Scottish Fire Danger Rating System (SFDRS) project

Final presentation, 9th December 2021

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THE UNIVERSITY of EDINBURGH
School of Engineering

firebreak

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Overview of SFDRS presentation:

- Presentation structure – Andrew C
- Brief overview of the project and conclusions - Andy T
- The Canadian Fire Weather Index – Michael B
- Predictive efficacy of the Canadian system for Scottish fires – Zisis G
- Fire characteristics in Scottish moorland fires – Rory H
- Scottish fuels and fuel types – Andy T
- Where do we go from here?

Overview of project

- The project was essentially an evaluation of the power of the Canadian Fire Weather Index System to predict potential ignition, fire spread and intensity of fires in moorland vegetation in Scotland.
- The system provided an excellent structure with which to investigate the many elements involved in developing a fire danger rating system in Scotland.

Overview of project

Results

- A detailed analyses of fire data from 571 fires in northern Europe showed that the majority of fires in the UK occurred in spring to early summer on shrublands and peatbogs
- The Fire Weather Index failed to predict the majority of these fires in Scotland and the rest of the UK, even though the initial sub-index - the Fine Fuel Moisture Code - gave satisfactory predictions of the fires

Overview of project

Results

- The fuel models within the Canadian Fire Weather Index System do not match the fuel structure of heather moorland and adequately capture the fire spread drivers in these systems;
- The fuel types and the fire behaviour of fires in Scottish moorlands appear to be very different from the original forest fire scenarios in which the system was developed.

Overview of project

Conclusion

We therefore suggest that new approaches are supported to develop a Fire Danger Rating System that captures the variables inherent with the particular combination of fuel types, seasonal condition of vegetation and fire weather in Scotland.

North-West Scotland, May 2011 – primarily grassland fire

https://www.ukclimbing.com/photos/dbpage.php?id=172378

Canadian Fire Weather Index System

Michael Bruce – Firebreak Services Ltd

<u>Fire Danger Rating Systems</u> (FDRS)

"A fire danger rating system is an assessment of both fixed and variable factors of the fire environment which determine:

- ease of ignition,
- rate of spread,
- difficulty of control
- and fire impact."

(Alexander & Merrill 1987)

Canadian Fire Weather Index System

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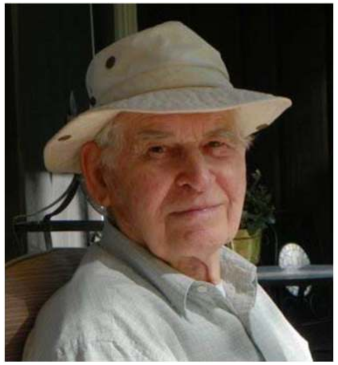
Goal of Fire Danger Rating Research



- *"Make an index such that any given value will represent the same fire behaviour, no matter what weather history leads to it.*

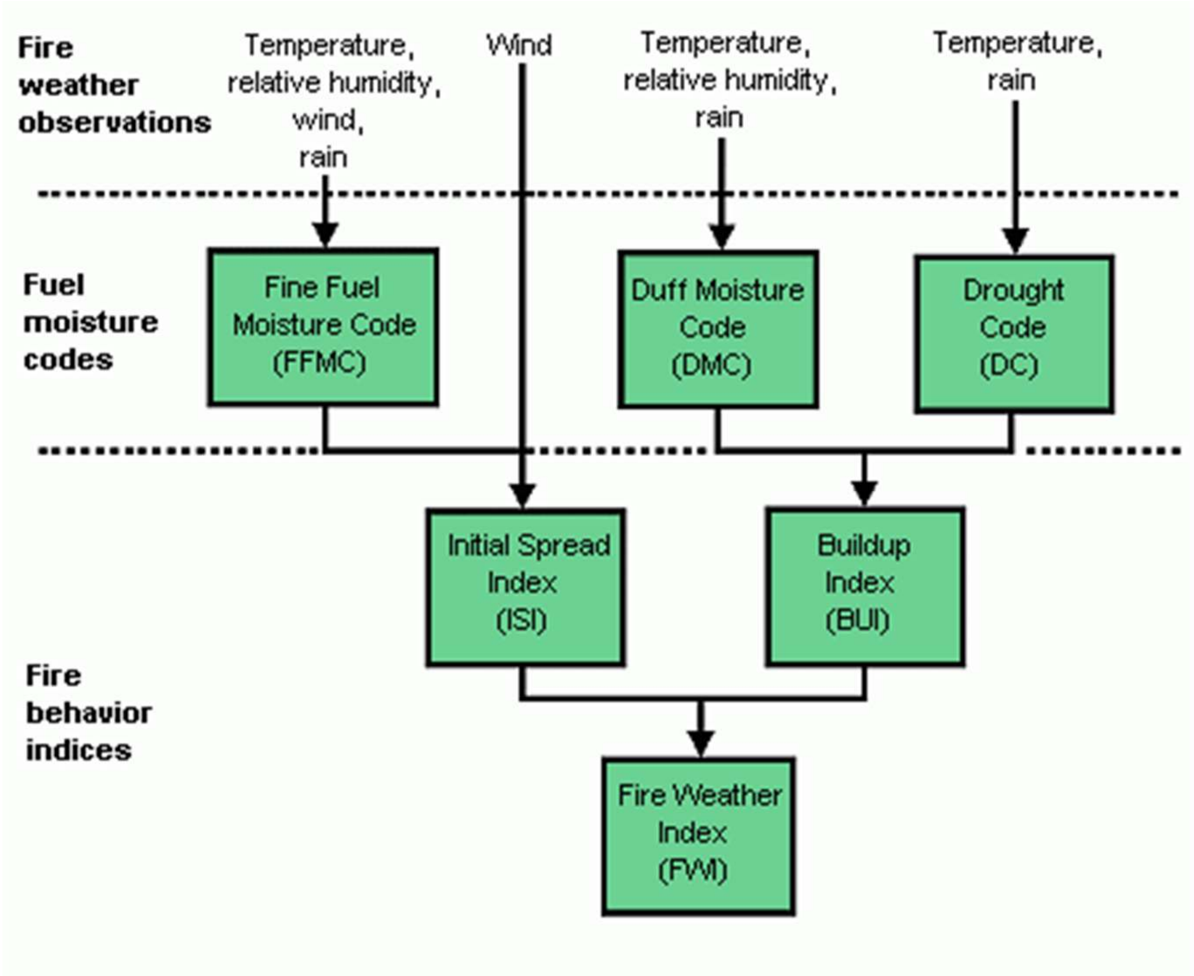
  This is a very stiff test… The trouble is one very quickly outruns the available practical knowledge."
  (Van Wagner 1970)

- *"The fact is that it's difficult to portray all the aspects of fire danger in a single number… One number can't be expected to cover the full range of fire management needs."*
  (Alexander 1994)

Canadian Fire Weather Index System

Thousands of field fuel moisture & fire behaviour experiments done to establish drying curves and fire behaviour models

Fire behaviour relationships established first, then 4 simple weather inputs used to apply empirical models on a continental scale



Canadian Fire Weather Index System

Moisture Codes	Represents
Fine Fuel Moisture Code (FFMC)	Moisture surface litter & cured fine fuels <1.2cm depth, in a Canadian forest
Duff Moisture Code (DMC)	Moisture loose organic matter 7cms depth
Drought Code (DC)	Moisture of deep compact organic layer 18cms depth

Canadian Fire Weather Index System

Fire behaviour indices	Represents
Initial Spread Index (ISI)	Rate of spread though combination wind & FFMC, without fuel quantity influence
Build Up Index (BUI)	Fuel available for spread, combination of DMC & DC
Fire Weather Index (FWI)	Intensity of the spreading fire, combination of ISI & BUI

Canadian Fire Weather Index System

Purpose of FWI sub-indices

Ignition potential (flammability)	FFMC
Spread rate	ISI
Control difficulty (fire intensity & mop-up)	FWI
Immediate post burn impact (fire severity)	FWI, DMC & DC

Canadian Fire Weather Index System

Fire Danger Rating Errors / Validation

	Danger Rating	
True State of Nature	**Low Danger**	**High Danger**
Low Danger	No error	Type I error—false positive
High Danger	Type II error—false negative	No error

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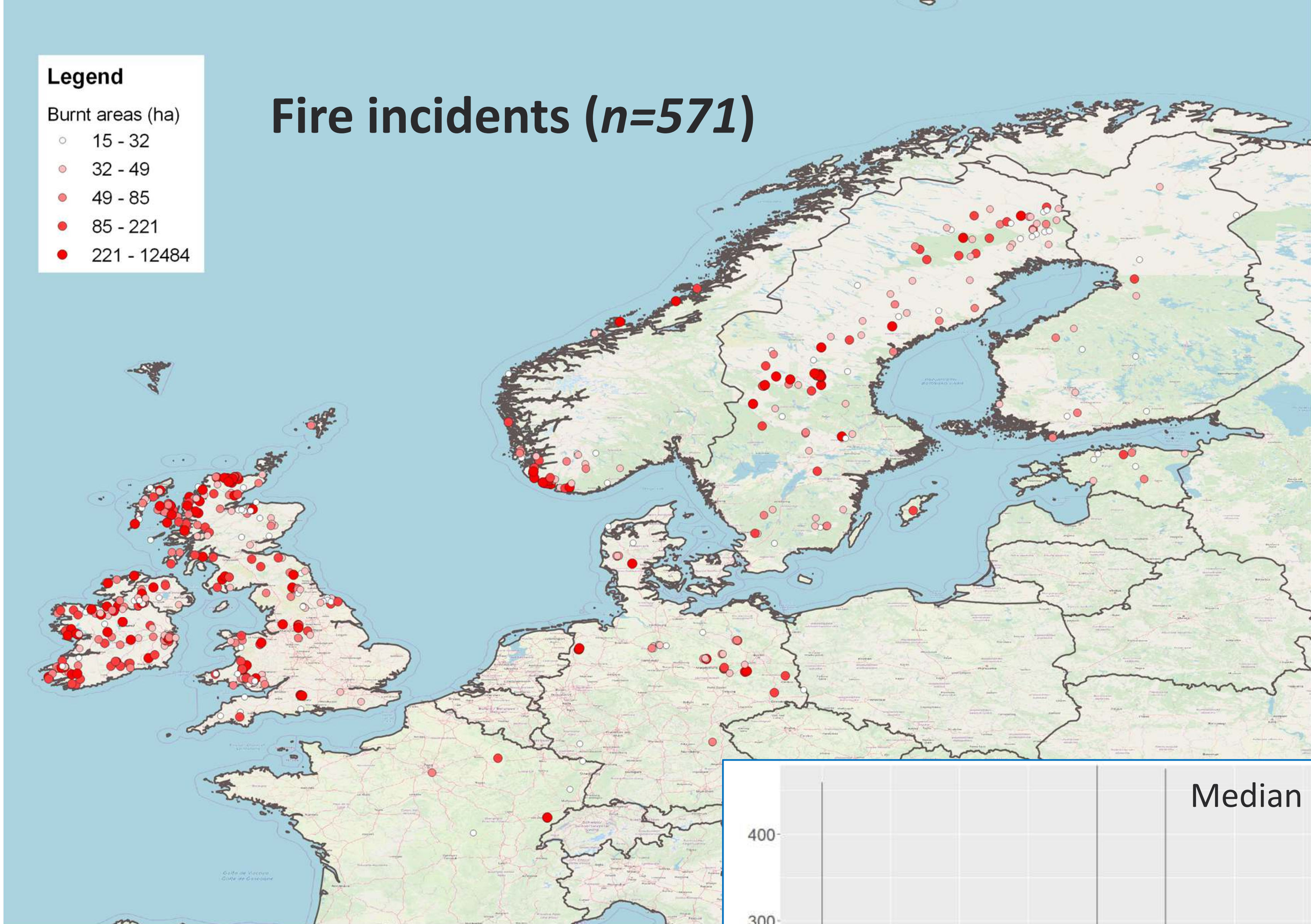
North-West Scotland, April 2013 – heathland and grassland fire

