	1	1	0
Dundee City	150	0	0	0	0	48	4	3	12	0	19	0	15	0
East Ayrshire	609	4	0	0	0	36	19	5	10	13	0	0	12	0
East Dunbartonshire	81	2	4	0	0	20	41	7	17	4	1	0	4	0
East Lothian	154	0	0	0	0	25	1	2	13	26	31	0	3	0
East Renfrewshire	35	6	0	0	0	23	63	0	3	3	0	0	3	0
Edinburgh City	200	0	12	0	0	15	11	6	10	14	21	2	12	0
Falkirk	357	2	0	0	0	11	14	2	15	51	1	0	3	1
Fife	414	1	3	0	0	20	9	8	15	28	11	1	2	1
Glasgow City	198	2	0	0	0	12	41	4	1	0	1	1	39	1
Highland	1852	10	32	0	0	14	15	7	4	16	0	0	0	0
Inverclyde	245	1	11	0	0	66	13	0	4	2	1	0	2	0
Midlothian	202	0	3	0	0	7	8	2	49	12	16	0	1	0
Moray	323	2	2	0	0	8	6	3	7	64	6	0	1	1
Na h-Eileanan Siar	644	18	23	0	0	1	45	1	3	0	0	1	5	3

LA	Sum	Bogs & peatlands	Shrubland	Montane	Cliffs	Grasslands	Improved grass	Broadleaves	Mixed woodland	Conifers	Arable	Fresh water	Built-up	No Data
North Ayrshire	187	3	1	0	0	26	48	2	3	3	1	0	9	4
North Lanarkshire	690	7	1	0	0	24	37	0	11	3	2	0	13	2
Orkney Islands	101	4	5	0	0	3	71	0	0	0	0	0	11	6
Perth & Kinross	182	1	5	0	0	26	7	12	25	17	7	0	1	0
Renfrewshire	195	3	0	0	0	33	39	2	8	3	6	0	8	0
Scottish Borders	257	0	6	0	0	21	19	4	11	35	2	0	2	0
Shetland Islands	83	11	16	0	1	10	41	0	0	0	0	0	20	1
South Ayrshire	87	0	1	0	0	23	45	7	11	8	2	0	2	0
South Lanarkshire	368	2	0	0	0	12	52	4	12	5	0	0	3	10
Stirling	211	2	2	0	0	27	9	8	28	15	5	0	3	1
West Dunbartonshire	145	1	9	0	0	30	19	1	20	4	0	0	14	1
West Lothian	684	16	0	0	0	18	28	0	5	21	4	0	5	2

Table 5.36 Total count of IRS wildfires with damage area greater than 1,000 m^2 and proportions (in %) of Broad Habitat (BH) types classified from Level 3 Property Types per Local Authority (LA).

LA	Sum	Shrubland	Grasslands	Broadleaves	Conifers	Arable	Linear features	Refuse	Other
Aberdeen City	3	100	0	0	0	0	0	0	0
Aberdeenshire	27	56	30	4	7	0	0	0	4
Angus	4	100	0	0	0	0	0	0	0
Argyll & Bute	59	64	25	2	8	0	0	0	0
Clackmannanshire	7	57	43	0	0	0	0	0	0
Dumfries & Galloway	33	61	27	6	6	0	0	0	0
Dundee City	2	50	50	0	0	0	0	0	0
East Ayrshire	30	23	60	0	17	0	0	0	0
East Dunbartonshire	4	50	25	0	25	0	0	0	0
East Lothian	5	80	20	0	0	0	0	0	0
Edinburgh City	2	0	100	0	0	0	0	0	0
Falkirk	7	57	29	0	14	0	0	0	0

LA	Sum	Shrubland	Grasslands	Broadleaves	Conifers	Arable	Linear features	Refuse	Other
Fife	17	6	47	12	29	0	0	0	6
Glasgow City	2	0	100	0	0	0	0	0	0
Highland	656	73	17	3	4	0	1	0	1
Inverclyde	8	75	13	0	13	0	0	0	0
Midlothian	4	25	25	25	25	0	0	0	0
Moray	25	24	24	16	32	0	0	4	0
Na h-Eileanan Siar	251	65	28	2	4	0	0	0	0
North Ayrshire	2	0	100	0	0	0	0	0	0
North Lanarkshire	26	50	42	4	4	0	0	0	0
Orkney Islands	11	36	45	0	18	0	0	0	0
Perth & Kinross	13	54	15	8	15	8	0	0	0
Renfrewshire	3	33	67	0	0	0	0	0	0
Scottish Borders	22	55	23	14	5	0	5	0	0
Shetland Islands	11	100	0	0	0	0	0	0	0
South Ayrshire	7	43	43	14	0	0	0	0	0
South Lanarkshire	16	63	38	0	0	0	0	0	0
Stirling	15	60	13	13	13	0	0	0	0
West Dunbartonshire	14	57	21	14	7	0	0	0	0
West Lothian	39	44	33	0	18	0	0	3	3

Table 5.37 Total count of IRS wildfires with damage area greater than 1,000 m^2 and proportions (in %) of Broad Habitat (BH) types classified from LCS88 classes per Local Authority (LA).

LA	Sum	Bogs & peatlands	Shrubland	Montane	Cliffs	Grasslands	Improved grass	Broadleaves	Mixed woodland	Conifers	Arable	Fresh water	Built-up	No Data
Aberdeen City	3	0	0	0	0	67	33	0	0	0	0	0	0	0
Aberdeenshire	27	11	33	0	0	22	4	0	7	22	0	0	0	0
Angus	4	0	75	0	0	0	0	0	0	25	0	0	0	0
Argyll & Bute	59	10	24	0	0	29	10	8	8	10	0	0	0	0
Clackmannanshire	7	0	0	0	0	71	29	0	0	0	0	0	0	0

LA	Sum	Bogs & peatlands	Shrubland	Montane	Cliffs	Grasslands	Improved grass	Broadleaves	Mixed woodland	Conifers	Arable	Fresh water	Built-up	No Data
Dumfries & Galloway	33	18	12	0	0	39	6	9	0	15	0	0	0	0
Dundee City	2	0	0	0	0	0	0	0	0	0	50	0	50	0
East Ayrshire	30	20	3	0	0	47	3	0	0	20	0	0	7	0
East Dunbartonshire	4	0	0	0	0	75	0	25	0	0	0	0	0	0
East Lothian	5	0	0	0	0	100	0	0	0	0	0	0	0	0
Edinburgh City	2	0	0	0	0	0	0	0	50	0	0	0	50	0
Falkirk	7	29	0	0	0	0	0	0	0	71	0	0	0	0
Fife	17	0	6	0	0	29	12	6	6	35	6	0	0	0
Glasgow City	2	0	0	0	0	50	50	0	0	0	0	0	0	0
Highland	656	13	43	0	0	14	14	8	2	6	0	0	0	0
Inverclyde	8	0	0	0	0	100	0	0	0	0	0	0	0	0
Midlothian	4	0	25	0	0	25	0	0	0	50	0	0	0	0
Moray	25	4	8	0	0	20	0	0	0	68	0	0	0	0
Na h-Eileanan Siar	251	27	26	0	0	1	40	0	1	0	0	1	3	2
North Ayrshire	2	0	0	0	0	100	0	0	0	0	0	0	0	0
North Lanarkshire	26	23	8	0	0	23	35	0	8	4	0	0	0	0
Orkney Islands	11	18	0	0	0	9	55	0	0	0	0	0	0	18
Perth & Kinross	13	8	23	0	0	38	8	0	15	8	0	0	0	0
Renfrewshire	3	0	0	0	0	33	0	0	33	0	0	0	33	0
Scottish Borders	22	0	23	0	0	41	14	0	0	23	0	0	0	0
Shetland Islands	11	9	36	0	0	9	36	0	0	0	0	0	9	0
South Ayrshire	7	0	14	0	0	14	43	14	0	14	0	0	0	0
South Lanarkshire	16	19	0	0	0	38	25	0	0	0	0	0	0	19
Stirling	15	20	0	0	0	60	7	0	13	0	0	0	0	0
West Dunbartonshire	14	0	21	0	0	71	0	0	0	7	0	0	0	0
West Lothian	39	46	0	0	0	10	21	0	0	21	0	0	0	3

5.3.4 Ignition motives

Wildfires caused by deliberate ignitions were the most frequent in 23 of the 32 LAs in Scotland (Table 5.38), accounting for 53% of total wildfires in the Stirling area and up to 95% in the Renfrewshire area and 97% in the Inverclyde areas. On the other hand, wildfires caused by accidental ignitions were the most frequent in the Argyll and Bute, Na h-Eileanan Siar, Dumfries and Galloway, Aberdeenshire, Perth and Kinross, Shetland Islands, Orkney Islands, Moray and Highland areas, where they accounted for 45% to 60% of all wildfires recorded. This was expected based on the finding (Section 5.2.5) that wildfires in the least accessible and least populated areas are more likely to be accidental, as most of the more remote and very remote areas in Scotland are concentrated in these LAs.

Table 5.38 Total count of IRS wildfires and proportions (in %) of recorded motive per Local Authority (LA).

LA	Sum	Accidental	Deliberate	Not known
Aberdeen City	125	22	70	7
Aberdeenshire	281	55	42	3
Angus	54	24	59	17
Argyll & Bute	355	60	33	7
Clackmannanshire	79	9	77	14
Dumfries & Galloway	177	56	38	6
Dundee City	150	1	90	9
East Ayrshire	609	4	90	5
East Dunbartonshire	81	5	89	6
East Lothian	154	17	60	23
East Renfrewshire	35	3	94	3
Edinburgh City	200	10	70	20
Falkirk	357	6	71	23
Fife	414	14	68	18
Glasgow City	198	2	94	4
Highland	1852	45	17	38
Inverclyde	245	2	97	2
Midlothian	202	7	78	15
Moray	323	46	42	12
Na h-Eileanan Siar	644	59	10	31
North Ayrshire	187	8	91	1
North Lanarkshire	690	4	92	4
Orkney Islands	101	50	26	24
Perth & Kinross	182	51	40	10
Renfrewshire	195	3	95	2
Scottish Borders	257	20	67	13
Shetland Islands	83	51	19	30
South Ayrshire	87	25	70	5
South Lanarkshire	368	14	83	3
Stirling	211	18	53	29

West Dunbartonshire	145	8	90	2
West Lothian	684	7	79	14

Looking at the subset of bigger wildfires, those caused by deliberate ignitions were the most frequent in 14 of the 31 LAs (Table 5.39), accounting for all wildfires in the Inverclyde, Renfrewshire, Dundee City and North Ayrshire LAs. On the other hand, wildfires caused by accidental ignitions were the most frequent in eight (8) LAs that include those where most bigger wildfires were recorded. In particular, accidental wildfires in the Aberdeenshire, Dumfries & Galloway, Argyll and Bute, Na h-Eileanan Siar and Highland areas accounted for 85%, 73%, 63%, 59% and 47% of all bigger wildfires in these LAs, respectively.

Table 5.39 Total count of IRS wildfires with damage area greater than 1,000 m^2 and proportions (in %) of recorded motive per Local Authority (LA).

LA	Sum	Accidental	Deliberate	Not known
Aberdeen City	3	67	33	0
Aberdeenshire	27	85	7	7
Angus	4	50	25	25
Argyll & Bute	59	63	27	10
Clackmannanshire	7	0	71	29
Dumfries & Galloway	33	73	18	9
Dundee City	2	0	100	0
East Ayrshire	30	10	87	3
East Dunbartonshire	4	0	75	25
East Lothian	5	0	80	20
Edinburgh City	2	0	0	100
Falkirk	7	0	29	71
Fife	17	18	35	47
Glasgow City	2	50	50	0
Highland	656	47	11	43
Inverclyde	8	0	100	0
Midlothian	4	50	25	25
Moray	25	40	16	44
Na h-Eileanan Siar	251	59	7	34
North Ayrshire	2	0	100	0
North Lanarkshire	26	15	81	4
Orkney Islands	11	73	0	27
Perth & Kinross	13	77	23	0
Renfrewshire	3	0	100	0
Scottish Borders	22	23	50	27
Shetland Islands	11	73	9	18
South Ayrshire	7	43	29	29
South Lanarkshire	16	44	56	0
Stirling	15	40	20	40
West Dunbartonshire	14	21	79	0
West Lothian	39	3	69	28

5.3.5 Burnt area size

Most wildfires in all LAs were small fires with burnt areas of less than 100 m^2, except for Na h-Eileanan Siar where bigger fires of more than 1,000 m^2 were the most frequent (39%) (Table 5.40). A significant proportion of bigger wildfires (35%) was also recorded in the Highland area. The greater numbers of small wildfires occurred in Renfrewshire, Falkirk, Aberdeen City, Glasgow City and Edinburgh City areas, where they accounted for more than 84% of all recorded wildfires. On the other hand, fewer small wildfires occurred in the Na h-Eileanan Siar, Highland and Argyll and Bute areas, where they accounted for 35%, 44% and 54% of all wildfires, respectively. Again, this finding is consistent with the previous analysis (Section 5.2.5) which showed that small fires are more likely to occur in easily accessible urban areas, while bigger fires tend to occur in more remote and less accessible areas.

Table 5.40 Total count of IRS wildfires and proportions (in %) of recorded Damage Area (DA) group: None; 0-100 m^2; 100-1,000 m^2 and >1,000 m^2 per Local Authority (LA).

LA	Sum	None	DA0_100	DA100_1000	DA>1000
Aberdeen City	125	4	85	9	2
Aberdeenshire	281	7	71	13	10
Angus	54	17	65	11	7
Argyll & Bute	355	7	54	23	17
Clackmannanshire	79	4	71	16	9
Dumfries & Galloway	177	6	57	19	19
Dundee City	150	5	81	13	1
East Ayrshire	609	9	69	17	5
East Dunbartonshire	81	4	83	9	5
East Lothian	154	5	81	11	3
East Renfrewshire	35	0	80	20	0
Edinburgh City	200	4	84	12	1
Falkirk	357	3	87	8	2
Fife	414	3	81	12	4
Glasgow City	198	9	84	7	1
Highland	1852	3	44	17	35
Inverclyde	245	2	75	20	3
Midlothian	202	13	77	8	2
Moray	323	2	78	12	8
Na h-Eileanan Siar	644	3	35	22	39
North Ayrshire	187	10	80	9	1
North Lanarkshire	690	5	79	13	4
Orkney Islands	101	10	65	14	11
Perth & Kinross	182	3	75	14	7
Renfrewshire	195	3	89	7	2
Scottish Borders	257	7	72	12	9
Shetland Islands	83	10	64	13	13
South Ayrshire	87	11	75	6	8
South Lanarkshire	368	7	77	12	4

Stirling	211	3	68	22	7
West Dunbartonshire	145	1	70	20	10
West Lothian	684	2	76	16	6

5.4 Local Authority Cluster Groups

5.4.1 Cluster analysis

As mentioned in Section 5.1, we used hierarchical cluster analysis to group Local Authorities (LAs) based on similarities of their wildfire characteristics, aiming to facilitate an easier comparison and understanding of wildfire occurrence patterns in different LAs. For this purpose, we compiled a dataset of wildfire characteristics recorded in the IRS for all identified wildfires occurring in each of the 32 LAs that consisted of the following values:

- Proportions (in %) of wildfires belonging to main Level 3 Property Types: grasslands, heathlands, refuse, scrub land, broadleaves, and conifers.
- Proportions (in %) of wildfires occurring in winter (December, January, February), spring (March, April, May), summer (June, July, August) and autumn (September, October, November) seasons.
- Proportions (%) of wildfires with burnt area estimates for Outdoor Damage Area classes of 0-100 m^2; 100-1,000 m^2 and more than 1,000 m^2.
- Proportions (in %) of wildfires with an accidental or a deliberate ignition motive.