https://www.theguardian.com/uk/2013/apr/02/firefighters-battle-control-highlands-blaze

Relationships between CFWI system and real fire data in Northern Europe

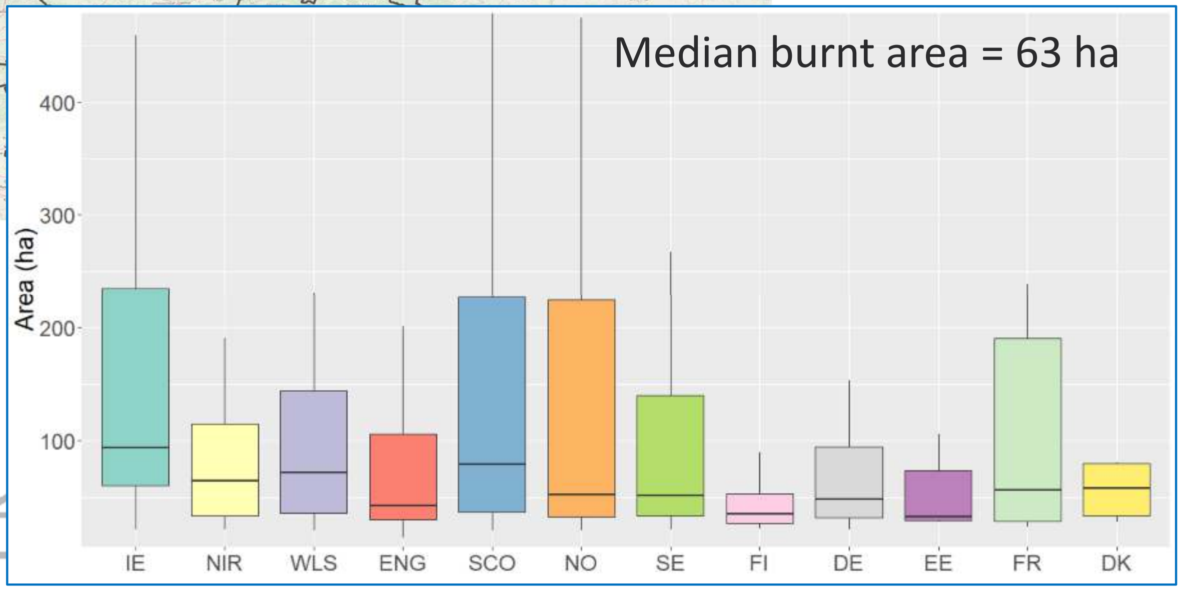
Zisis Gagkas, Ina Pohle - JHI

- Objective:
  - Assess performance of CWFIS for predicting fire danger in Scotland & rest of Northern Europe by assessing sensitivity to changing geographical settings & vegetation types.
- Methods
  - Datasets obtained from EFFIS (01/07/2013 – 15/06/2019):
    - MODIS Burnt Area polygons.
    - The EFFIS European Fuel map (250m grid cell).
    - Layers of daily Fire Weather Index CFWIS indices.
  - Spatial analyses:
    - Proportions of fuel type covers & median CWFIS indices values for each burnt area polygon.

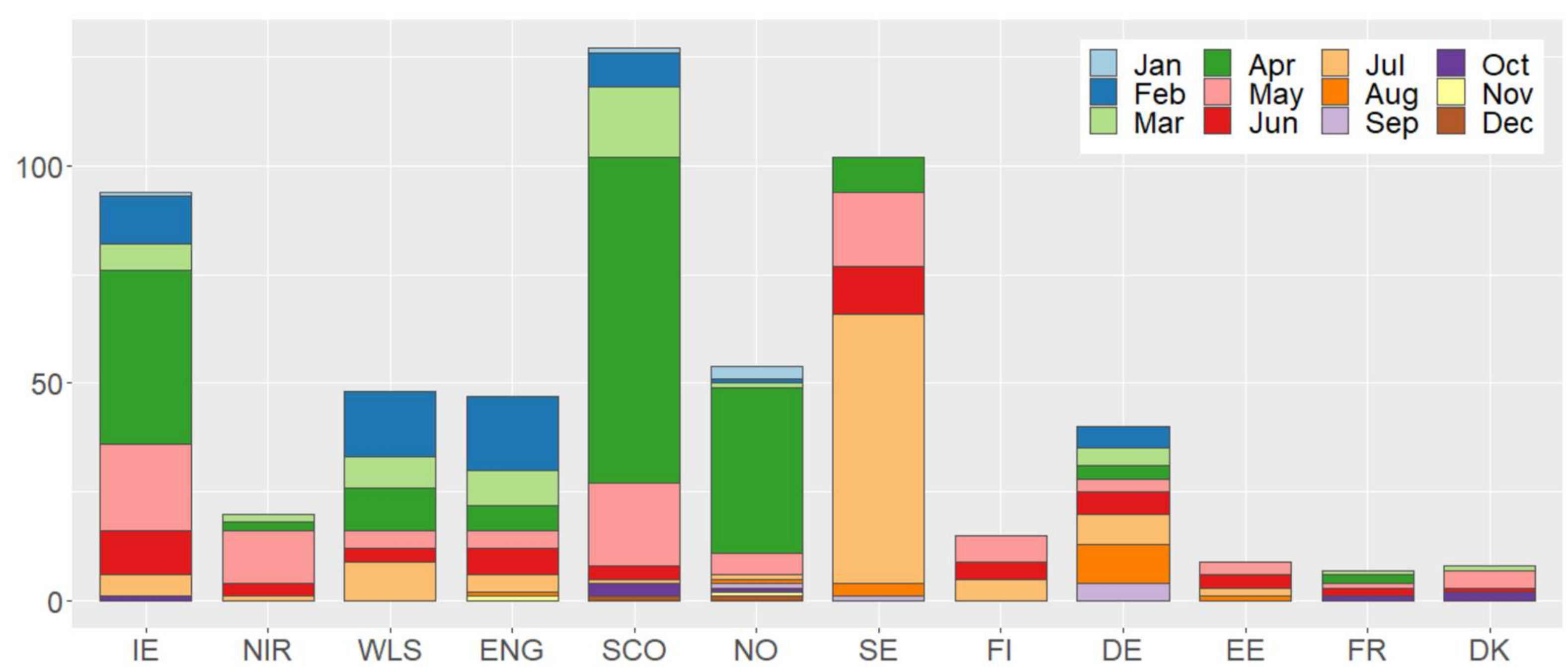


Country	Count
SCO	127
SE	102
IE	94
NO	54
WLS	48
ENG	47
DE	40
NIR	20
FI	15
EE	9
DK	8
FR	7

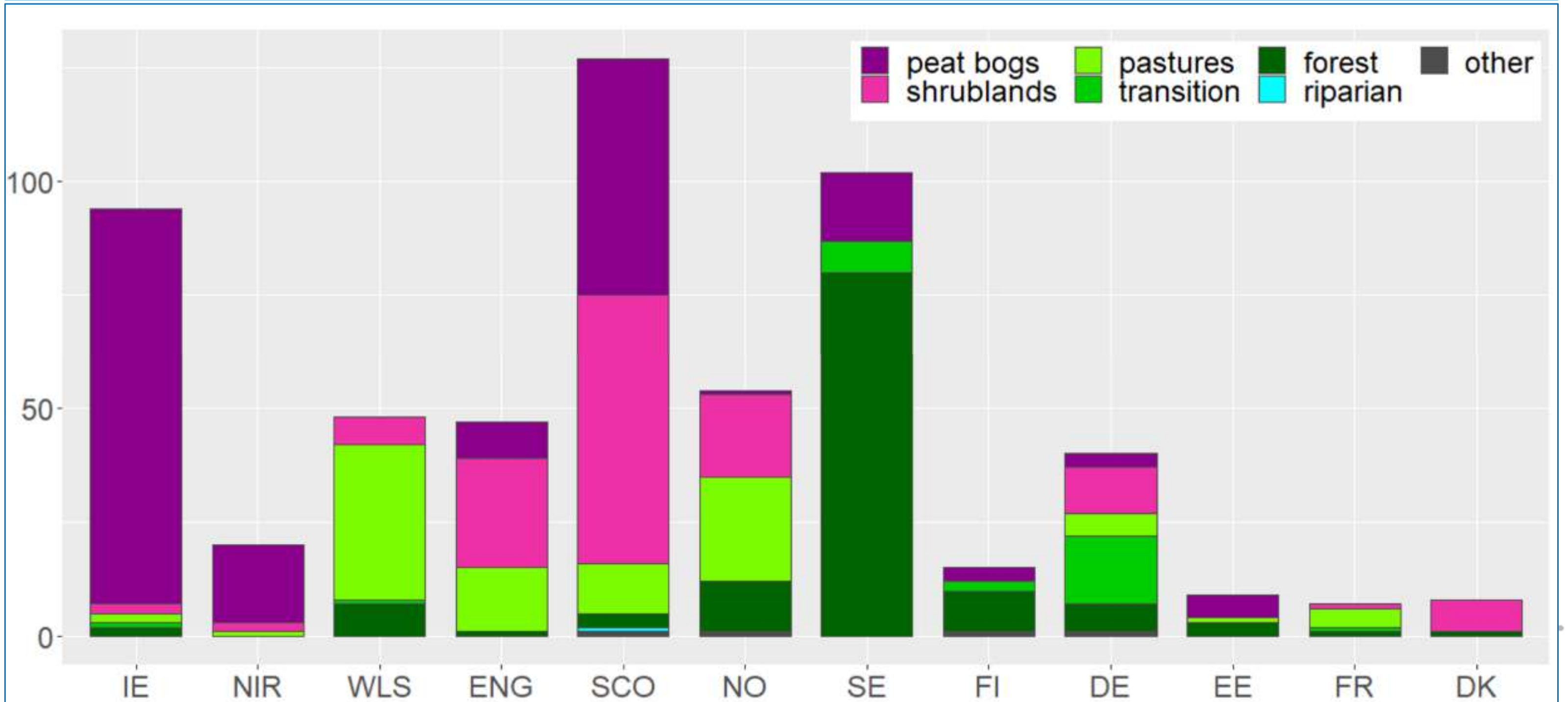
Study area: IE, UK (ENG, SCO, WLS, NIR), FR, DE, DK, NO, SE, FI, EE



Fire Seasonality & Fuel Type across N. Europe



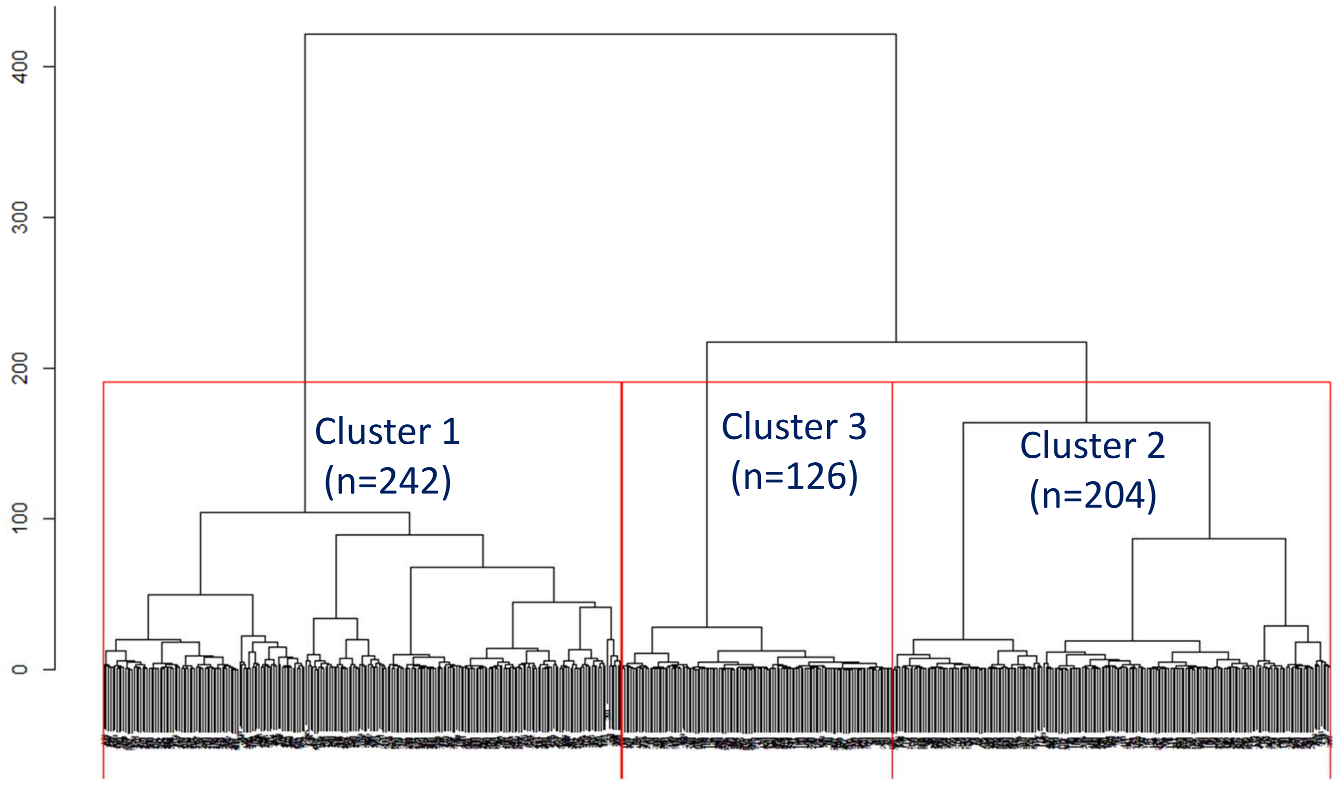
- Scotland: 72% fires in March-April
- Norway: 70% fires in April
- Sweden: 61% fires in July



- Scotland: 87% fires in shrublands & bogs
- Norway: 43% fires in pastures
- Sweden: 85% fires in conifers & transition

Hierarchical cluster analysis

- Investigate patterns→ identify similarities in fire occurrence.
- Variables used within each burnt area polygon:
  - Burnt area (in ha)
  - % cover of main fuel type groups (forest, peat bogs, shrublands, pastures, transition)
  - Median values of CFWIS indices.



N. Europe wildfire seasonal pattern, by fuel type

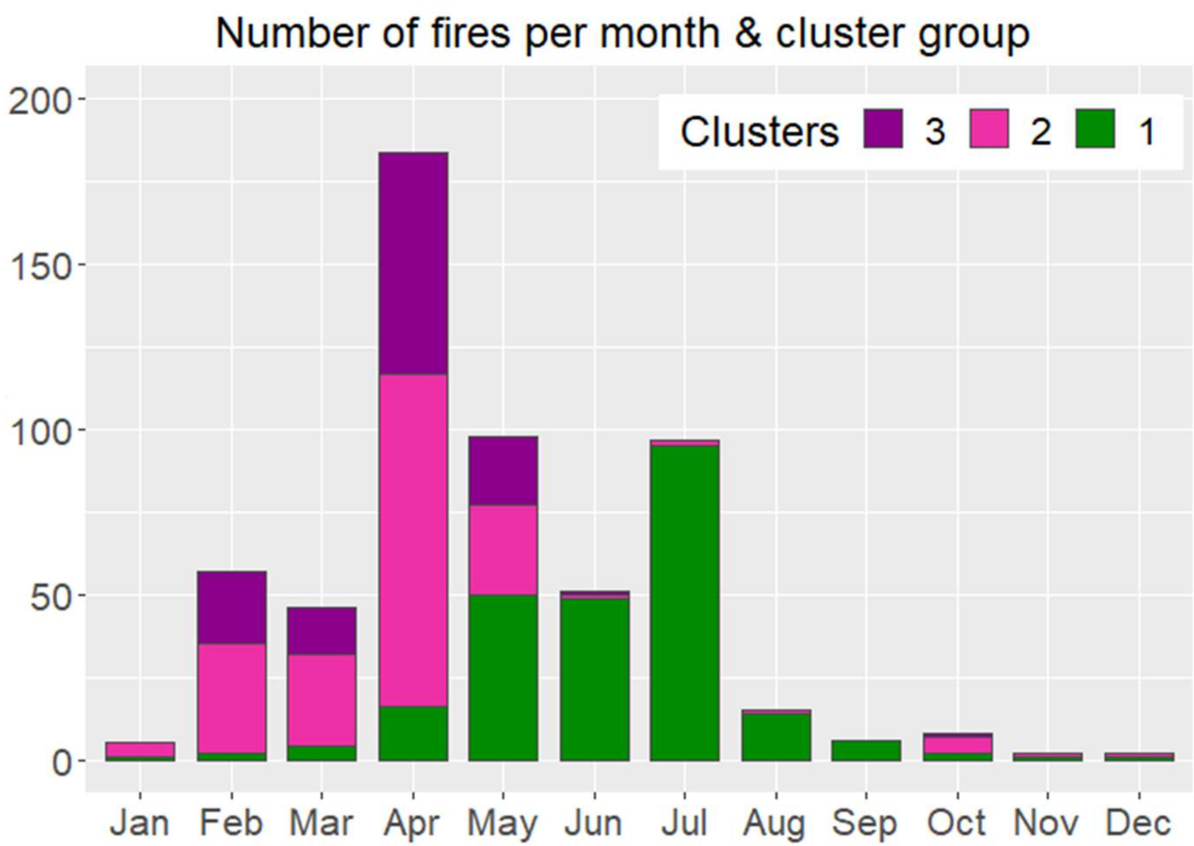
(571 fires 2013-2019 – EFFIS)