We calculated and used proportions because cluster analysis requires using numeric variables. We used Ward's method of hierarchical cluster analysis implemented in the R statistical software using the dataset with all wildfire characteristics (Clusters A) and without the proportions of ignition motive (Clusters B); this was done in consultation with the SFRS aiming to assess the effect that motive of ignition, which is prone to a certain degree of subjectivity because of personal beliefs or experience, has on the groupings of LAs.

Figure 5.13 shows the result of the cluster analysis in the form of two dendrograms based on similarity distance between LAs. The analysis using the dataset with all wildfire characteristics produced two main cluster groupings (Figure 5.13a): the smaller Cluster group A2 consisting of six (6) LAs and the bigger Cluster that was divided into Cluster sub-groups A1 and A3, consisting of nineteen (19) and seven (7) LAs, respectively. Regarding the number of wildfires within Cluster groups, Cluster groups A1, A2 and A3 contained 4,441, 3,212 and 2,072 wildfires, respectively.

Removing the motive of ignition from the analysis resulted in two main cluster groupings that each was split into two sub-groups (Figure 5.13b): Cluster sub-groups B1 and B3, consisting of eleven (11) and seven (7) LAs, respectively, and Cluster sub-groups B2 and B4, consisting of twelve (12) and two (2) LAs, respectively. Cluster groups B1, B2, B3 and B4 contained 2,434, 3,578, 1,217 and 2,496, respectively.

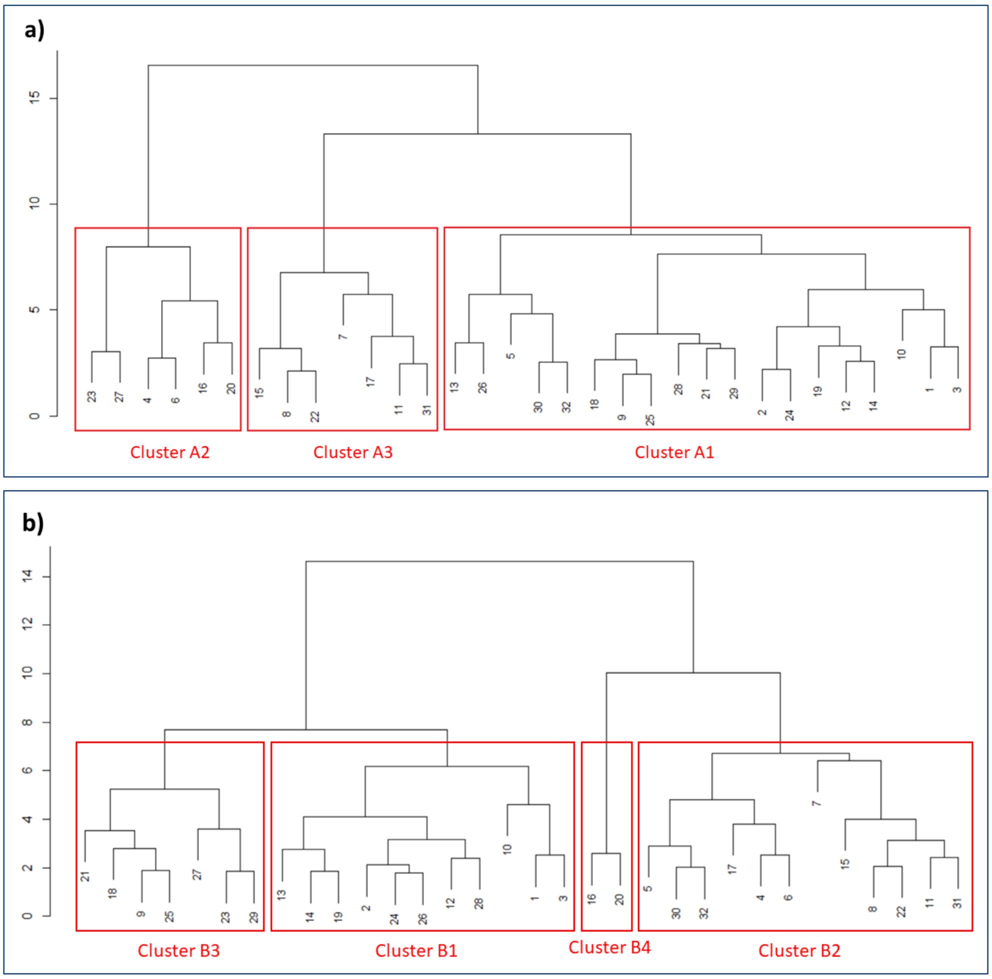


Figure 5.13 Dendrogram showing groupings from a) Clusters A and b) Clusters B. Numbers correspond to the ID column in Table 5.41.

Table 5.41 Cluster groupings of each Local Authority (LA).

ID	LA	Clusters A	Clusters B	ID	LA	Clusters A	Clusters B
1	Aberdeen City	1	1	17	Inverclyde	3	2
2	Aberdeenshire	1	1	18	Midlothian	1	3
3	Angus	1	1	19	Moray	1	1
4	Argyll & Bute	2	2	20	Na h-Eileanan Siar	2	4
5	Clackmannanshire	1	2	21	North Ayrshire	1	3
6	Dumfries & Galloway	2	2	22	North Lanarkshire	3	2
7	Dundee City	3	2	23	Orkney Islands	2	3
8	East Ayrshire	3	2	24	Perth & Kinross	1	1
9	East Dunbartonshire	1	3	25	Renfrewshire	1	3
10	East Lothian	1	1	26	Scottish Borders	1	1
11	East Renfrewshire	3	2	27	Shetland Islands	2	3
12	Edinburgh City	1	1	28	South Ayrshire	1	1
13	Falkirk	1	1	29	South Lanarkshire	1	3
14	Fife	1	1	30	Stirling	1	2
15	Glasgow City	3	2	31	West Dunbartonshire	3	2
16	Highland	2	4	32	West Lothian	1	2

Looking at Table 5.41 and Figure 5.14, it becomes evident that Cluster group A2 consists of the LAs that include more remote rural areas, while Cluster groups A1 and A3 consist of LAs where most urban and accessible rural areas are found. Similarly, Cluster groups B2 and B4 consist of the LAs with more rural areas and Cluster groups B1 and B3 consist of LAs with more urban and accessible rural areas. The main difference between Cluster A and B groups is that the Highland and Na h-Eileanan Siar LAs form a separate group (Cluster B4) consisting of bigger wildfires on bogs and shrublands, while those two (2) LAs are included in the Cluster A2 group. There are also differences in cluster groupings in the more urban areas in the Central Belt, while there are similarities in groupings in the eastern parts of Scotland.

To understand differences in wildfire occurrence patterns within the identified cluster groups, we conducted the same analysis as in Sections 5.2 and 5.3 looking at patterns of seasonality, fuel type, motives of ignition, burnt area sizes along with accessibility aspects based on the Urban-Rural classification.

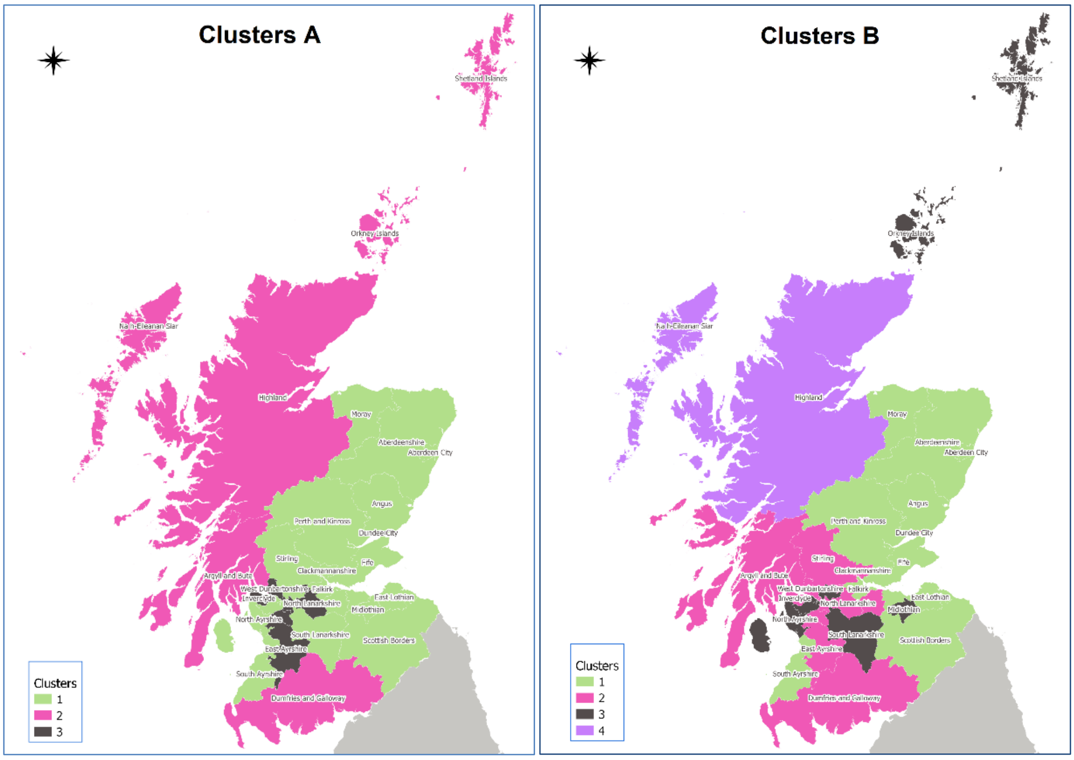


Figure 5.14 Local Authorities mapped per cluster groups

5.4.2 Temporal – Seasonality

Figure 5.15 shows overall limited inter-annual variability with regards to the relative proportions of wildfire incidents belonging to the different cluster groups. There seem to be fewer than average Cluster group A2 and B4 wildfires between 2015 to 2017 proportionally to Cluster groups A1 and A3 and B1, B2, B3 wildfires, respectively. This indicated that fewer than expected remote wildfires were recorded for these years.

Figure 5.15 Yearly stacked proportions of IRS wildfires from 2009 to 2020 per a) Clusters A and b) Clusters B groups.

Looking at seasonality at a monthly basis, most Cluster group A3 wildfires occurred in April, and this was the same but to a lesser extent for the Cluster group A2 wildfires (Figure 5.16a). On the other hand, most wildfires in Cluster group A1 occurred almost equally in April and May. Similarly, most wildfires in Cluster groups B2 and B4 occurred in April, but there was a greater proportions of early spring wildfires (in March) than late spring wildfires (in May) in Cluster group B4 compared to group B2 (Figure 5.16b). Most wildfires in Cluster groups B1 and B3 occurred almost equally in April and May, but their combined proportion was greater in Cluster group B3 than in B1, with the latter also having the greater proportion of summer wildfires compared to the other three (3) groups.

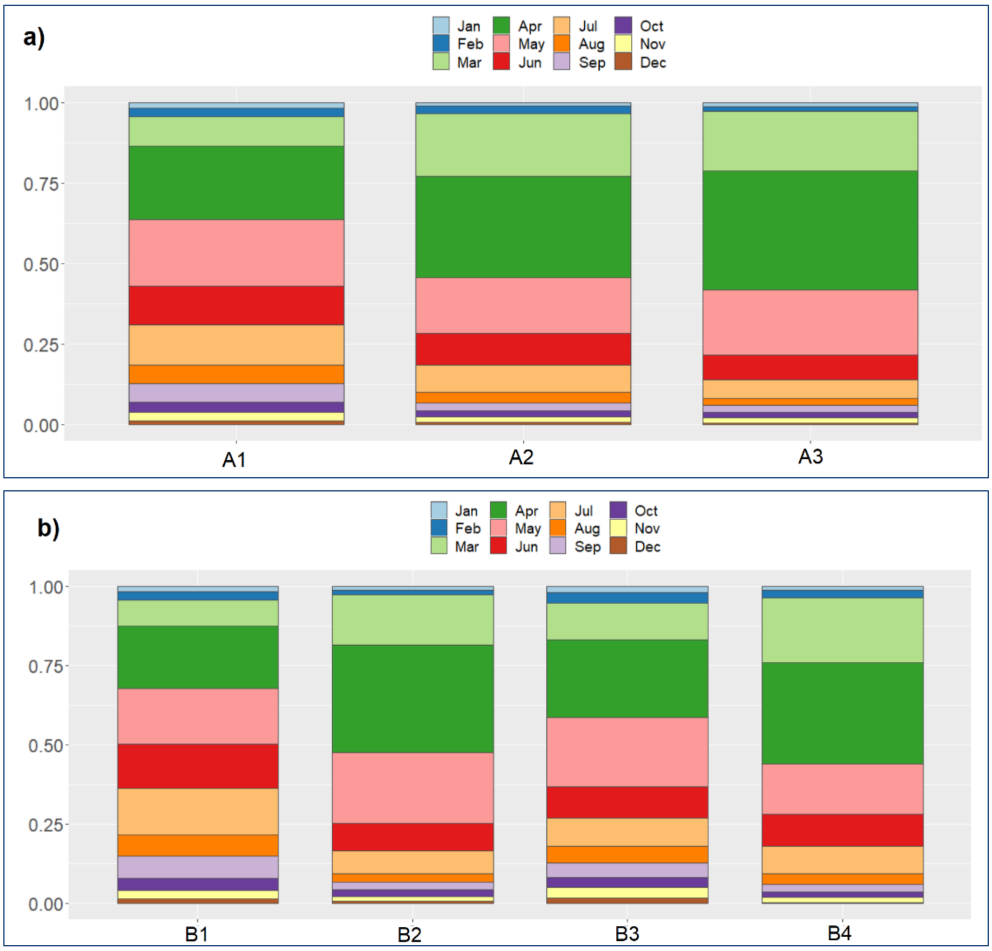


Figure 5.16 Monthly stacked proportions of IRS wildfires for the 2009-2020 period per a) Clusters A and b) Clusters B groups.