Habitat

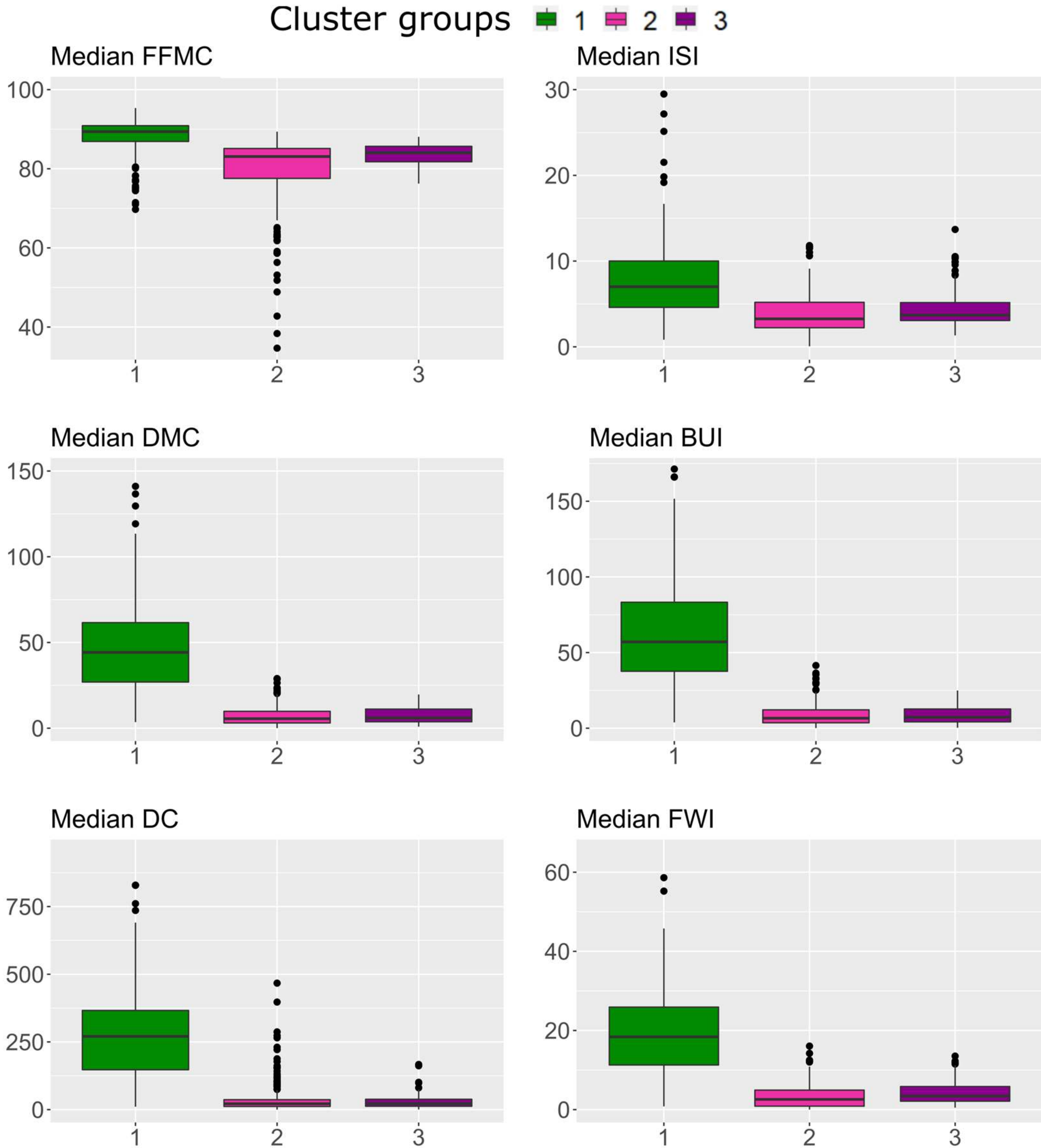
- Cluster 1: forests
- Cluster 2: pasture & shrubs
- Cluster 3: bogs

Seasonality

- Cluster 1 occur largely in summer
- Clusters 2 & 3 have similar late winter-spring seasonal patterns

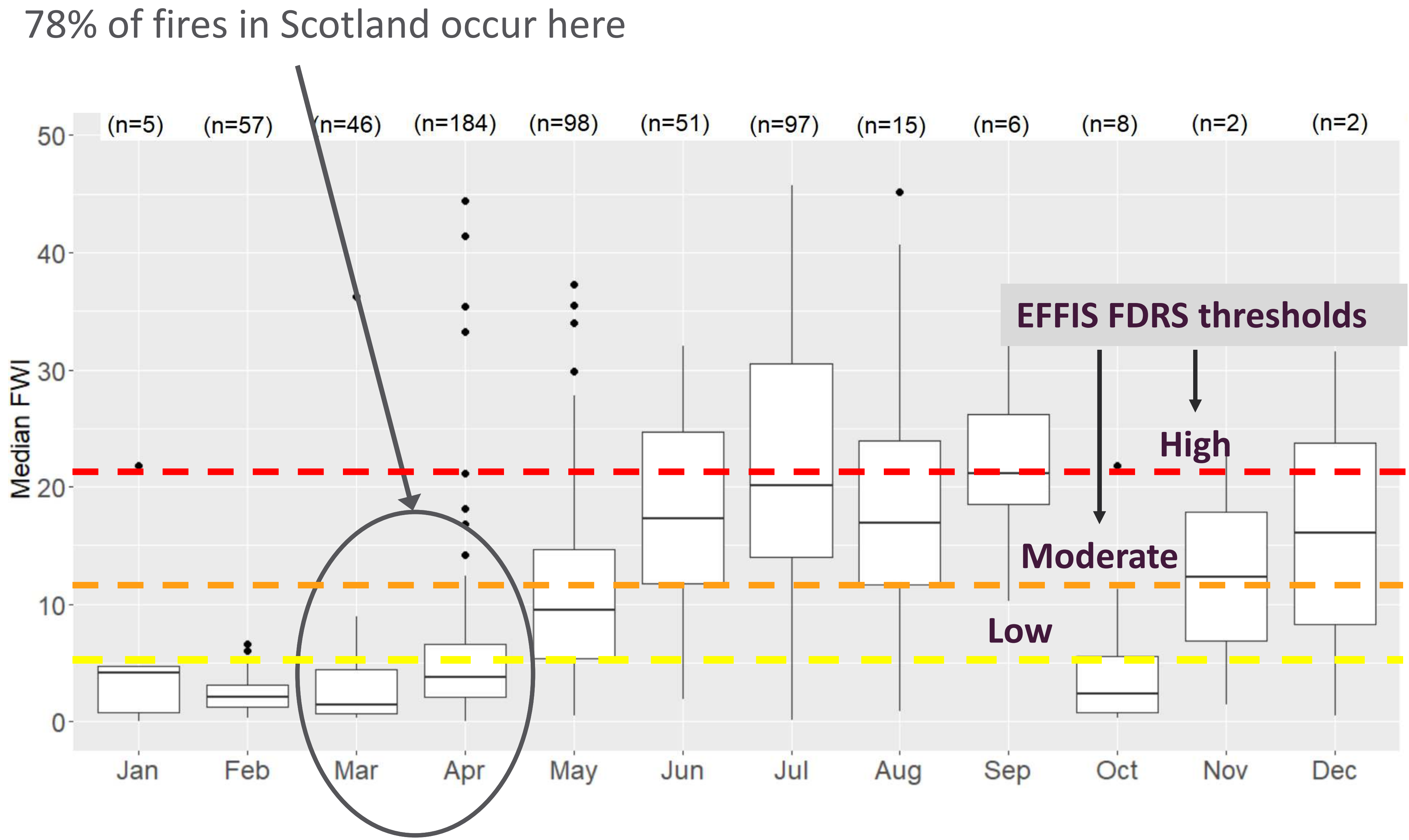


CFWIS indices



Fire Weather Index seasonal discrepancies

(N. Europe data)



Conclusions

- Fires in Northern Europe are igniting at lower FFMC values than the European average:
  - Predominance of late winter/spring fires at FFMC <85.
- CFWIS works relatively well for forest fires in late spring/summer & in shrublands/peat bogs in summer when DMC and DC are higher.
- CFWIS does not predict fires in shrublands in late winter/spring.