5.4.3 Fuel type

Figure 5.17 shows clear patterns related to fuel type composition between cluster groups. Cluster group A2 includes a greater number of wildfires on shrub and on bogs and peatlands compared to Cluster groups A1 and A3 (Figure 5.17a). This was expected since Cluster group A2 includes LAs with a more remote and rural character. Based on Broad Habitats (BH) classified from both IRS Level 3 Property Types and LCS88 classes, Cluster group A3 is dominated by grassland wildfires and has the greater proportion of wildfires on built-up areas. Grassland fires are also frequent within Cluster group A1, but this group also has the greater proportion of woodland fires (mainly for mixed woodlands and conifer forests) and of fires on arable land (Figure 5.17b).

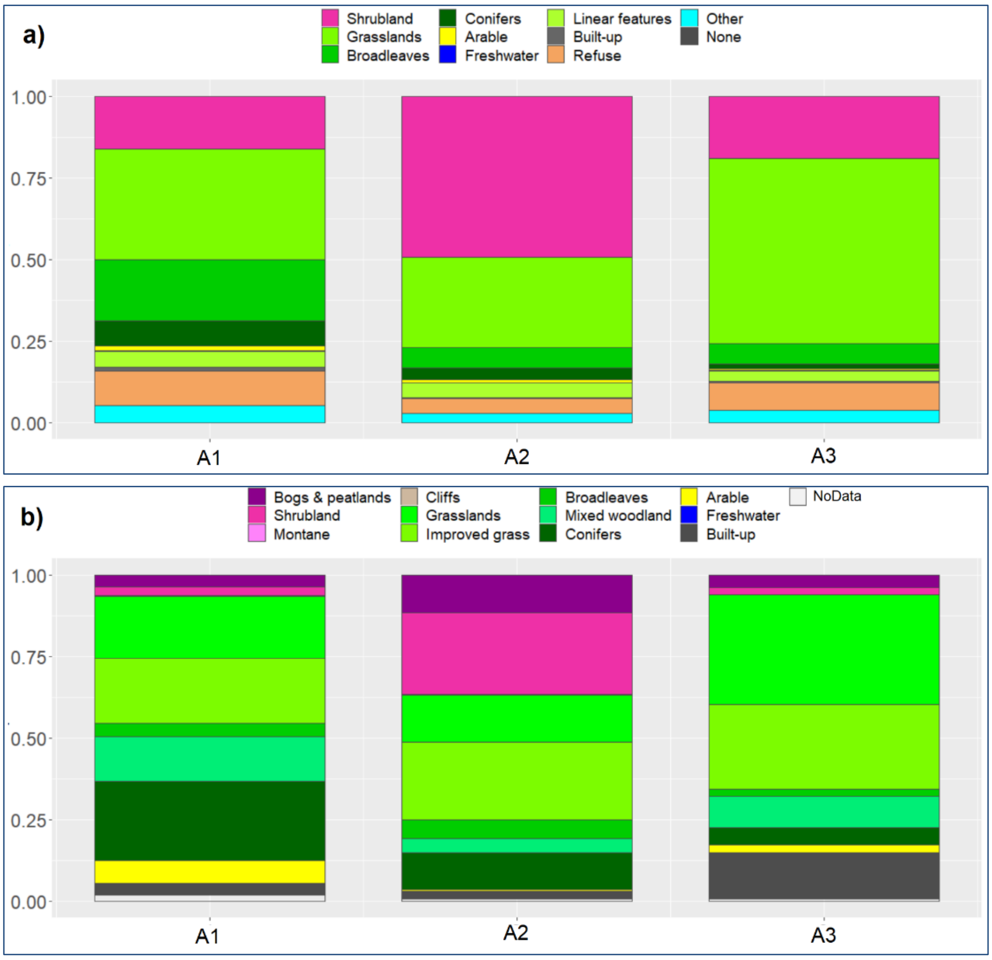


Figure 5.17 Stacked proportions per Clusters A groups of IRS wildfire Broad Habitat (BH) types classified from a) Level 3 Property Types and b) LCS88 classes.

Similar patterns of fuel type composition emerge for the Cluster B groups (Figure 5.18). More than half of wildfires included in Cluster group B4 were on shrub using BHs based on Level 3 Property types, while wildfires on bogs and peatlands and on shrubland were the dominant in group B4 based on LCS88 classes. This was expected based on information given in Tables 5.36 and 5.37 for the Highland and Na h-Eileanan Siar areas. Based on BHs classified from both IRS Level 3 Property Types and LCS88 classes, Cluster group B2 is dominated by grassland wildfires and has the greater proportion of wildfires on built-up areas. Grassland fires are also frequent within Cluster group B1, but this group also has the greater proportion of woodland fires (mainly for conifer forests), while Cluster group B3 had the greater proportion of wildfires on improved grassland and on mixed woodland (Figure 5.18b).

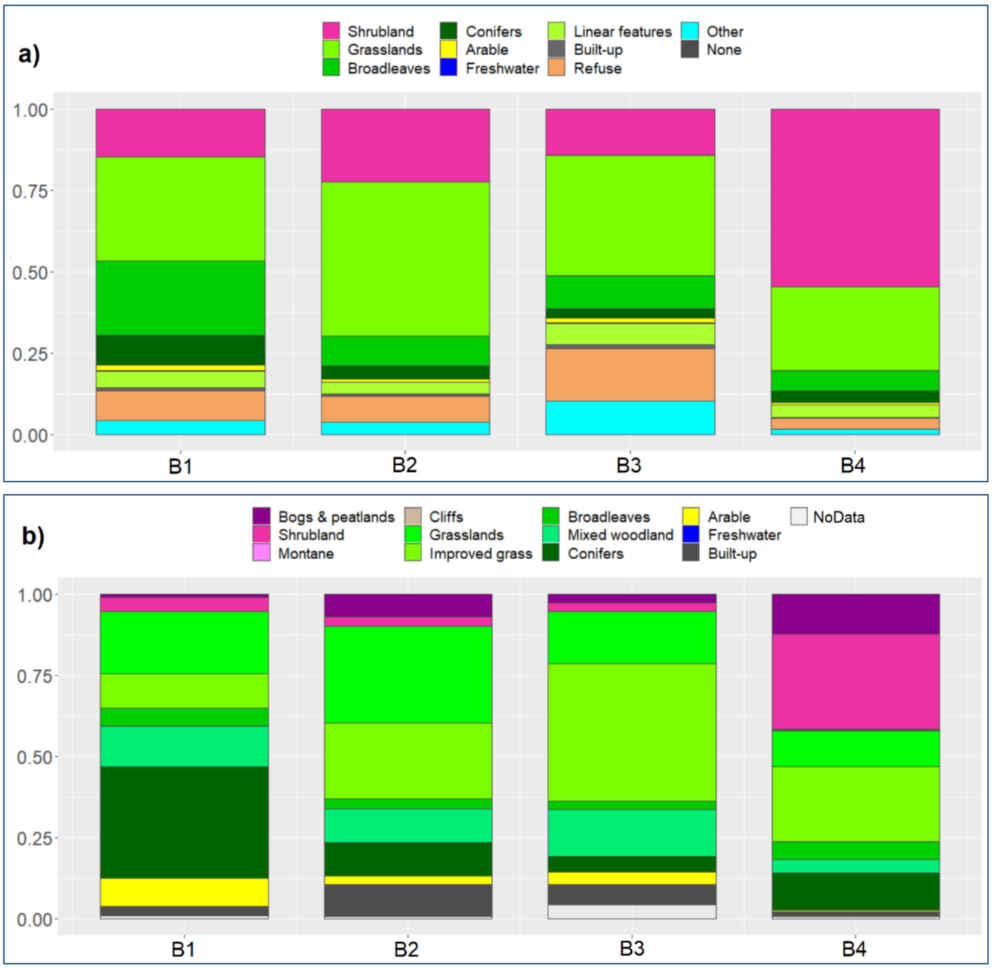


Figure 5.18 Stacked proportions per Clusters B groups of IRS wildfire Broad Habitat (BH) types classified from a) Level 3 Property Types and b) LCS88 classes.

5.4.4 Ignition motives

Figure 5.19a shows that one of the main parameters causing the split between Cluster (sub) groups A1 and A3 is the motive of ignition. While both Cluster groups A1 and A3 consist of wildfires in more urban or accessible rural areas, Cluster group A3 consists almost exclusively of wildfires caused by deliberate ignitions, compared to Cluster group A2, where deliberate wildfires are also the most frequent ones but there are also important proportions of wildfires with an accidental or unknown motive of ignition. On the other hand, accidental ignitions followed by unknown ignitions were the most frequent motives for the wildfires belonging to Cluster group A2.

Ignition motive was not used in the analysis for Cluster B groups. As expected, accidental wildfires were the dominant ones in Cluster group B4 (Highland and Na h-Eileanan Siar areas), which also had the smaller proportion of wildfires caused by deliberate ignitions between the different cluster groups (Figure 5.19b). Cluster group B1 had the second greater proportion of accidental wildfires, but deliberate ignitions were the most frequent in this group and in Cluster groups B2 and B3, both of which had similar proportion of wildfires with accidental, deliberate and unknown motives.

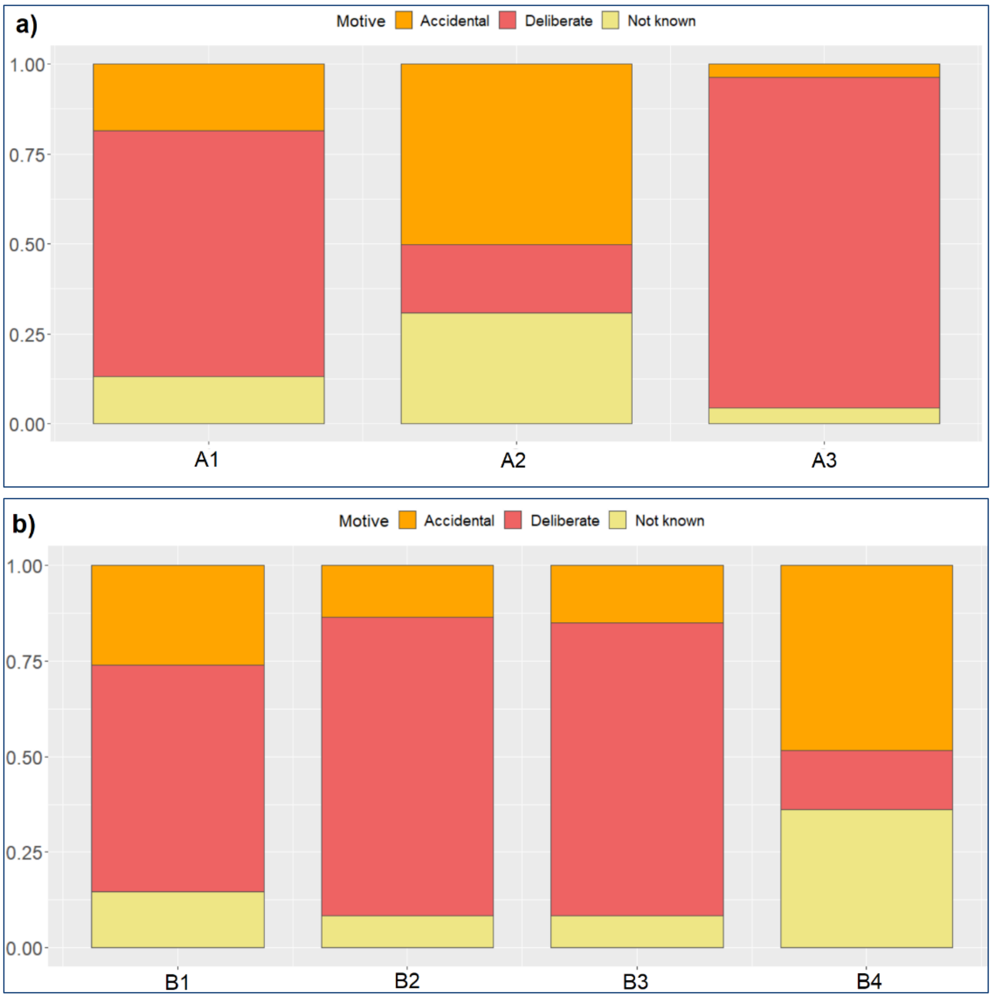


Figure 5.19 Stacked proportions of recorded motive for IRS wildfires per a) Clusters A and b) Clusters B groups.

5.4.5 Burnt area size

Figure 5.20a shows that most of the smaller wildfires with estimated burnt areas less than 100 m^2 are found in Cluster groups A1 and A3, while the bigger wildfires with burnt areas between 100 m^2 and 1,000 m^2 and more than 1,000 m^2 are more frequent in Cluster group A2. Looking at Cluster B groups (Figure 5.20b), most of the bigger wildfires (>1,000 m^2) are found in Cluster group B4, while Cluster groups B2 and B4 have almost equal proportions of wildfires with burnt areas between 100 m^2 and 1,000 m^2. Cluster groups B1 and B3 have similar proportions of wildfires falling in the different damage area classes.

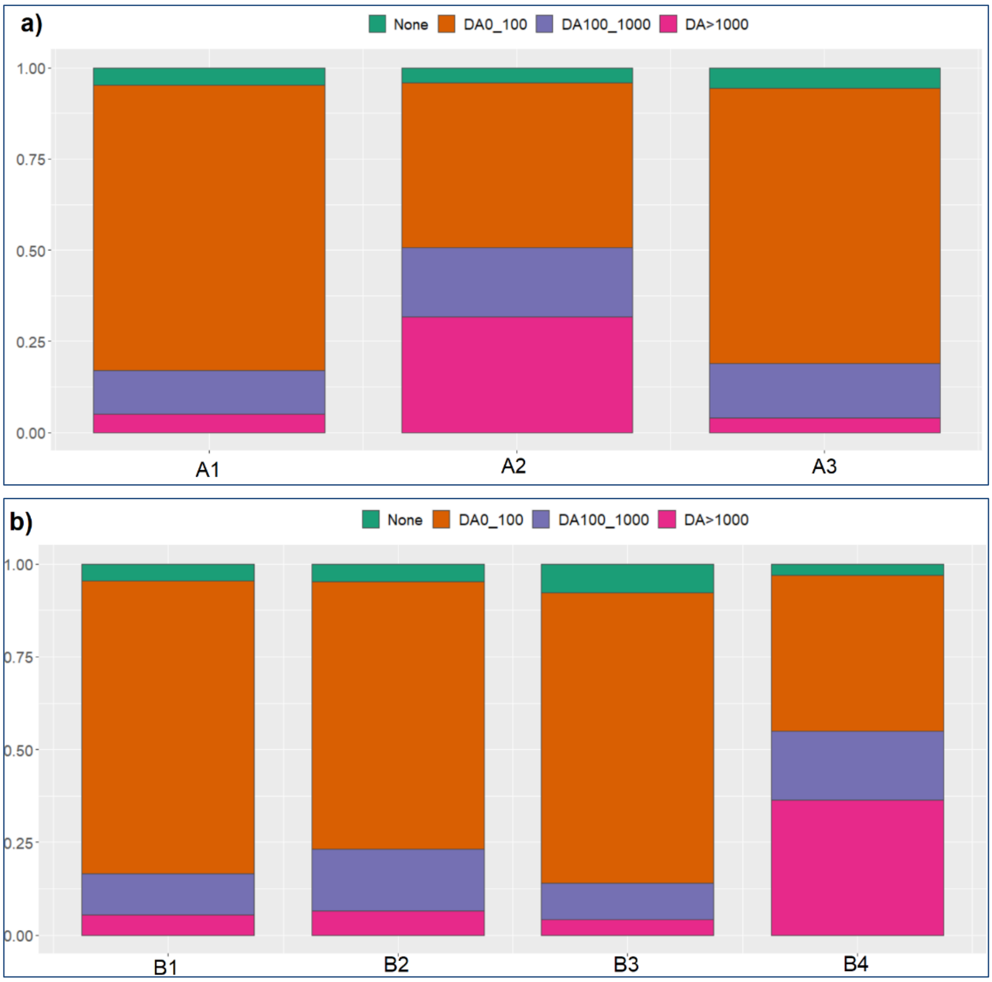


Figure 5.20 Stacked proportions of IRS wildfire recorded Damage Area (DA) group: None; 0-100 m^2; 100-1,000 m^2 and >1,000 m^2 per a) Clusters A and b) Clusters B groups.

5.4.6 Urban – Rural Classification

Based on Figure 5.21a, most wildfires in Cluster group A2 occurred in very remote areas (66%), while an almost equal number of wildfires occurred in remote and accessible rural areas (around 16% of all wildfires for both areas). Cluster groups A1 and A3 showed similar patterns with regards to the number of wildfires within the different folds of the Urban Rural classification. This was expected because wildfires belonging to both clusters occurred mostly within accessible rural areas; the difference being that these wildfires were slightly more frequent in Cluster group A1 than in group A3 (82% compared to 69%). On the other hand, around 10% of wildfires in Cluster group A3 occurred in urban areas, which was the greatest proportion between the three Cluster A groups.

Regarding Cluster B groups (Figure 5.21b), most wildfires in Cluster group B4 occurred in very remote areas (67%), while, as in the case of Cluster group A2, an almost equal number of wildfires occurred in remote and accessible rural areas (around 16% of all wildfires for both areas). Cluster groups B1 and B3 had similar proportions of wildfires in accessible rural areas (78% and 74%, respectively), but a greater proportion of wildfires in very remote areas was found in Cluster group B3 than in group B1 (14% compared to 3%) and a greater proportion of wildfires in remote areas occurred in Cluster group B1 than in group B3 (13% compared to 3%). Cluster group B2 shows a pattern that is intermediate to Clusters groups B1 and B3 and Cluster group B4, with 67% of wildfires in this group occurring in accessible rural areas, 16% of wildfires occurring in remote areas and 8% of wildfires occurring in very remote areas.

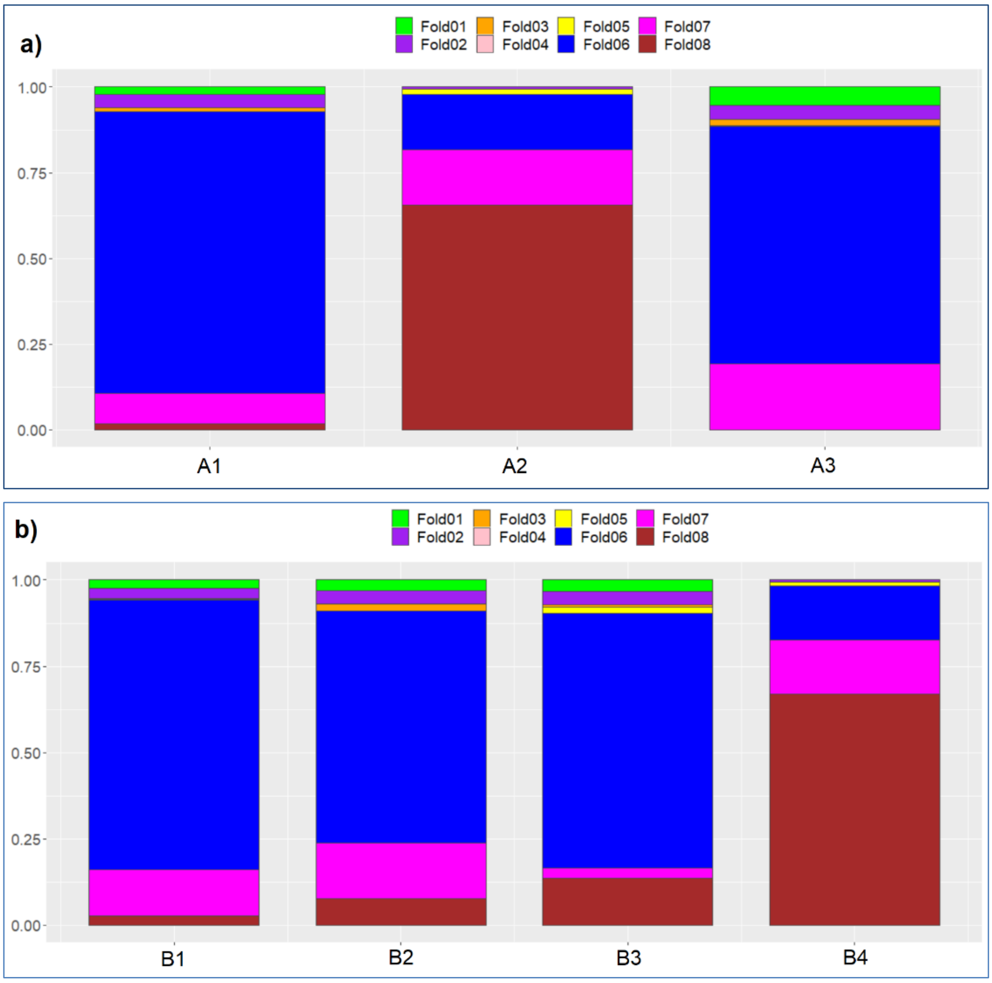


Figure 5.21 Stacked proportions of IRS wildfire 8-fold Urban Rural (UR) classification system per a) Clusters A and b) Clusters B groups.

5.4.7 Conclusions

The results of the cluster analysis revealed clear groupings of LAs that were based on similarities regarding wildfire occurrence patterns and characteristics:

- LAs where bigger wildfires, in terms of larger burnt area sizes, caused by accidental ignitions are more frequent and more likely to occur that mainly affect remote seminatural habitats (i.e., bogs and peatland and heathlands/shrubland) (Cluster group A2). When motive of ignition is ignored, then the bigger and very remote wildfires affecting bogs and peatlands and heathlands are mainly found in Cluster group B4 (Highland and Na h-Eileanan Siar areas), while other wildfires mainly on shrubs and seminatural grasslands in accessible and remote rural areas are found in Cluster group B2, which consists of LAs located in the central and south-western parts of Scotland.

- LAs where small or smaller wildfires, mainly on grassland and in proximity of urban areas or in relatively accessible rural areas, are more frequent and that are caused by either a mix of ignition motives (Cluster group A1) or predominantly by deliberate ignitions (Cluster group A3). Again, when motive is removed from the analysis, LAs with smaller wildfires in relatively accessible rural areas and located at central and eastern Scotland are split mainly based on fuel type composition between those where woodland fires are dominant (Cluster group B1) and those where fires on (mainly improved) grassland are dominant (Cluster group B3).

We need to stress that since this is a data-driven approach, its outcomes depend purely on the variables used to conduct the analysis. For example, splitting between Cluster groups A1 and A3 seemed to be greatly influenced by the motive of ignition, while removing this variable changed the outcome of the analysis to a certain degree and resulted in different cluster groupings. However, this approach provides an objective way to identify LAs with similarities in their wildfire occurrence patterns, which could be useful for making decisions about prioritising areas of certain wildfire patterns or characteristics to improve preparedness or enhancing the wildfire suppression capability of certain regional SFRS regional stations.

6 Comparison with datasets of burnt areas

6.1 Datasets and methods

As mentioned in Section 4.1, visual inspection of wildfires locations and findings from previous studies (Davies and Legg, 2016) have shown that it is unclear whether the location recorded in the IRS is where the fire was reported or where fire-fighting resources were marshalled instead of from the core or ignition point of the fire itself. In addition, our analysis showed extensive differences or disparities between recorded fuel type information from IRS Property Types and fuel types extracted from land use maps at wildfire locations. Moreover, while all wildfires have records of an estimated burnt area class (in m^2) a limited number exists of wildfires where the burnt/damage area is also recorded in numeric terms (in ha); hence it is unclear how well the categorical and numeric estimates of burnt areas compare to each other and which of the two is closer to the actual burnt area.

For this purpose, in this section we provide a quantitative assessment of a) how close the recorded wildfire locations are to the actual burnt areas; b) how representative the recorded vegetation/habitats are of the main fuel types burnt and c) how close is the damage/burnt area reported in the IRS to the actual burnt area by respective fire incidents.

We used polygons of burnt areas in Scotland delineated from satellite imagery analysis to conduct the assessment. We obtained access to the following spatial datasets:

- Burnt area polygons (*n*=23) generated by NatureScot using Sentinel-2 multispectral satellite imagery (SNH, 2019) for wildfires that have occurred in 2018, 2019 and 2020.
- Burnt area polygons (*n*=101) generated by the European Forest Fire Information System (EFFIS; https://effis.jrc.ec.europa.eu/) using MODIS satellite imagery (areas >30ha) for the 2014-2020 period. Polygons from 2014 to 2019 have been previously obtained for the Scottish Fire Danger Rating System (SFDRS) project and were re-used in this project after gaining permission from EFFIS.

Both datasets were in ESRI shapefile format. Each burnt area polygon contained information about the location of the fire, date the fire occurred and/or detected and the size of the burnt area. Both polygon datasets were loaded into QGIS along with the locations the IRS wildfire incidents. There were a few overlapping burnt area polygons between the two datasets; when this was detected, we removed the EFFIS ones because the NatureScot dataset is of better spatial accuracy. We used a time window of ± 10 days around the IRS wildfire date and used these dates to associate individual IRS wildfire incidents with burnt area polygons. We then selected the wildfire incidents that were closer to the burnt area polygons via visual inspection of the satellite imagery and added the burnt polygon IDs to the attributes of associated wildfire incidents. This process showed that in cases of bigger fires, more than one wildfire incident was associated with a burnt area polygon, often with them having different dates.

We delineated additional burnt areas (*n*=23) to increase the number of wildfires analysed by mapping the burnt area of associated IRS wildfire incidents following a similar approach used by NatureScot. We chose to delineate new burnt areas that corresponded to wildfire incidents within the Highland LA because these were the wildfires more likely to be bigger, and hence easier to detect from satellite imagery, and were also more likely to have a significant impact on seminatural vegetation. In brief, new burnt areas were digitised using the following steps:

- We initially identified 88 IRS wildfire incidents (different to the ones corresponding to the NatureScot and EFFIS burnt area polygons) with good spatial coverage of the Highland LA that were likely to be big fires on peatland and shrubland, using fuel type information and burnt area estimates.
- We used the locations and recorded dates of the selected wildfire incidents to check whether relatively cloud-free Sentinel-2 satellite images were available from Sentinel Hub Playground (Access: https://apps.sentinel-hub.com/sentinel-playground) for the dates prior and after the wildfire incidents and visually inspected the available images in colour infrared (combination of bands 8, 4 and 3) to detect scars of burnt areas.
- We downloaded individual extracts of Sentinel-2 images from Sentinel Hub Playground in infrared band combination as jpegs, loaded them in QGIS and georeferenced them in OS British Grid using easily-identified control points. We then overlaid the wildfire incident locations and visually detected burnt areas that were in proximity to them, which were then digitised to create polygons of burnt areas (in ESRI shapefile format) (see Figure 6.1).
- We added the following information in the polygon attribute table: Incident Id of the corresponding wildfire incident; Unique polygon ID; Date of satellite imagery; and calculated burnt area (in ha). When more than one wildfire corresponded to the burnt area polygon, we added the Incident Id of the fire incident that was closest to the burnt area perimeter.
- Due to high cloud coverage, it was not always feasible to detect burnt areas corresponding to selected wildfires.

A total of 125 unique wildfire incidents were included in the analysis that corresponded to 71 burnt area polygons (16 from NatureScot, 38 from EFFIS and 17 delineated by us). This number of fire incidents was lower than anticipated considering the number of available polygons, but we found little correspondence mainly between wildfire incidents and the EFFIS burnt areas. The locations of the selected burnt areas are shown in Figure 6.2.

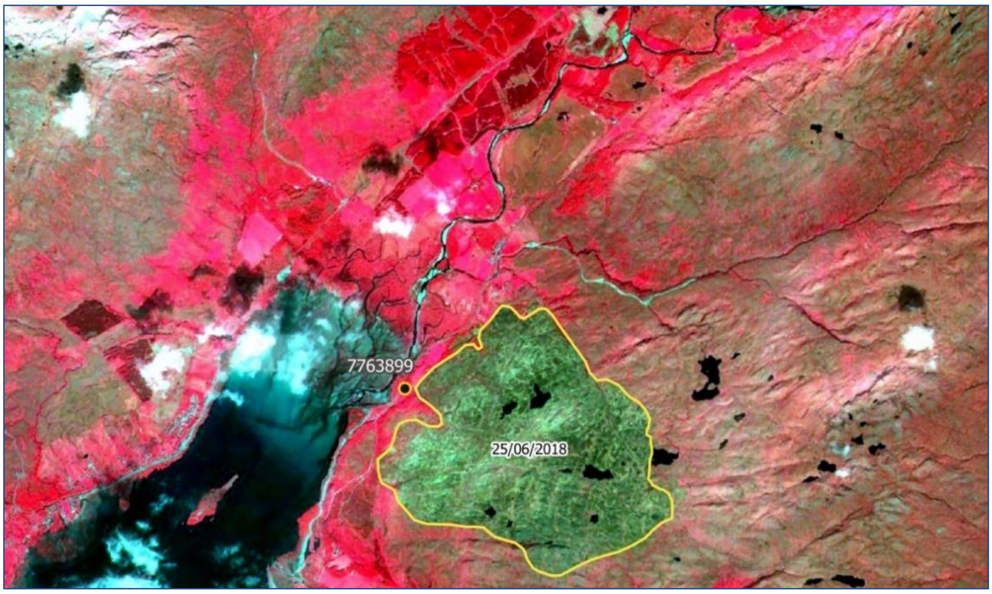


Figure 6.1 Delineated burnt area using Sentinel-2 imagery (colour infrared) close to Strathcarron, Highland LA. Black dot is the location of recorded IRS wildfire corresponding to the burnt area polygon, dot label gives the Incident ID and polygon label gives the date the satellite imagery was taken.