Controlled burn with instrumentation rig, Fettercairn estate, April 2021

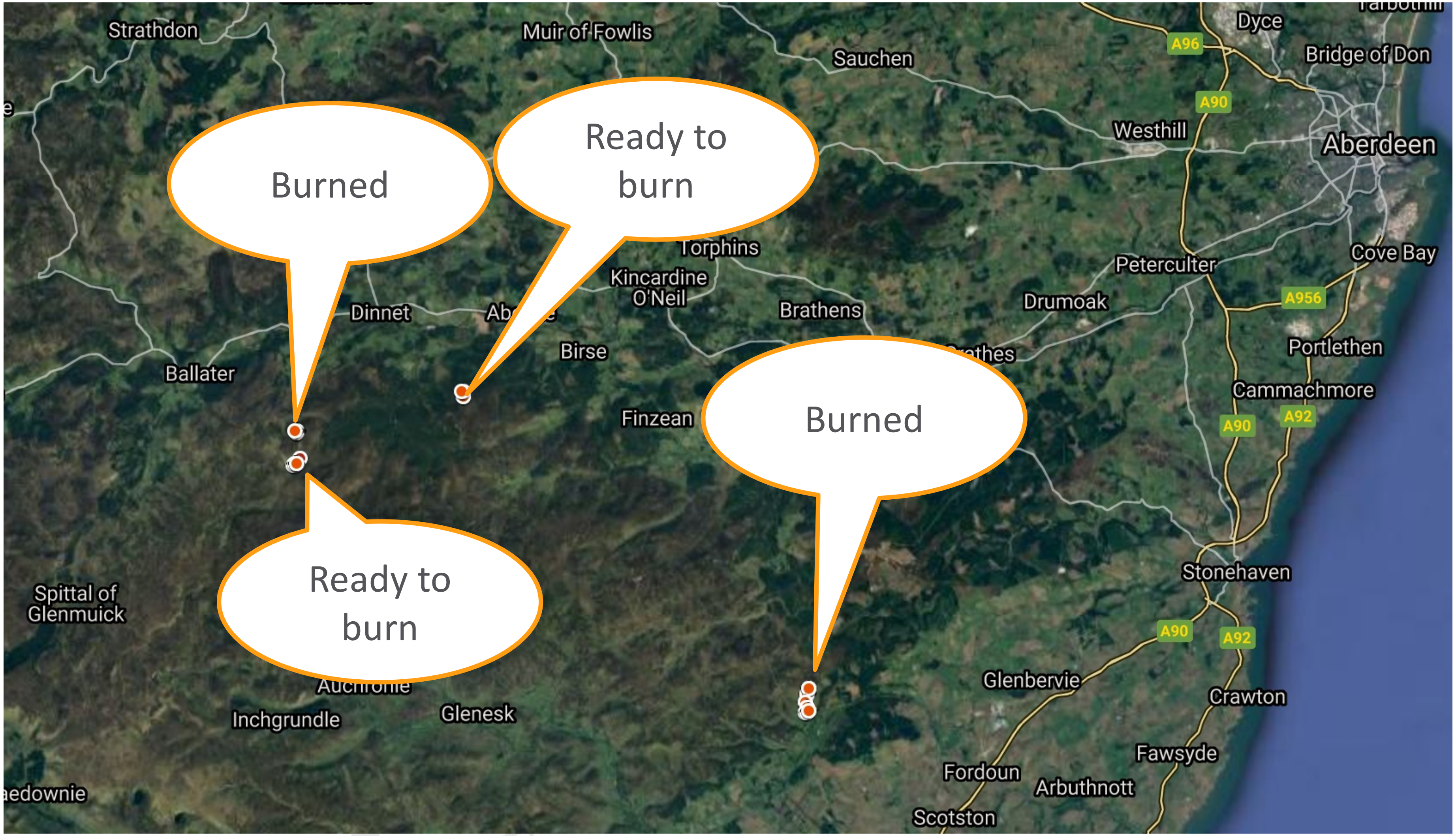
Fire behaviour

- Rory

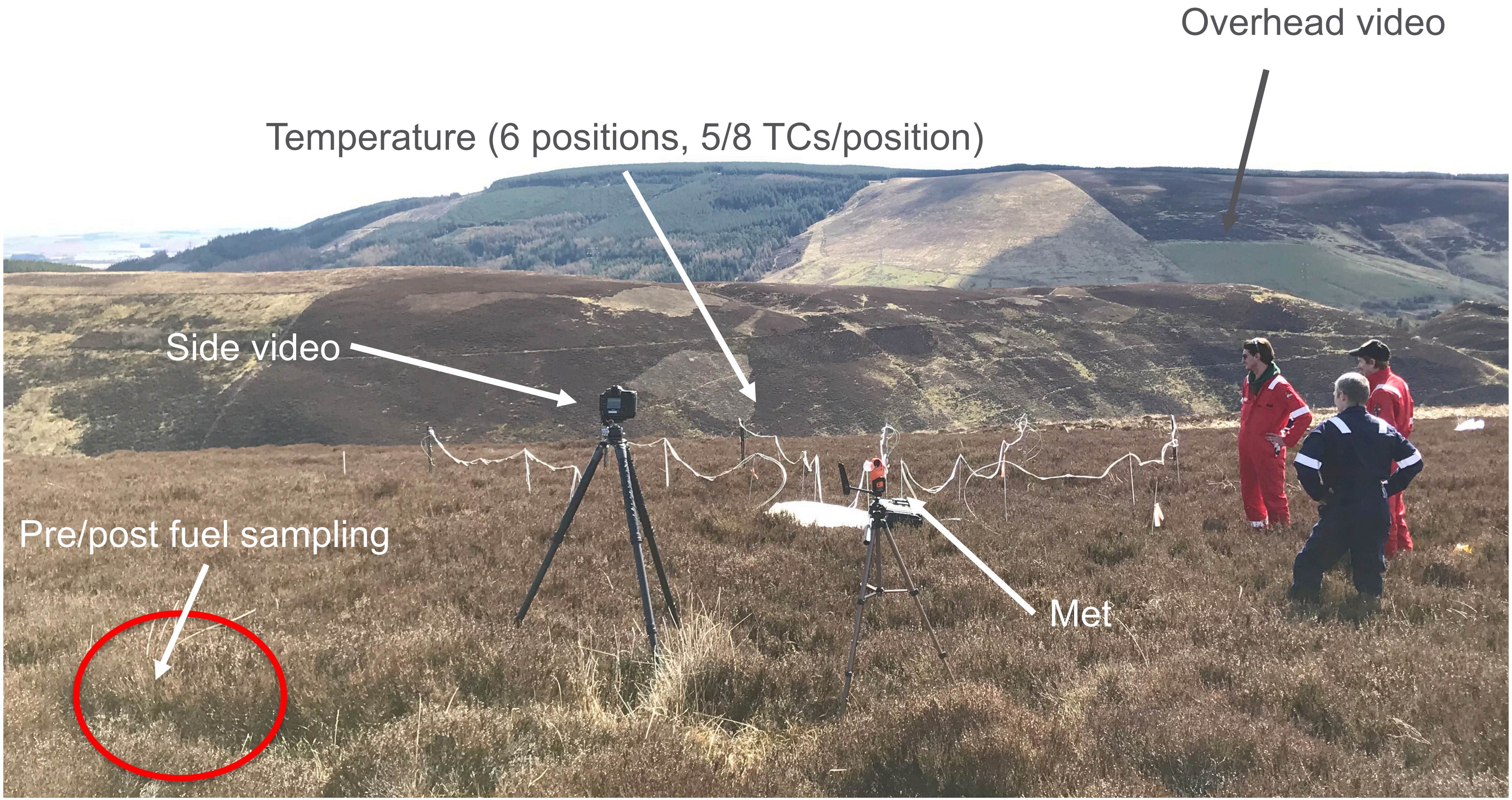
Fire characteristics on Scottish Moorlands

- Objectives
  - Evaluate fire behaviors (spread rate, intensity) in Scottish Fuels and explore relationships (if any) with the fuel properties, weather and the Canadian system.
  - Evaluate the ignitability of Scottish fuels.
- Team
  - Eric V Mueller, Zak Campbell Lochrie, Vasilis Koutsomarkos, Carlos Walker-Ravena, Simone Zen.

Fieldwork locations



Fieldwork set up



Video 1 – GT 2

Video 2 – FC2

Weather, FMC and fire behaviour

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								Fuel moisture content, %					
Burn No.	Plot No.	Ignition time (GMT)	Temp (C)	RH (%)	Wind speed (m/s)	Wind dir (deg)	Shrub fuel load (g/m2)	Fine green	Fine dead	Coarse	Moss	Average mass consumed, %	Average spread rate, cm/s
1	GT.8	14:21:21	11.4	64.8	5.45	~225	1275	77.9	19.8	74.2	458	69.8[1]	9.80
2	GT.9	15:25:05	9.6	74.7	3.1	~225	n.d.	74.6	20	75.7	465	49.0[1]	7.69
3	Gs.8	13:36:10	14.7	49.1	3.2	313	n.d.	88.7	60.3	69.8	119	n.d.	11.76
4	Gs.9	14:52:00	14	50.8	3.1	272	n.d.	87.7	64	78.6	124.1	n.d.	9.62
5	Gs.10	16:17:13	12.2	58.2	5.9	298	n.d.	86.1	71.6	76.7	155.5	n.d.	15.15
6	GS.5	14:00:00	15.7	46.8	3.9	136	792	70.6	13.9	79.6	57.9	88.6	n.d.[2]
7	GS.6	15:51:52	10.3	51.2	2.74	167	1230	62.3	19.9	78.8	74.5	87.7	13.56
8	GS.7	16:58:53	11	50.3	3	179	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	8.89
9	Fc.	12:34	14	46	4.4	120	3165	66.5	15.2	74.9	21.1	93.3	6.02
10	Fc.	15:33	11	53	3.3	95	2987	57.4	11.07	76.9	27.9	89.9	24.24

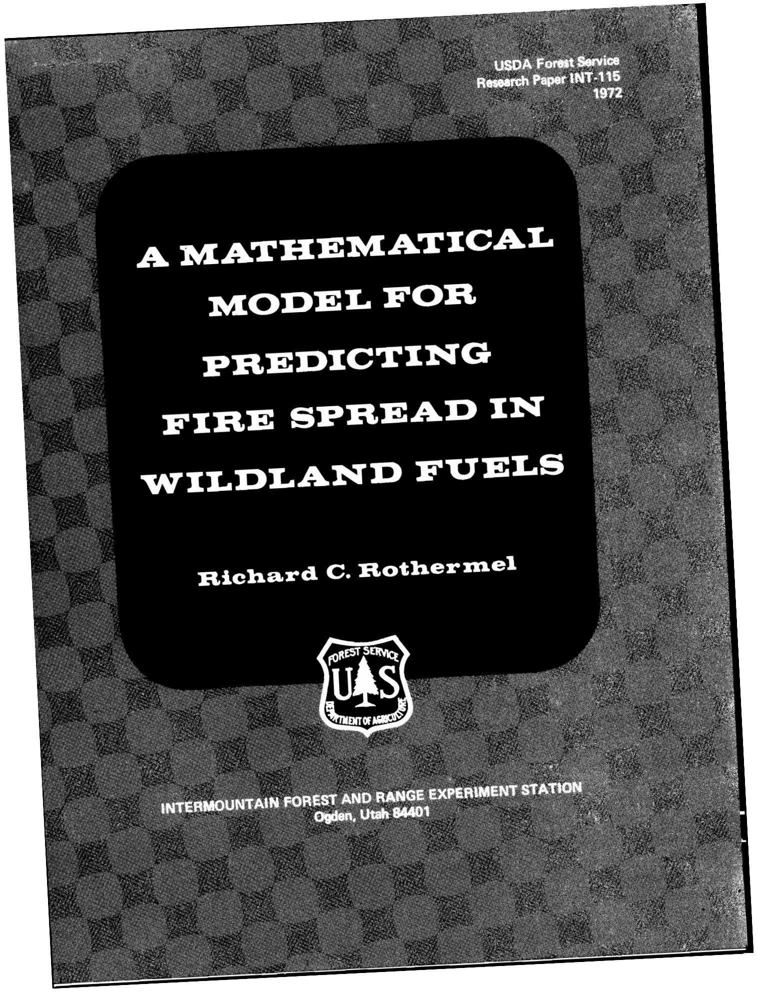
Correlations to indices

Burn Number	FFMC	DMC	DC	ISI	BUI	FWI	Intensity corrected for actual fuel consumption, kW/m
1	73	1.2	4.8	0.9	1.5	0.3	2600
2	73	1.2	4.8	0.9	1.5	0.3	1400
7	84.6	10.9	33.5	3	12	3.5	2600
8	84.6	10.9	33.5	3	12	3.5	2300
9	82.9	18.5	55.1	2.3	20.1	3.7	4300
10	82.9	18.5	55.1	2.3	20.1	3.7	14700

Roles of fuel layers

Burn	Fuel moisture content, %				Fuel consumed, %				Intensity corrected for actual fuel consumption, kW/m
	Fine green	Fine dead	Coarse	Moss	Fine green	Fine dead	Coarse	Moss/litter	
1	77.9	19.8	74.2	458	100	84.3	25.2	-6.1	2600
2	74.6	20	75.7	465	100	83.5	-36.4	26.6	1400
7	62.3	19.9	78.8	74.5	100	100	63.9	90.6	2600
8	n.d.	n.d.	n.d.	n.d.	100	100	63	87.7	2300
9	66.5	15.2	74.9	21.1	100	100	79.1	94.1	4300
10	57.4	11.07	76.9	27.9	100	100	81.1	78.6	14700