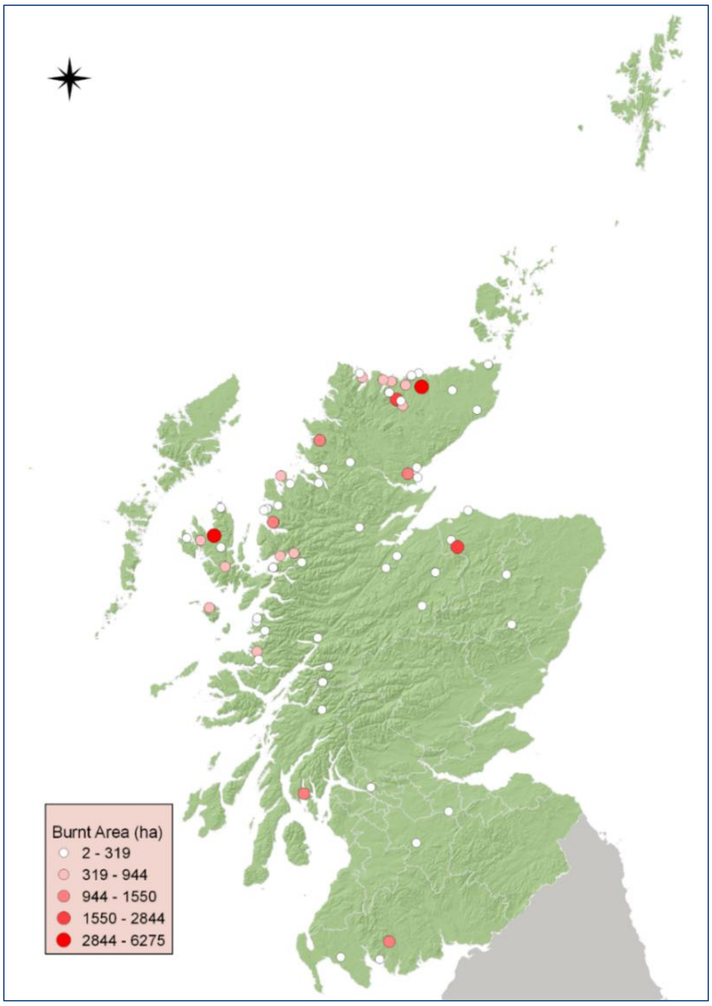


Figure 6.2 Distribution of burnt area polygons mapped using calculated burnt area size. White lines indicate local authority boundaries.

6.2 Distances to burnt area polygons

Table 6.1 shows the number of wildfire incidents within respective Local Authorities (LAs) and their nearest distances from the locations of wildfire incidents to the perimeters of the corresponding burnt area polygons, calculated using the Distance to Nearest Hub tool in QGIS. 104 of the 125 wildfires included in this analysis occurred within the Highland LA, while another ten (10) wildfires occurred in the Moray LA and just one (1) to three (3) wildfires occurred in the remaining LAs. Hence, we can be confident about the findings of this analysis only for those wildfires within the Highland LA. Median nearest distance to burnt area polygons for wildfires that occurred in the Highland LA was 260 m. There were 27 and 79 Highland wildfire incidents that were located less than 100m and 1,000m to the perimeter of their corresponding burnt areas, respectively, while there were 11 wildfire incidents located at distances more than 2km but only one at a distance more than 4km. Nearest distances to corresponding polygons were relatively small for the remaining wildfire incidents, with median distances ranging from just 4m to 389m, apart from the two wildfires in the Argyll and Bute LA that had a median distance of 1,741m.

Table 6.1 Counts of wildfire incidents per Local Authority (LA) and minimum, median, mean and maximum nearest distances (in metres) between polygons and corresponding IRS wildfires.

LA	Count	Minimum	Median	Mean	Maximum
Aberdeenshire	2	0	38	38	76
Argyll & Bute	2	239	1,741	1,741	3,244
Dumfries & Galloway	3	0	4	583	1,736
Highland	104	0	260	680	4,719
Moray	10	20	389	534	1,214
South Lanarkshire	1	67	67	67	67
West Dunbartonshire	2	53	58	58	64
West Lothian	1	106	106	106	106

The results of this analysis suggest that the location of wildfire incidents recorded in the IRS is relatively close to the actual corresponding burnt areas, at least for the wildfires occurring in the Highland LA, despite these wildfires generally occurring in very remote areas of low accessibility. However, these fires tend to be bigger, hence it is more likely for the recorded location to be closer to the fire perimeter. In fact, most of the wildfire incidents in the Highland LA (n=72) corresponded to burnt area sizes above 100 ha, while 39 and 14 wildfire incidents corresponded to burnt area sizes above 500 and 1,000 ha, respectively.

6.3 Land cover/fuel type

We intersected the burnt area polygons with the available land use and fuel type maps (EUNIS, LCS88, LCM15 and EFFIS FT) within QGIS and calculated the proportions of areal covers of each respective Broad Habitat (BH), along with the dominant (in terms of overall coverage) BH for each burnt area polygon. Overall, heathlands and shrub were the most frequent fuel type, followed by bogs and peatland. For example, based on the LCS88 classes 78 wildfires were on shrub and 38 on bogs and peatlands, whilst there were also eight (8) grassland fires and four (4) fires on conifer forest. Looking at the BHs of the associated wildfire incidents (classified from Level 3 Property Types), there were 103 wildfires on shrubland, 10 grassland fires and 8 fires on conifer forest.

The dominant BHs of the burnt area polygons were compared to BHs classified from IRS Level 3 Property Types for the associated wildfire incidents, excluding those wildfires that were classified as bogs and peatlands since the IRS property types do not provide this distinction. The results of this comparison are given in Table 6.2 and show very good agreement for wildfires where shrubland was the dominant fuel type, especially when the LCS88 and LCM15 classes were considered (94% and 92% agreement, respectively). There was moderate agreement for conifer forest fires and for grassland fires when LCM15 and LCS88 classes were used, respectively (50% agreement for both land use maps). Overall agreement was high for both the LCS88 and LCM15 maps (82% and 81%, respectively), but this was partially due to the dominance of wildfires on shrubland in the dataset and the exclusion of wildfires on bogs and peatlands from the comparison (most of which were recorded as shrubland fires in the IRS).

Table 6.2 Agreement (%) of individual Broad Habitat (BH) classifications between BHs classified from the recorded IRS Level 3 Property Types and dominant (i.e. covering greater area) BHs of burnt area polygons using the EUNIS habitat types, Land Cover Scotland 1988 (LCS88) classes, Land Cover Map 2015 (LCM15) classes and European Fuel Types 2000 (FT2000), and overall agreement for all BHs for each dataset. Results do not include polygons with bogs and peatlands as dominant cover.

Property Type BH	EUNIS BH	LCS88 BH	LCM15 BH	EFFIS FT BH
Broadleaves	0	0	0	0
Conifers	0	20	50	25
Grasslands	40	50	43	15
Linear features	0	0	0	0
Other	0	0	0	0
Shrubland	86	94	90	84
Overall accuracy	69	82	81	70

6.4 Burnt area comparisons

We compared the calculated burnt area sizes of fire polygons with the burnt area estimates in the corresponding IRS wildfires recorded as a) damage area classes (available for all 125 wildfire incidents) and b) numeric damage area estimates in ha (available for 49 wildfire incidents).

Regarding damage area classes, the calculated burnt area of the corresponding polygons fell within the same area class for 51 wildfires, but this was not the case for 72 wildfire incidents, while there were two (2) wildfire incidents with no burnt area estimate recorded in IRS. 44 of the 51 wildfires with matching calculated and estimated burnt areas had occurred within the Highland LA.

There was a strong linear relationship between calculated burnt polygon areas and numeric damage areas for the 48 wildfires with both values available (Figure 6.3a, R^2=0.70). However, this strong relationship was mainly driven by the big fire of March 2018 in the Highlands (burnt area of 6,275 ha). Removing this wildfire from the analysis resulted in a much weaker relationship (R^2=0.26), due to large differences between calculated and estimated burnt areas for the wildfire incidents that had damage areas recorded the IRS mainly between 2 ha to 50 ha and in general less than 500 ha (Figure 6.3b).

Overall, the findings of this analysis suggest that in most cases the burnt area estimates recorded in the IRS fail to reflect accurately the extent of damage caused by the respective wildfires, while usually IRS records tend to underestimate the size of burnt areas and thus potentially underestimate the damage caused to impacted seminatural habitats (Figure 6.3).

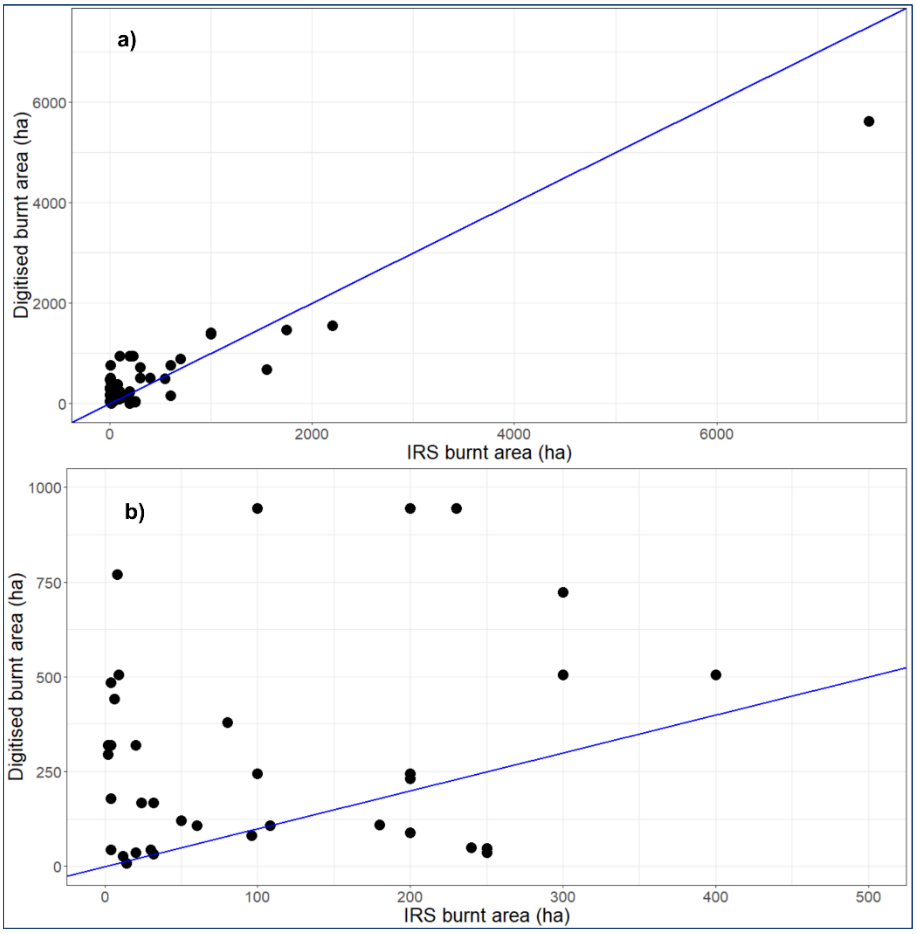


Figure 6.3 Recorded IRS wildfire burnt area (in ha) vs calculated burnt area for corresponding burnt area polygons based on a) all wildfire incidents with available information (*n=48*) and b) wildfire incidents with burnt area recorded less than 500 ha (*n=36*). Blue line represents 1:1 relationship.

7 Comparison with European wildfires

In this Section we compared wildfires that occurred in selected Northern European countries with similar bioclimatic conditions and land management practices to Scotland using available datasets of European coverage. For this reason, we obtained 733 polygons (in ESRI shapefile format) of burnt areas recorded by the European Forest Fire Information System (EFFIS; https://effis.jrc.ec.europa.eu/) from MODIS satellite imagery (areas >30ha) from 2014 to 2020 for Scotland (SCO) and the rest of the UK (England (ENG), Wales (WLS) and Northern Ireland (NIR)), the Republic of Ireland (IE), Norway (NO), Sweden (SE) and Finland (FI) (Figure 7.1).

The objective of this analysis was to investigate and compare the presence of a) seasonality; b) burnt area size; and c) fuel type patterns. Information on fire dates and size of burnt areas were available from the EFFIS burnt area polygons. Fuel type information was obtained from the EFFIS European Fuel type Map; we loaded the EFFIS burnt area polygons and the fuel type map on QGIS and calculated the areal proportions of fuel types within the burnt area perimeters along with the dominant (i.e., greater areal coverage) fuel type for each polygon.

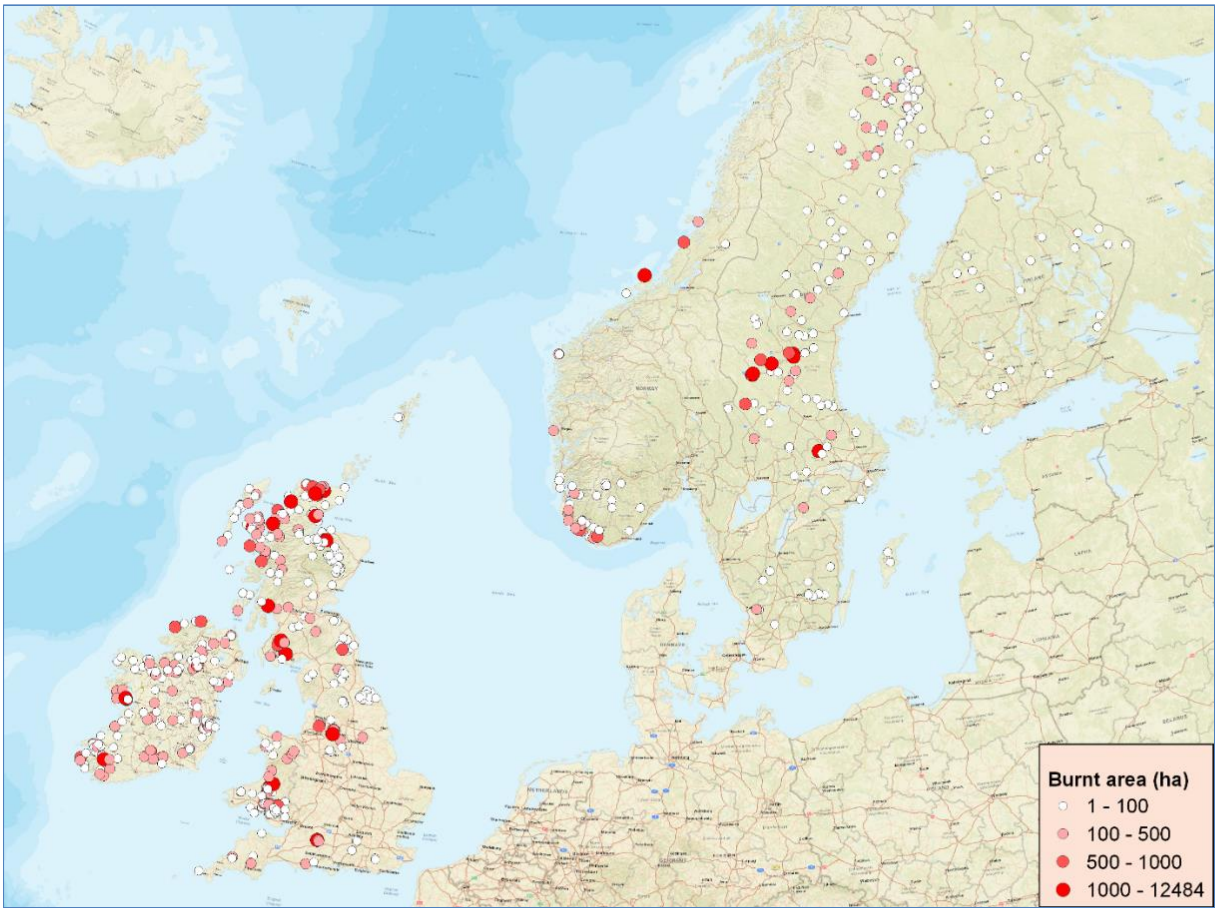


Figure 7.1 Distribution of EFFIS burnt area polygons mapped based on burnt area classes.