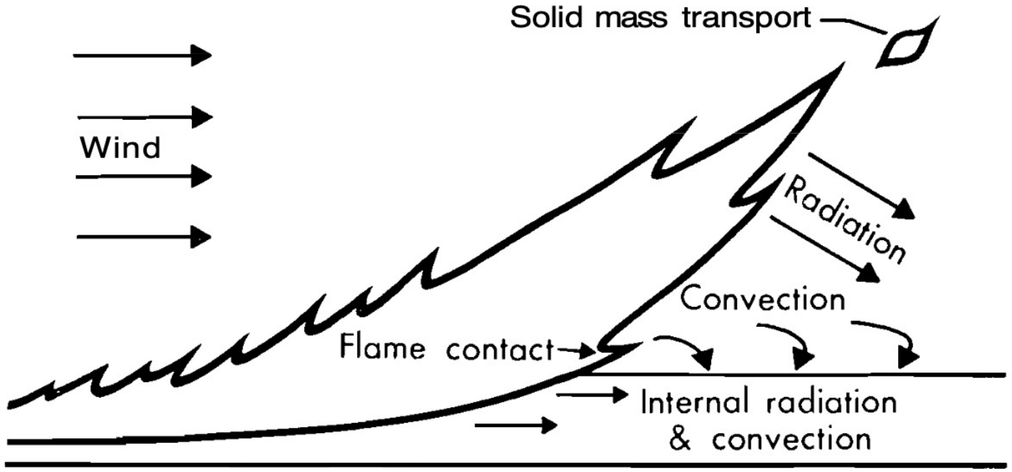
Starting point


USDA Forest Service
Research Paper INT-115
1972

A MATHEMATICAL MODEL FOR PREDICTING FIRE SPREAD IN WILDLAND FUELS

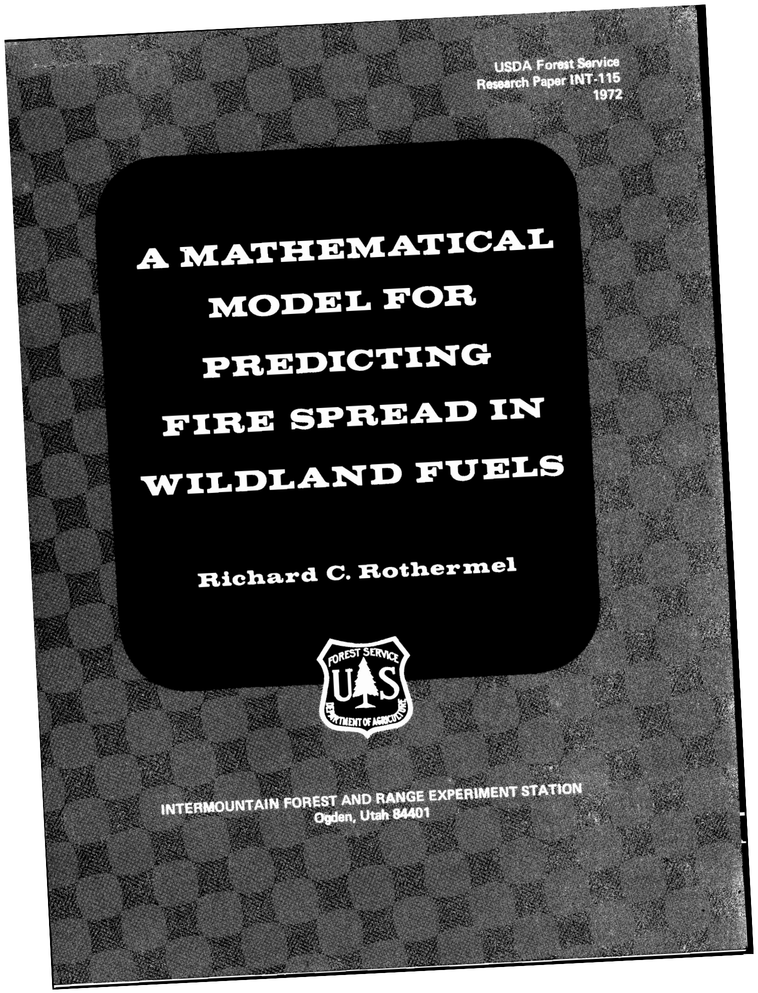
Richard C. Rothermel

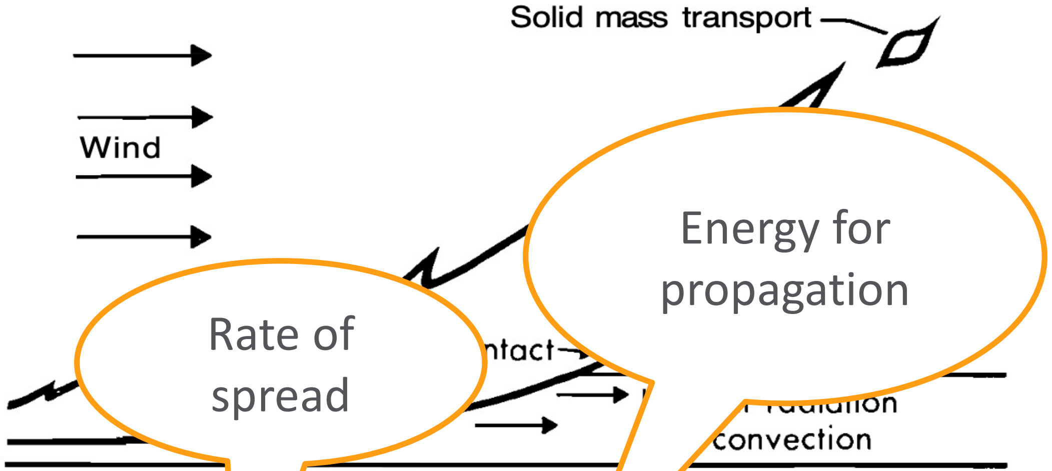
INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Ogden, Utah 84401



$$R = \frac{(I_p)_o(1+\phi_w+\phi_s)}{\rho_b \varepsilon Q_{ig}}$$

Starting point

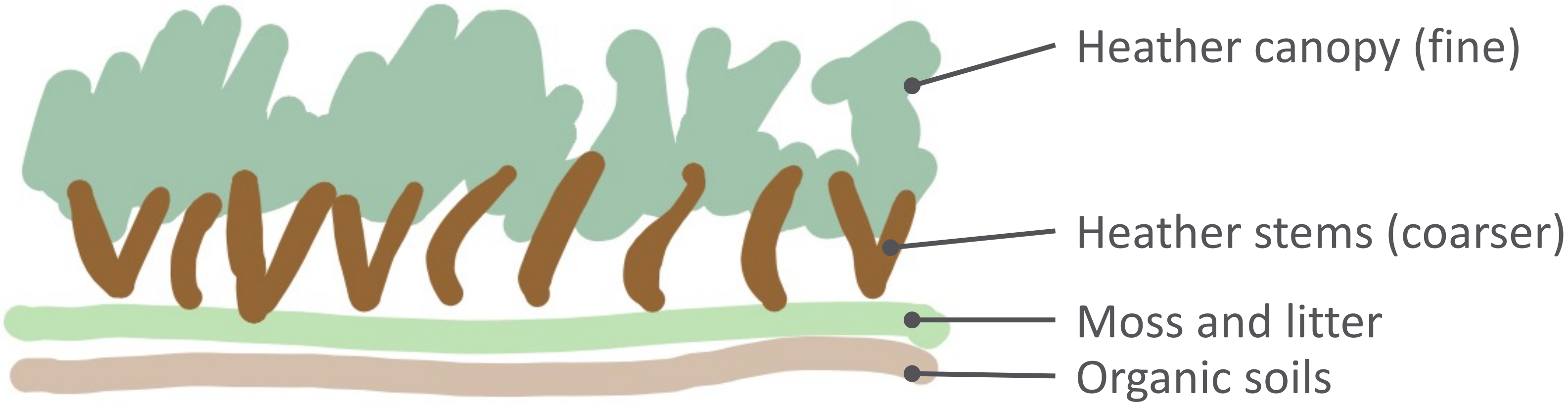




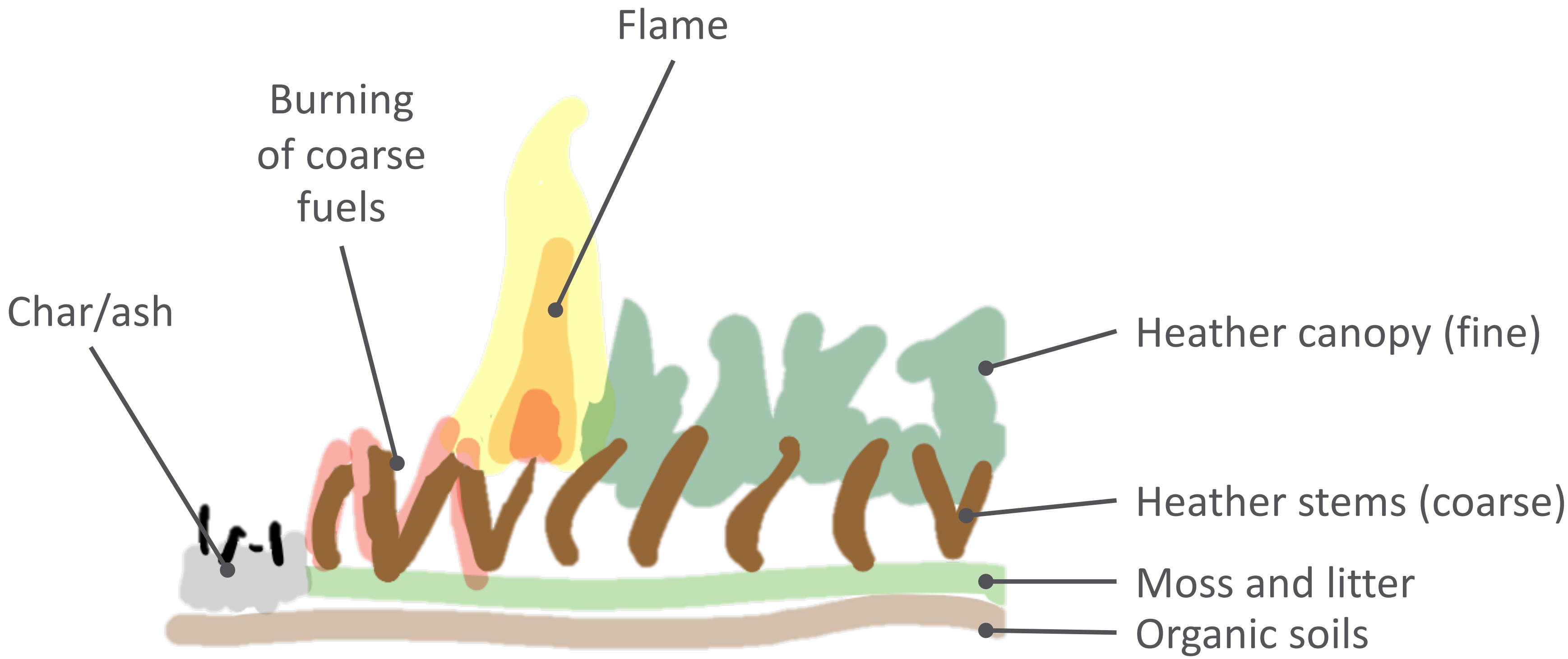
$$R = \frac{(I_p)_o(1+\phi_w+\phi_s)}{\rho_b \varepsilon Q_{ig}}$$