Most fire/burnt area polygons were located in Scotland, the Republic of Ireland and Sweden (Figure 7.2a). With regards to the monthly distribution of fires for all countries studied, most fires occurred in April (*n*=224) followed by May (*n*=120), June (*n*=99) and July (*n*=93) (Figure 7.2b).

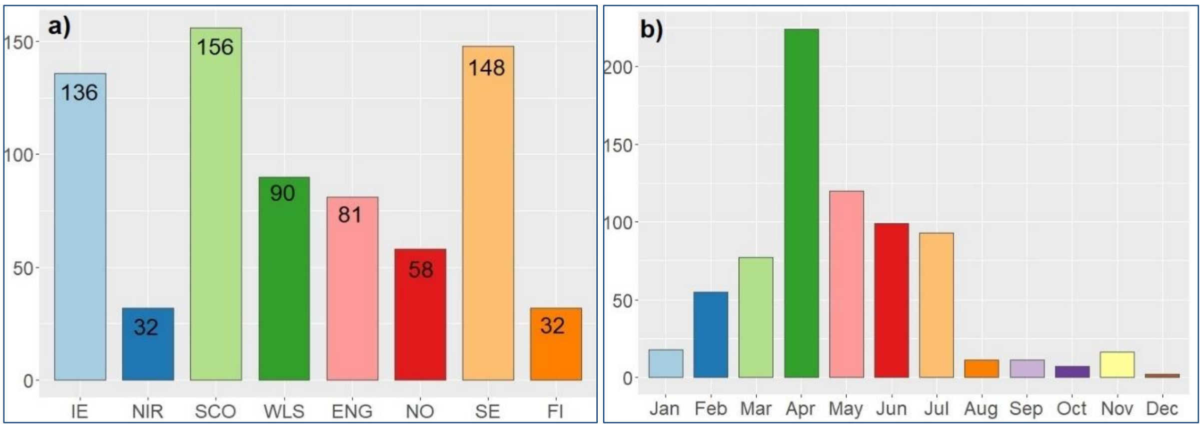


Figure 7.2 Counts of EFFIS burnt area polygons per a) studied countries; and b) month for all countries.

Fires occurring in spring (March to May) were the most frequent in Scotland, the Republic of Ireland, Wales, Northern Ireland, and Norway, while summer fires (June to August) were the most frequent in Sweden and Finland (Table 7.1). Spring fires were also dominant in England (33 out of 81 fires in total), however a relatively large proportion of the English fires occurred in January and February (22 fires). March was the month with the most recorded fires for Wales, April was for Scotland, the Republic of Ireland and Norway, May was for Northern Ireland, June for Finland, and July for Sweden.

Table 7.1 Monthly counts of EFFIS burnt area polygons for the countries included in the analysis.

Country	IE	NIR	SCO	WLS	ENG	NO	SE	FI
January	1	0	3	0	12	2	0	0
February	11	0	8	15	20	1	0	0
March	13	2	17	30	13	1	1	0
April	52	9	81	24	11	39	8	0
May	32	13	23	7	9	7	23	6
June	13	7	3	5	6	1	44	20
July	7	1	1	9	4	3	63	5
August	0	0	0	0	2	1	7	1
September	6	0	2	0	0	1	2	0
October	1	0	3	0	2	1	0	0
November	0	0	14	0	2	0	0	0
December	0	0	1	0	0	1	0	0

Median sizes of burnt areas were relatively similar for all studied countries, ranging from 18.5 ha in Finland to 79 ha in the Republic of Ireland (Table 7.2). The largest burnt area recorded in the dataset was for a summer (31/7/2014) fire in Sweden with a burnt area of

12,484 ha of mainly conifer forest, followed by a spring (13/05/2019) fire in Scotland that burned an area of 5,430 ha of mainly peatlands. There were 733 fires with burnt areas less than 100 ha, which accounted for 74% to 77% of fires in Northern Ireland, England and Sweden, for 60% to 67% of fires in Ireland, Scotland, Wales and Norway and for all fires in Finland. Regarding bigger fires, there were 25 fires with burnt areas more than 1,000 ha, most of which were found in Scotland (11 fires) and Sweden (6 fires).

Table 7.2 Minimum, median, mean and maximum recorded burnt areas (in hectares) for the countries included in the analysis.

Countries	Burnt area (ha)			
	Minimum	Median	Mean	Max
IE	4.0	79.0	177.1	3,865.0
NIR	6.0	45.5	106.8	666.0
SCO	2.0	63.5	266.8	5,430.0
WLS	5.0	70.0	161.4	1,322.0
ENG	4.0	43.0	126.7	1,478.0
NO	8.0	52.0	154.3	1,065.0
SE	1.0	37.5	255.5	12,484.0
FI	1.0	18.5	24.3	90.0

Table 7.3 gives information about fuel type composition in the studied countries. Peat bogs or shrublands were the most frequent fuel type groups in the Republic of Ireland, Scotland, Northern Ireland, and England, while pastures (grasslands) were the most frequent fuel types in Wales and Norway, and forests in Sweden and Finland. Fires on heathlands/shrublands accounted for 49% and 55% of fires that occurred in Scotland and England, respectively, while fires on peat bogs were the most frequent in the Republic of Ireland and Northern Ireland, accounting for 90% and 72% of total fires, respectively. Around 37% of Scottish fires also occurred on peat bogs, while around 35% of Norwegian fires were on shrublands.

Table 7.3 Number of EFFIS burnt area polygons with dominant covers of main fuel type groups for the countries included in the analysis.

Fuel Type Group	IE	NIR	SCO	WLS	ENG	NO	SE	FI
Peat bogs	122	23	58	0	16	1	20	6
Shrublands	3	3	76	11	45	20	0	0
Pastures	4	4	16	64	18	23	0	0
Transition	4	0	0	2	1	1	16	3
Forest	2	2	4	13	1	12	109	22
Riparian	1	0	1	0	0	0	0	0
Other	0	0	1	0	0	1	0	1
Non-fuel	0	0	0	0	0	0	3	0
Total	*136*	*32*	*156*	*90*	*81*	*58*	*148*	*32*

Figure 7.3 shows the monthly variation in fuel type composition within burnt areas polygons for individual countries. In the Republic of Ireland and Northern Ireland peat bog fires were the most frequent for all months, apart from fires in June in Northern Ireland when more pasture/grassland fires occurred than on peat bogs. In Scotland, fires on shrublands were more frequent in April than on peat bogs, while slightly more fires on peat bogs occurred in March and May than on shrublands. Almost all grassland fires in Scotland occurred in April. Grassland fires were always the most frequent in Wales, while fires on shrublands were the most frequent in England for all months, apart from April and June when grassland fires were the most frequent. There was an almost equal number of grassland and shrubland fires in April and May in Norway, while forest (mostly conifer) fires were by far the most frequent in Sweden and Finland from late spring till the end of the summer.

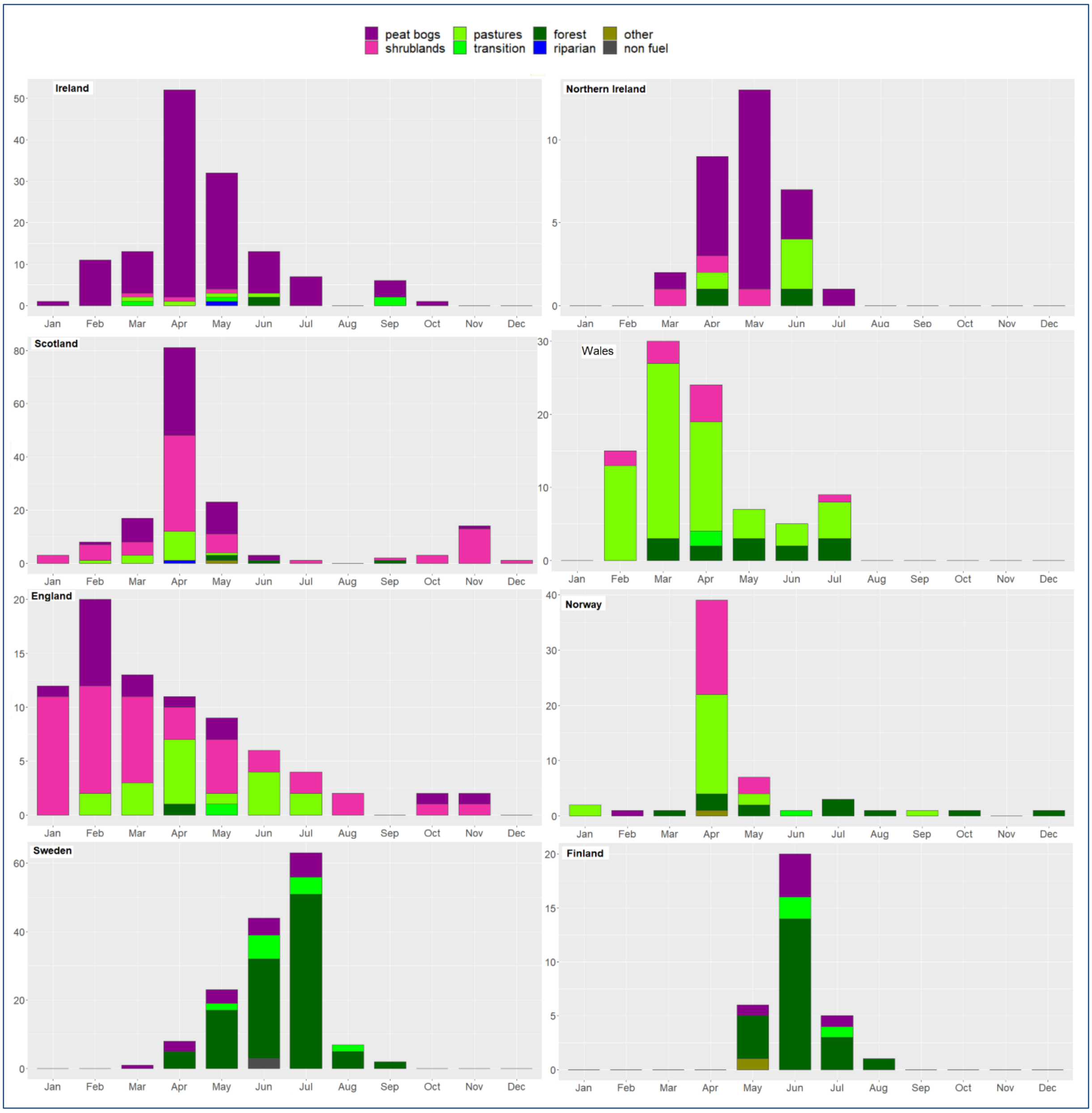


Figure 7.3 Monthly stacked counts of dominant cover fuel type groups of the EFFIS burnt polygons for the countries included in the analysis.

Results of this analysis show common seasonality patterns of fire occurrence for the Republic of Ireland, Northern Ireland, Scotland, Wales and Norway where most fires occurred in spring months, although fires in Wales seem to start earlier in late winter. Most fires in England occurred in late winter and spring, while summer forest fires are clearly the dominant wildfire type in Sweden and Finland. In terms of fuel type composition, we can identify that peat bogs and heathlands are the most frequent fuel groups for the Republic of Ireland, Northern Ireland, Scotland, England and Norway, fires on grasslands and/or shrublands are the most frequent in Wales and also in Norway, while forest fires are the most frequent in Sweden and Finland. Fires in the Republic of Ireland and the UK seem to share similar wildfire occurrence patterns due to similarities in fuel type compositions and the prevalent oceanic climatic conditions. This also seems to be the case for fires close to the west coast of Norway, where the climate is oceanic and heathlands are the predominant vegetation (Fernandez-Anez et al, 2021). On the other hand, the dominance of forest fires in Sweden and Finland can be attributed to the high forest coverage in both countries combined with the presence of more temperate climatic conditions that lead to hotter summers, at least in central and southern areas of Sweden where the biggest summer forest fires occurred (Figure 7.1).

8 Relating wildfires to explanatory variables

8.1 Exploring wildfire-variables relationships

In this Section we explored relating the spatial distribution of selected IRS wildfires to information derived from readily available spatial layers of explanatory variables of fire, with the aim to improve our understanding of causative factors of wildfire ignition. We selected the Highland Local Authority (LA) to pilot this approach because previous analysis showed that this is where most bigger wildfires affecting important seminatural habitats (peatlands and heathlands) are more likely to occur.

We selected variables that are directly related to wildfire ignition and fire behaviour, shown in Table 8.1. These included:

- Bioclimatic variables (e.g., mean annual temperature and precipitation);
- Topography (elevation and slope);
- Variables related to accessibility and population densities (e.g., distances to nearest roads, settlements, and water features, along with the Urban Rural classification);
- Fuel type information at Broad Habitat (BH) level classified from the Land Cover Scotland 1988 (LCS88) map; and
- Two (2) integrated indices of socioeconomical factors (including employment, health, education, crime, and housing): the Rural Socio-economic performance index (SEP, Copus and Hopkins, 2015), which is a multivariate index devised to improve understanding of contemporary geographical variation in socio-economic characteristics in rural areas; and the Scottish Index of Multiple Deprivation (SIMD) 2020, which is the Scottish Government's official tool for identifying concentrations of deprivation in Scotland. Both datasets are available as maps at a Data Zone level. We used the actual numeric SEP index values for each Data Zone and the quantiles of SIMD that provide a measure of relative deprivation at Data Zone level.