Fuel properties

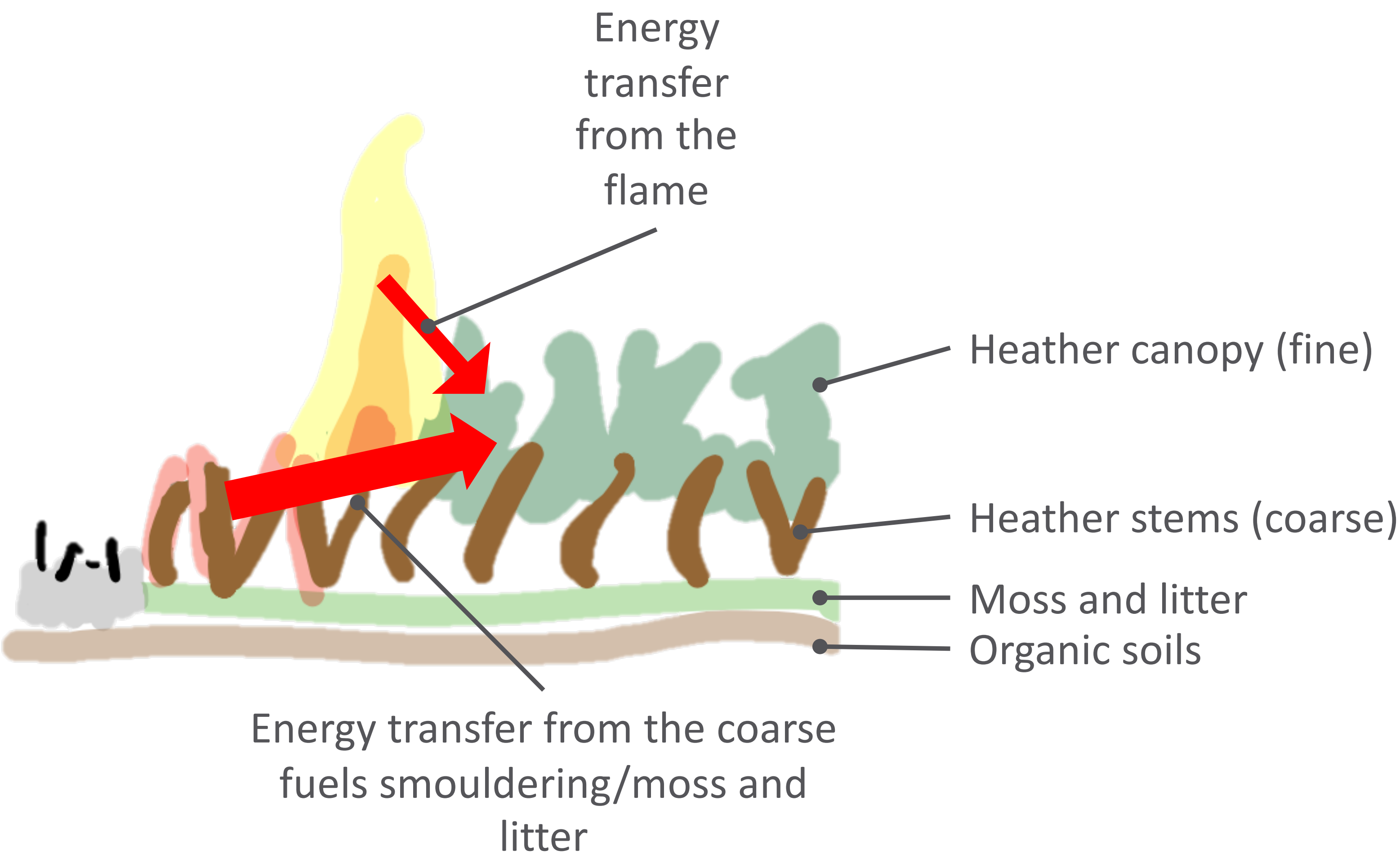
Heather fuels



Heather fuels



Heather fuels



Laboratory studies

Very dry moss and heather

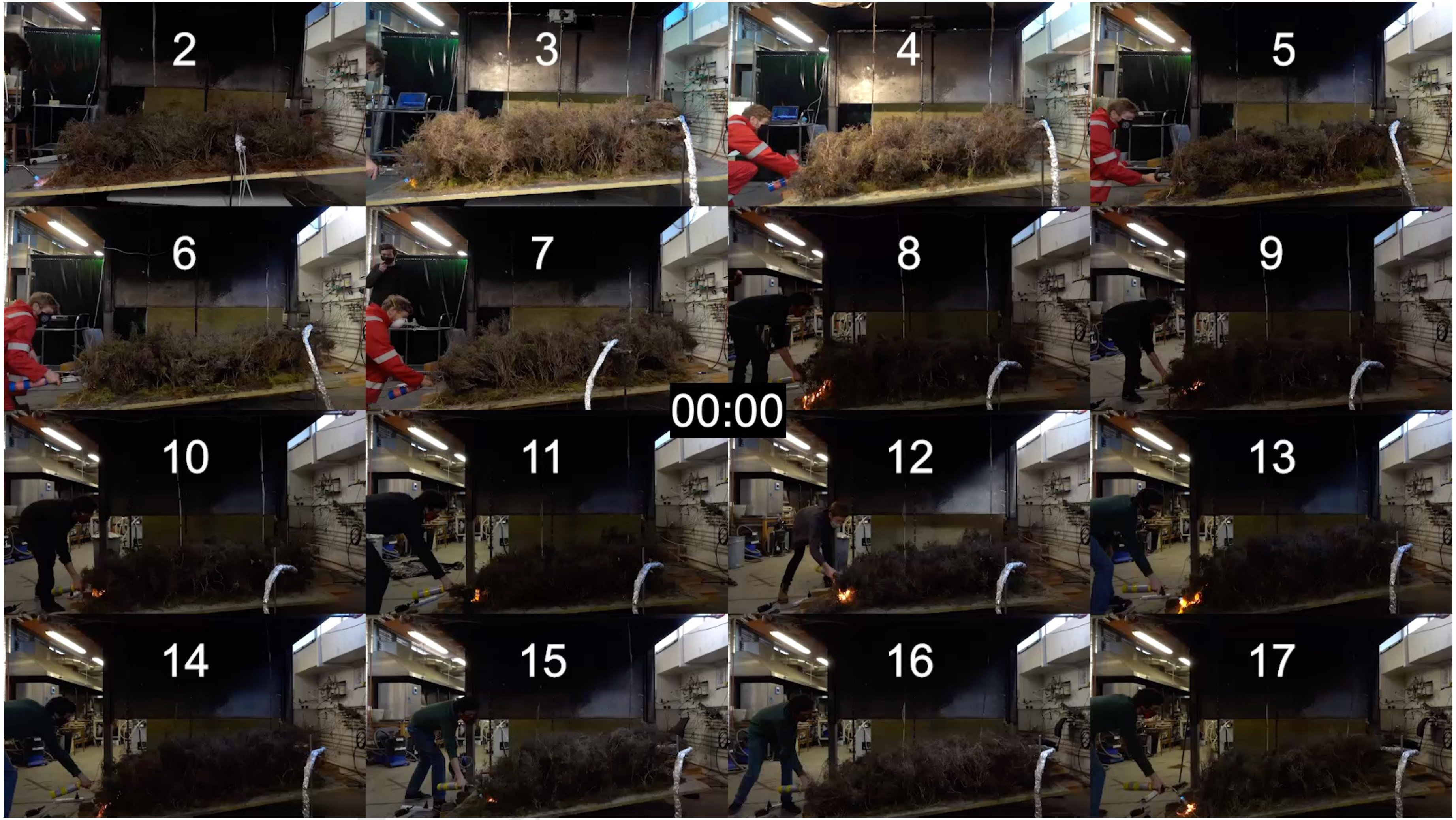
Laboratory studies

Wet heather and dry moss

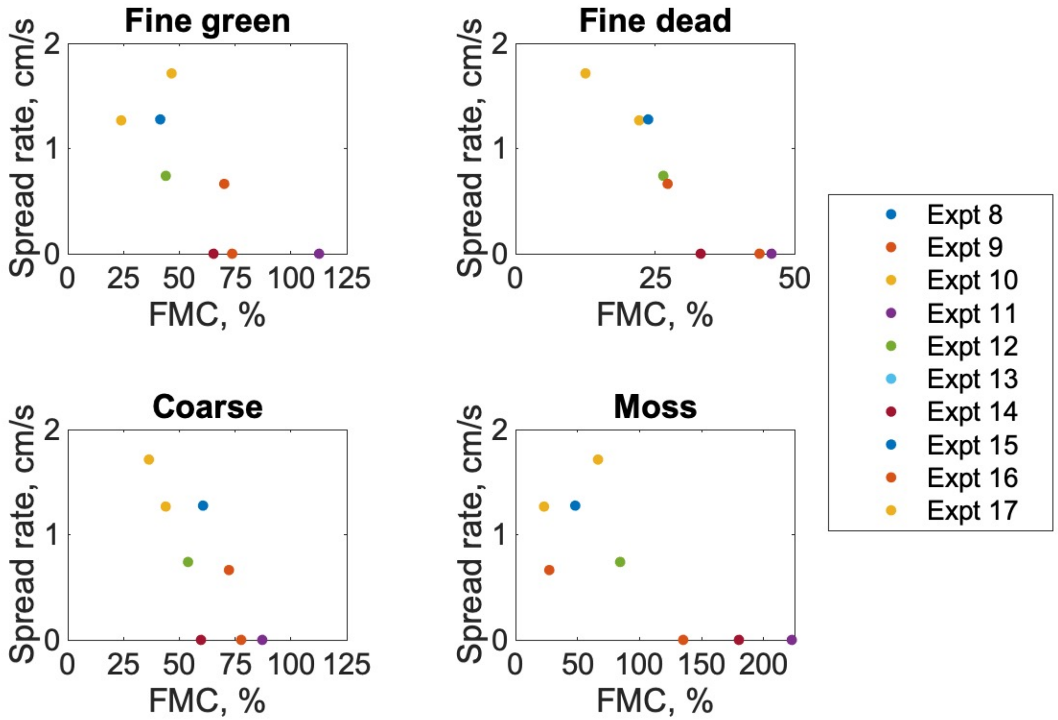
Laboratory studies

Wet moss and dry heather

Laboratory studies



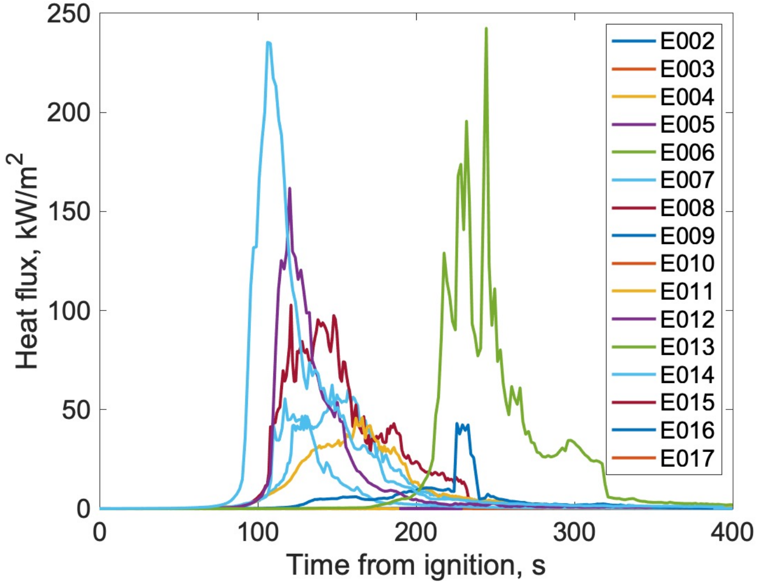
Effects of FMC on spread rate



Thresholds of FMC required for fire spread under lab conditions

Fuel element	FMC threshold for spread, %
Fine green	47—65
Fine dead	26—33
Coarse	54—60
Moss	84—135

Links to Rothermel…



Energy for propagation

Rate of spread

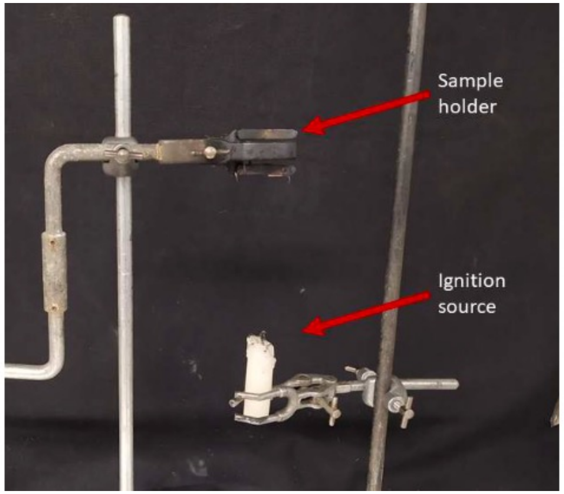
$$R = \frac{(I_p)_o(1+\phi_w+\phi_s)}{\rho_b \varepsilon Q_{ig}}$$

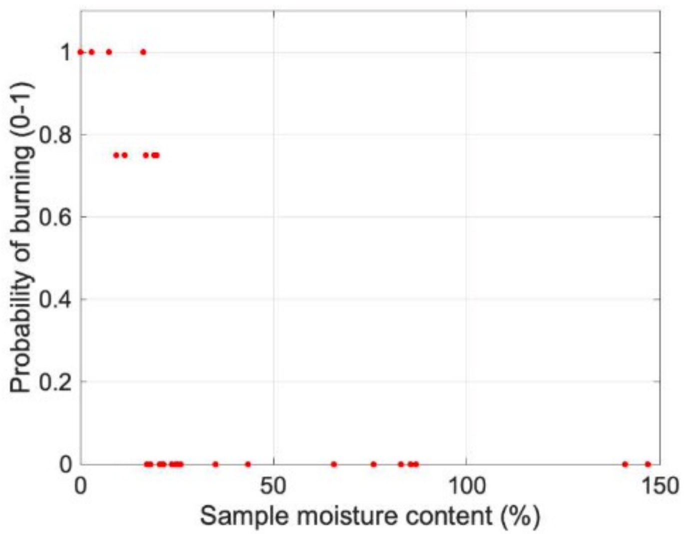
Fuel properties

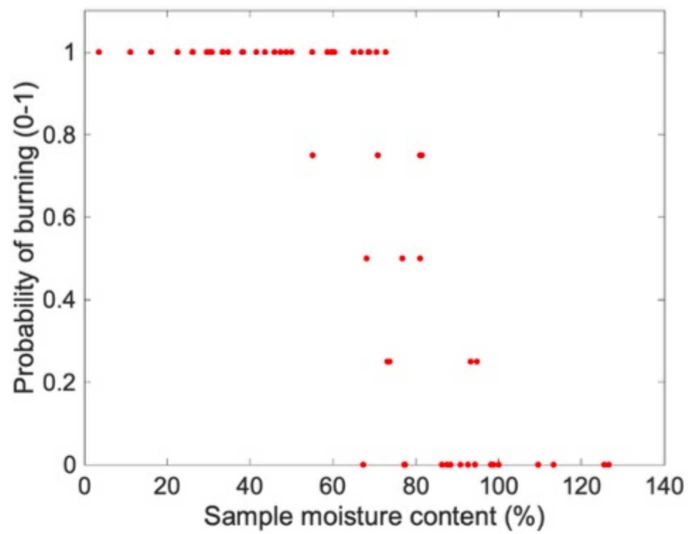
Fuel ignitability studies

Moss

Molinia







Conclusions

- Fire spread in heather is largely driven by the FMC of the fine parts of the vegetation.
- “Above ground” fuels drive fires.
  - Not included in Canadian system
- Interactions between burning of fuel layers are significant in determining fire behavior in heather moorland.
- FMC thresholds for ignition of ‘fine’ fuels has been determined.

Lochailort fire in the Scottish Highlands, May 2011

Ken MacDonald - https://wildfiretoday.com/2011/05/08/wildfire-in-the-scottish-highlands/

Comparison between shrub and grassland fuels and represented fuels in CFWI system

Andy Taylor, Debbie Fielding JHI