Table 8.1 Description of selected variables.

Code	Description	Type	Source	Processing	Reference
Bio1	Annual mean temperature (°C)	Continuous	WorldClim v.2 (1970-2000) 1km grid resolution	Downscaled to 250m (bilinear transformation)	Fick and Hijmans (2017)
Bio4	Temperature Seasonality (standard deviation ×100)	Continuous			
Bio12	Annual precipitation (mm)	Continuous			
Bio15	Precipitation Seasonality (Coefficient of Variation)	Continuous			

Code	Description	Type	Source	Processing	Reference
Elev	Elevation above sea level in metres	Continuous	Ordnance Survey digital elevation model at 50m grid resolution (OS DTM 50)	Reclassified (by mean) to 250m grid resolution	OS Open Data
Slope	Slope (degrees)	Continuous		Derived from DTM 100m grid resolution	Zevenbergen and Thorne (1987)
DistRoad	Distance to nearest road	Continuous	OS Open Roads network	Calculated using the Distance to nearest hub tool in QGIS 3.12	OS Open Data
DistSettl	Distance to nearest settlement	Continuous	NRS Settlement boundaries (2016)		Open Government Licence (OGL)
DistWater	Distance to nearest water feature	Continuous	OS Open Rivers		OS Open Data
LCS88	Land Cover of Scotland 1988	Categorical	Macaulay Land Use Research Institute (MLURI, now The James Hutton Institute)	Broad Habitats (BH) based on Table 4.3. Grassland was separated as seminatural grassland and improved grassland	MLURI (1993)
SEP	Rural Socio - economic performance index	Continuous	https://www.hutton.ac.uk/sites/default/files/files/SEPDATA_RST.csv	Various national statistics linked to Data Zones 2001	Copus and Hopkins (2015)
SIMD	Scottish Index of Multiple Deprivation (SIMD) 2020	Categorical	https://spatialdata.gov.scot	SMDI Quantiles	OGL
UR8Fold	Scottish Government Urban Rural Classification (2016)	Categorical	https://spatialdata.gov.scot	Urban Rural 8-Fold classification	OGL

We converted all datasets in Table 8.1 to raster layers with a specified spatial resolution of 250m grid cells. The spatial resolution was informed by the median nearest distance between recorded IRS wildfire location and the perimeter of burnt area polygons within the Highland LA (Table 6.1) and accounted for the known uncertainty in IRS fire incident locations. We extracted the values of the variables in Table 8.1 at the locations of the wildfire incidents that fell within the Highland LA, which resulted to a dataset of complete values for all variables for 1,752 of the 1,852 Highland LA wildfires.

Table 8.2 gives the descriptive statistics for the continuous (i.e., numeric) explanatory variables at wildfire locations. Based on median values, wildfires in the Highland LA tend to occur in warmer and drier areas of relatively low altitude and relief that are to a certain extent close to the road network. Based on the Urban Rural classification, 61% of Highland wildfires occurred in very remote rural areas, followed by 22% that occurred in remote rural areas. Around 32% of Highland wildfires were on shrub followed by fires on improved grassland (16%), conifer forest fires (15%), seminatural grassland fires (14%) and peatland fires (11%). Most wildfires fell into the 3rd and 4th SIMD quantiles (36% and 22%, respectively), while the median SEP index was at 6.1.

Table 8.2 Descriptive statistics of numeric covariates in the locations of the Highland LA IRS wildfires.

Covariates	Min	Median	Mean	Max
Bio1	4.9	8.1	8.1	9.8
Bio4	295.7	385.4	383.7	442.8
Bio12	644.2	1,722.9	1,603.6	2,643.6
Bio15	17.0	32.5	30.2	39.2
Elev	0.7	61.8	96.9	711.3
Slope	0.1	4.4	5.7	30.0
DistRoad	126.0	408.0	499.6	3,837.0
DistSettl	2.0	136.5	206.6	1,840.0
DistWater	1.0	154.0	210.0	2,017.0
SEP	0.0	6.1	5.9	8.3

8.2 Ignition risk mapping

Building the dataset of spatial relationships between wildfires and explanatory variables enabled us to explore modelling and mapping ignition risk in the Highland LA using statistical methods. The objective of this analysis was to demonstrate how the IRS wildfires can be utilised to produce ignition risk maps that can be used alongside other datasets, e.g., maps of fire danger predictions, to assist in wildfire preparedness and prevention and mitigation planning.

Several recent studies have utilised a logistic regression approach to mapping wildfire ignition risk (e.g., Catry et al., 2009; Dixon and Chandler, 2019), while ensemble decision trees, such as the Random Forests (RF) algorithm (Breiman et al., 1984), are also robust alternative methods to logistic regression for modelling non-linear relationships (Kirasich et al., 2018). Both approaches of predictive modelling treat the wildfire incidents as the dependent variable, while the information extracted from the explanatory variables at wildfire locations are used as the model predictors. The result of this modelling exercise is a map of probabilities of ignition (0-1) that can be classified into risk classes to produce an ignition risk class map or to produce a map of wildfires based on specified thresholds of probability ignition. An additional important output of the modelling are metrics of relative importance of the different explanatory variables used as predictors of fire ignition risk, which can provide some causative explanation of wildfire occurrence in the study area.

The models require non-ignition sample points as well as the ignition points (i.e., wildfire locations) for training. Following the approach by Dixon & Chandler (2019), we randomly selected non-ignition points within the study area, excluding areas within 250m of a known ignition to ensure that no ignition point was accidently included as a non-ignition point. Around twice as many non-ignition (3,682) than ignition (1,752) points were created, to better represent the greater spatial coverage of non-ignitions compared to recorded wildfires. As in the case of the ignition points/wildfires, we also extracted variable/predictor values at the locations of non-ignitions and merged them with the wildfires and variable values dataset. We used a 70% random sample of the merged dataset for training the model (3,805 points), leaving 30% for independent testing/validation (1,629 points not used for training the models). After building the ignition risk model, it was spatially deployed using the predictor maps to produce maps of probabilities of ignition risk at a 250m grid resolution for the Highland LA.

We built ignition risk models using both logistic regression and RF. Here, we present the results from the RF modelling because RF performed better than logistic regression in this case. We were also keen to explore RF because we have substantial experience in using it (e.g., Gagkas and Lilly, 2009) for environmental modelling and because RF are a machine-learning algorithm with many advantages for complex modelling, such interpretability, their ability to deal with missing data and with autocorrelated variables and their ability to utilise both discrete (i.e., categorical) and numeric predictors (Liaw and Wiener, 2002). Ignition risk was predicted with RF using binary classification (ignition vs non-ignition) and with fine-tuning algorithm parameters such as the number of classification trees generated. Variable importance was calculated using the mean decrease accuracy (MDA), which gives the average accuracy for the predictor minus the decrease in accuracy after permutation of the predictor.

Overall, RF models produced had very high accuracies of above 90%; this was expected to a certain degree because there are relatively clear, end hence relatively easy to model, patterns of wildfire occurrence in the Highland LA. We would expect smaller accuracies if building an ignition risk model covering the whole of Scotland that had to model more complex patterns and interactions between wildfire occurrence and variable spatial variation. Distance to the nearest road was the most important model predictor (Figure 8.1), which is consistent with findings from similar studies, e.g., as in the Peak District National Park (Dixon and Chandler, 2019), followed by elevation and bioclimatic variables (annual temperature and precipitation). The importance of accessibility and proximity to populated areas was also highlighted by the fact that both distance to settlements and the Urban Rural classification scored relatively high in terms of MDA. Fuel type (based on LCS88) and the socioeconomical indices gave low MDA scores; this is explained by the relatively moderate variability in fuel type composition and predominant remote rural character of the Highland LA that exhibited little spatial variation of SIMD and SEP values. It is expected that the relative importance of fuel types and socioeconomic indices would be greater when developing a national cover ignition risk model due to the greater spatial variation of these variables at national scale and the presence of more complex interactions than those in the Highland LA.

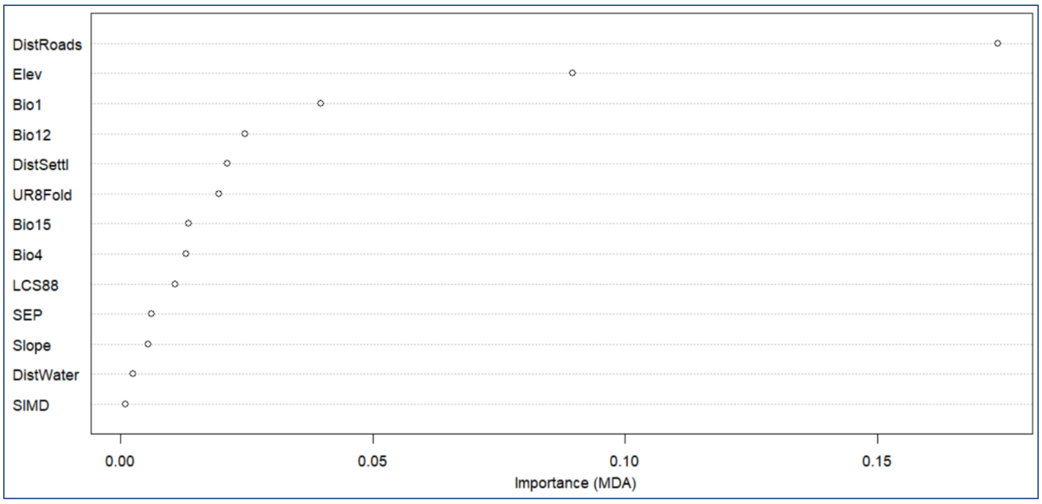


Figure 8.1 Importance of covariates used for ignition risk modelling based on MDA.

Results of independent testing using the left-out sampling points (Table 8.3) showed very high sensitivity (0.97), i.e., the avoidance of false negatives (predicting non-ignition where actually there was an ignition). The model's specificity was also high (0.87), highlighting its good ability to avoid predicting false positives (predicting ignition where actually the cell was non-ignition). We used a 0.6 threshold (i.e., the model predicts "fire" if there is a >60% probability of a fire occurring at this location) to calculate these statistics. As Dixon and Chandler (2019) note, the user should make this threshold decision, as the cost of a false positive is likely not equal to the cost of a false negative. For example, attending a call-out in which no ignition has occurred may be preferable to not attending a call-out in which there is an ignition. Therefore, it might be preferable to set higher thresholds to reduce the likelihood of a false negative (the model predicts no ignition when actually there is an ignition).

Table 8.3 Accuracy statistics of the ignition risk model calculated using the independent sample points.

	Predicted non-ignition	Predicted ignition
Actual non-ignition	1,074 (True negative)	59 (False positive)
Actual ignition	28 (False negative)	466 (True positive)

Figure 8.2 shows the locations of predicted locations of wildfires using a probability threshold of 0.6, and Figure 8.3 shows predicted wildfire locations in relation to burnt area polygons in two identified hotspots of predicted fire occurrence.

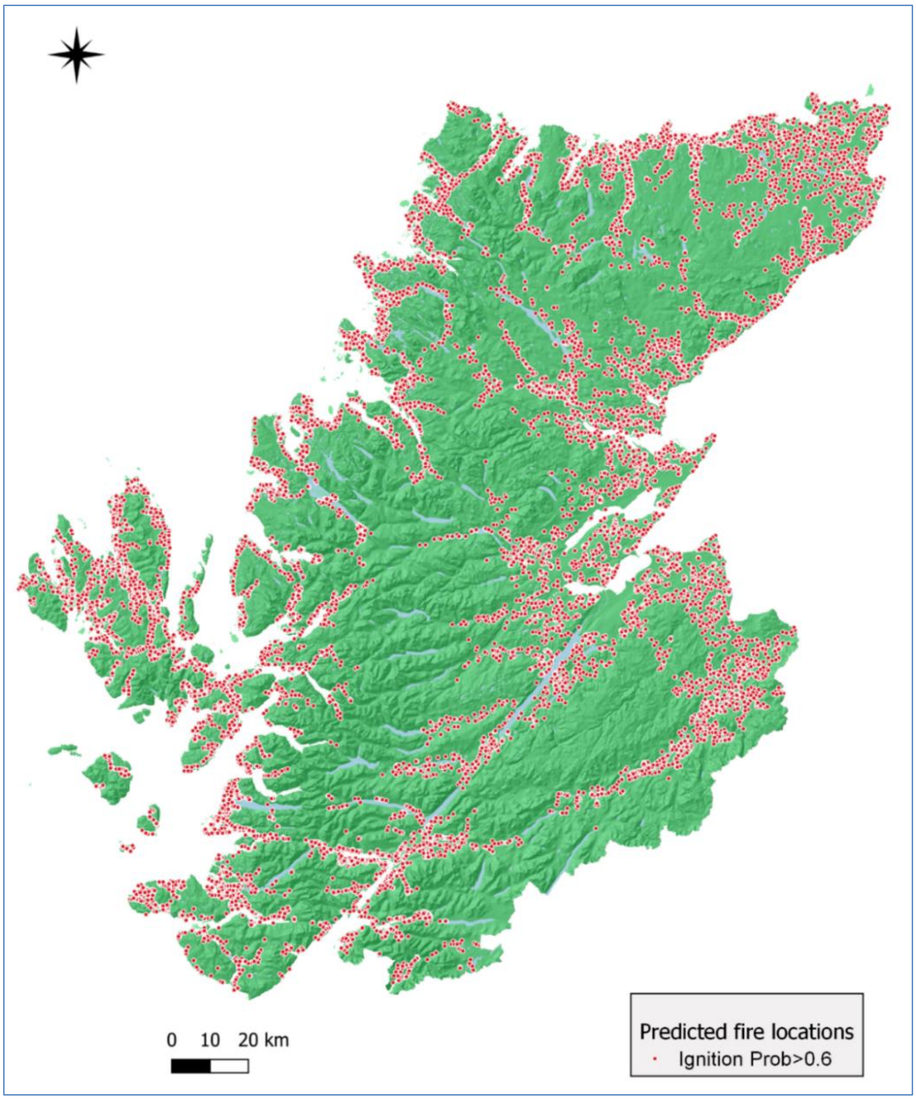


Figure 8.2 Predicted fire locations with probability of ignition greater than 0.6. Red dots represent the centroids of 250m grid cells.

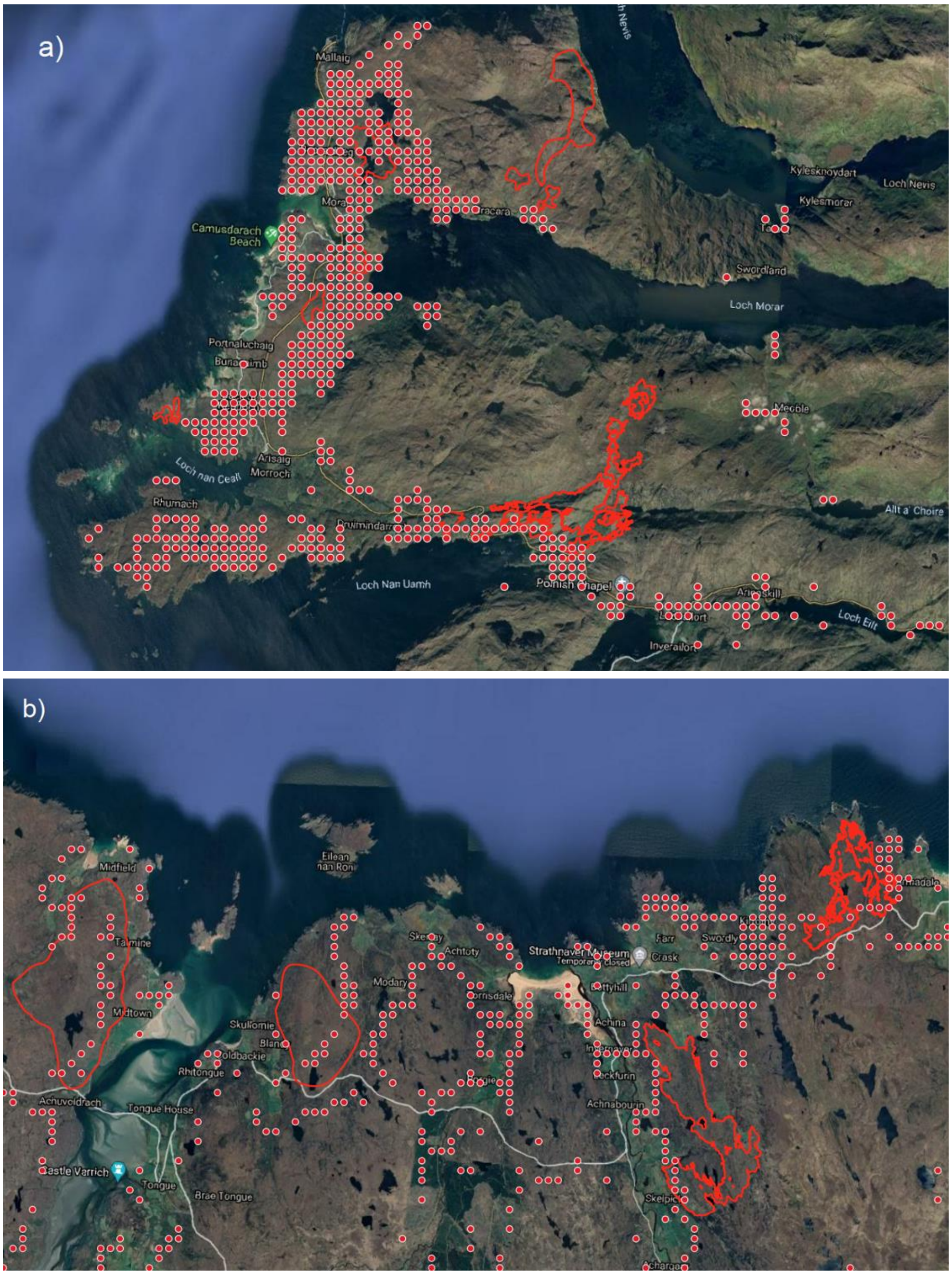


Figure 8.3 Predicted fire locations (probability of ignition >0.6) in relation to burnt area polygons in a) the area around Loch Morar and b) area around Strathnaver, both in the Highland LA. Red dots represent the centroids of 250m grid cells.

Overall, the ignition risk model succeeded in predicting fire locations in close proximity to almost all available burnt area polygons, most often close to the existing road network. We need to stress that the results of this modelling show the locations where a successful ignition is likely to occur and not the areas where the fire is likely to spread. The range of values of selected variables for predicted fire locations (ignition probability >0.6) and non-ignitions (ignition probability <0.6) (Figure 8.4) shows clear distinctions in variable values, such as distance to roads and annual precipitation, between ignition and non-ignition locations. In addition, a slightly greater proportion of predicted ignitions was in accessible rural areas (7%) compared to non-ignitions (4%), while 77% of predicted ignitions was in very remote rural areas compared to 83% of non-ignitions. Regarding fuel types, the model predicted a greater proportion of fires in seminatural grasslands and conifers (both 14%) compared to non-ignitions (8% and 5%, respectively), whereas more non-ignitions (in proportion) were predicted in shrublands and peatlands (46% and 21%, respectively) than ignitions (16% and 38%).

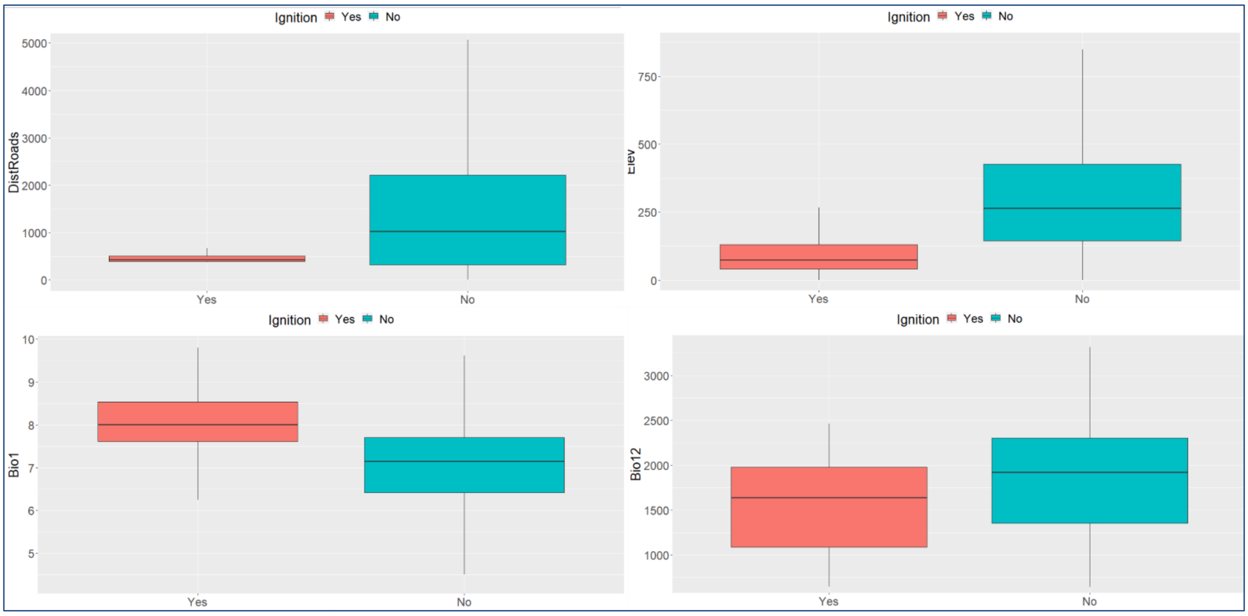


Figure 8.4 Boxplots of values of nearest distance to roads, elevation, mean annual temperature and mean annual precipitation for the areas predicted as positive ignitions (i.e., fire locations) and negative ignitions (i.e., no fire occurrence) using a probability threshold of 0.6.

Overall, the results of the Highland LA case study show that models built using a statistical approach can provide objective assessments of the relative importance of explanatory variables of fire occurrence. In addition, predictive models can provide accurate spatial predictions of ignition risk and hence can become a useful tool for wildfire preparedness and mitigation planning. However, we need to stress that these purely data-driven approaches require extensive "sense checking", ensuring that the variables selected make physical sense and that the identified patterns and relationships are sound conceptually and are not simply statistical artefacts.

9 Synthesis & recommendations

9.1 Synthesis & overview

The Incident Reporting System (IRS) is a very well-structured dataset and a valuable resource for keeping records of the characteristics of different types of fires occurring in Scotland. However, our analysis found that it is extremely difficult to use information recorded in the IRS to run an automated filtering and identification of wildfires, and hence we had to resort to extensive visual inspection of satellite imagery to complement the filtering process. This is due to uncertainties in the recording of fire incident locations and ambiguities in the description of fuel types, with regards to the type of vegetation communities or habitats they describe. We attempted to consider these issues to a certain degree in our analysis by using different datasets of habitat types and land use classes at different scales and resolutions. However, the results of comparing locations and fuel type information from the identified IRS wildfires with respective information derived from burnt area datasets showed that there are extensive differences and disparities in fuel type composition between actual burnt areas and IRS records.

Nevertheless, the selected wildfires from IRS were identified and selected using a robust filtering process and were verified with extensive visual inspection; hence we are confident that wildfires identified are indeed wildland fires affecting seminatural habitats. Around 7.3% (9,725 fires) of the outdoors IRS fire incidents for the 2009-2020 period were identified as wildfires; we cannot ascertain whether this number of wildfires is realistic for the studied period or an underestimation of wildfire activity in Scotland because we are lacking robust estimates of wildfires occurrence. It has been suggested previously that recorded fire incidents are likely to be biased towards smaller burns in more accessible and/or more urban areas (Davies and Legg, 2016); this is because reporting of fires in rural upland areas is likely to be incomplete for social reasons (e.g., due to reluctance of gamekeepers and land-managers in areas where traditional managed burning is still prevalent to involve the SFRS) or due to sheer remoteness. However, in this study we identified several big wildfires within the IRS that caused extensive damage to important seminatural habitats in remote rural areas, and in several cases we also managed to associate them with their respective burnt areas. These results provide an indication that, despite issues mentioned above, the IRS dataset is a good resource for identifying important wildfire incidents in Scotland, even in the most remote areas.

Our extensive investigation of patterns of wildfire occurrence identified three (3) main types of wildfires occurring in Scotland: a) Wildfires caused in very remote and remote rural areas affecting mainly heathlands/shrublands and bogs and peatlands that seem to be caused mainly by accidental ignitions; b) Wildfires in accessible rural areas and smaller urban centres that affected grasslands and woodlands; and c) Small fires close to settlements and urban centres affecting mainly grasslands that seemed to be caused by deliberate ignitions.

Wildfires in remote areas tended to be bigger and were mainly caused by bonfires or other intentional burns that got out of control, which might be associated with traditional land management practises or tourism/recreational activities. Small deliberate fires in or close to urban centres seemed to be driven mainly by anti-social behaviour or relatively trivial cases of negligence with fire, while the causes of fires in the more accessible rural areas could be a mixture of burns getting out of control or careless handling of equipment or other heat sources along with ignitions from anti-social behaviour.

Despite differences in fuel type compositions, burnt area sizes, motives of ignition and accessibility, wildfires in Scotland exhibit a clear seasonal pattern with most fire incidents occurring during the months in spring, with most monthly fires recorded in April. This temporal pattern was common in other countries with similar bioclimatic conditions and vegetation communities (Republic of Ireland, rest of the UK and west coast of Norway). However, we need to consider that predicted warmer summers and increased frequencies of drought in Scotland could cause the occurrence of big and particularly damaging wildfires also in summer months, as is the case in central parts of Sweden. Finally, our Highland LA case study showed that the IRS wildfires can be a useful resource for ignition risk modelling and mapping using statistical methods. Maps of ignition risk classes and/or predicted fire locations could be useful tools when used alongside other datasets related to fire danger and risk for enhancing wildfire suppression and mitigation capability.

9.2 Recommendations

Based on the results of our analysis, we propose a set of recommendations with the aim to improve the utility of the IRS dataset for detecting wildfires and to make IRS fire incidents a more relevant and reliable resource for wildfire planning and decision making in Scotland and for supporting wildfire research and analysis. Recommendations for improvement proposed are related mainly to describing and characterising fuels and recording wildfire location in relation to point of ignitions and distances to actual burnt areas.

Although the IRS provides a comprehensive list of categories for recording fuel types, these are currently not appropriate for easily identifying wildfires as they can be ambiguous as to specific vegetation types or communities impacted by respective fire incidents. For example, we found that the “Grassland, pasture, grazing etc” property type includes fires on seminatural, grazed or improved grasslands and that fires belonging to the “Grassland, pasture, grazing etc” or the “Scrub land” property types can include grassland, heathland, or bog fires. This is problematic because different habitat or vegetation communities have different structure which influences fire behaviour. In addition, the IRS doesn’t include a peatlands category, even though bog and peatland fires are quite frequent and very damaging to particularly sensitive and important habitats. Therefore, adopting a new, comprehensive system for reporting and describing fuels could greatly improve both the identification of wildfires in the IRS, but also its value as a resource for wildfire planning and analysis.

In our opinion the National Vegetation Classification (NVC) Phase 1 system or the EUNIS habitat classes of Table 4.2 would be a potentially good option for broadly describing fuels within the IRS, as both systems strike a good balance between ecological specificity and moderate training and natural history skill requirements and could be relatively easily adapted for fuels. An implication of this approach is that there are significant differences in fire behaviour across stages of the *Calluna* (heather) cycle (relevant to fire behaviour in peatlands and heathlands), so this information would probably need to be incorporated in the system. In this respect, our recommendation is that we need to a) collate all available fuels information collected across multiple projects and conduct analyses to reliably classify fuels based on structure and predicted fire behaviour; and b) compile this information into an illustrated fuels guide complete with predicted fire behaviours that could be used to support training of a select group of SFRS personnel. This approach could be trialled first in regional SFRS offices where the more damaging wildfires are expected to occur to assess its feasibility and identify weaknesses or knowledge gaps.

In addition, getting an accurate read on fire location is quite important, especially for determining the ignition point that can be helpful in trying to understand fire causation. A first step could be to add a new field in the IRS stating whether the recorded location is the ignition point or some other location, e.g., where the fire resources were marshalled. In addition, at least for the bigger wildfires, it would be helpful to record multiple locations at the fireline or burnt area perimeter. This information could be used by SFRS staff to quickly draw rough polygons of burns using free and easy to use web mapping tools (e.g., OpenSteetMap: https://www.openstreetmap.org) and use them to calculate burnt area size to better inform the Outdoor Damage Area fields in the IRS, which currently are either incomplete or partially inaccurate. Moreover, the recorded locations could be used by others working with fires (e.g., NatureScot staff or researchers) to help with detecting and digitising burn scars using satellite imagery to refine calculations of burnt area sizes and conduct further analysis (e.g., for fire severity). During our analysis we encountered difficulties when trying to detect burnt areas that corresponded to IRS wildfires by just using the recorded location information. We have shown that using basic GIS skills it is feasible to conduct fairly accurate delineations of burnt areas. At the same time, NatureScot staff are currently digitising some wildfire extents from analysis of Sentinel imagery. It is suggested that SFRS liaises with NatureScot for flagging IRS wildfire incidents that can be further analysed and characterised with the aim to inform and improve IRS records, as in the case of the burnt/damage area estimates.

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