Heather moorland, Glensaugh

Molinia grassland, Ben Shieldaig

Comparison between shrub and grassland fuels and represented fuels in CFWI system

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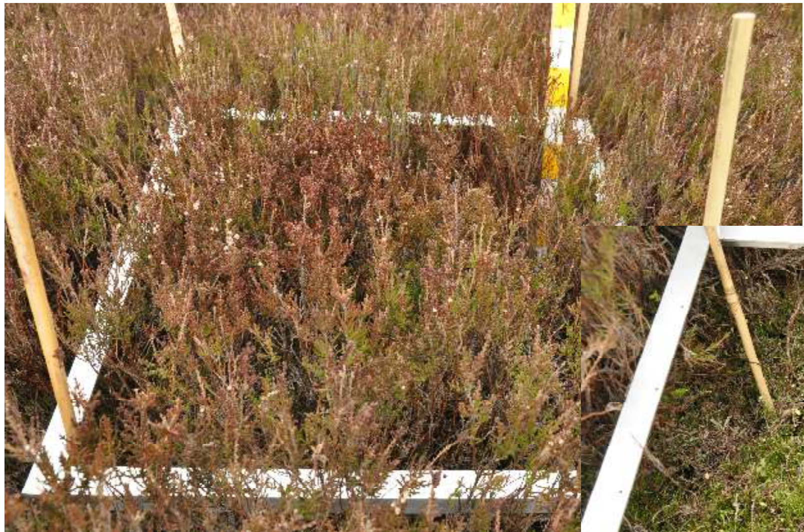
Code	Fuel description Canadian FWI (Van Wagner, 1974, 1987)	Possible Scottish vegetation equivalent (mass data this project)
Fine Fuel Moisture Code (FFMC)	Litter and other cured fine fuels in a forest stand, in a layer of dry weight about 0.05 lb/ft^2 (0.25 kg/m^2). Nominal depth (1.2cm)	Litter, moss and fibrous organic material down to amorphous organic material, dry mass 0.4-1.2 kg/m^2
Duff Moisture code (DMC)	Loosely compacted, decomposing organic matter 2 to 4 inches deep (Nominal depth 7cm) and weighing about 1 lb/ft^2 (5 kg/m^2) when dry	The LF layer – No equivalent in heathlands and grasslands
Drought code (DC)	Deep layer of compact organic (Nominal depth 18cm) matter weighing perhaps 10 lb/ft^2 (49 kg/m^2) when dry (10 – 20cm)	Amorphous organic layer with a highly variable depth (cms to ms in deep peats) Median depth for shallower layers is 19 cm. The FWI 49kg is equivalent to ca. 30cm organic layer

Comparison between shrub and grassland fuels and represented fuels in CFWI system

Fuels in a heather moorland



Shrub layer

Moss and litter layer

Organic layer

Comparison between shrub and grassland fuels and represented fuels in CFWI system

Moss and litter layer

Currently fuel contributing to FMCC would be moss and litter layer

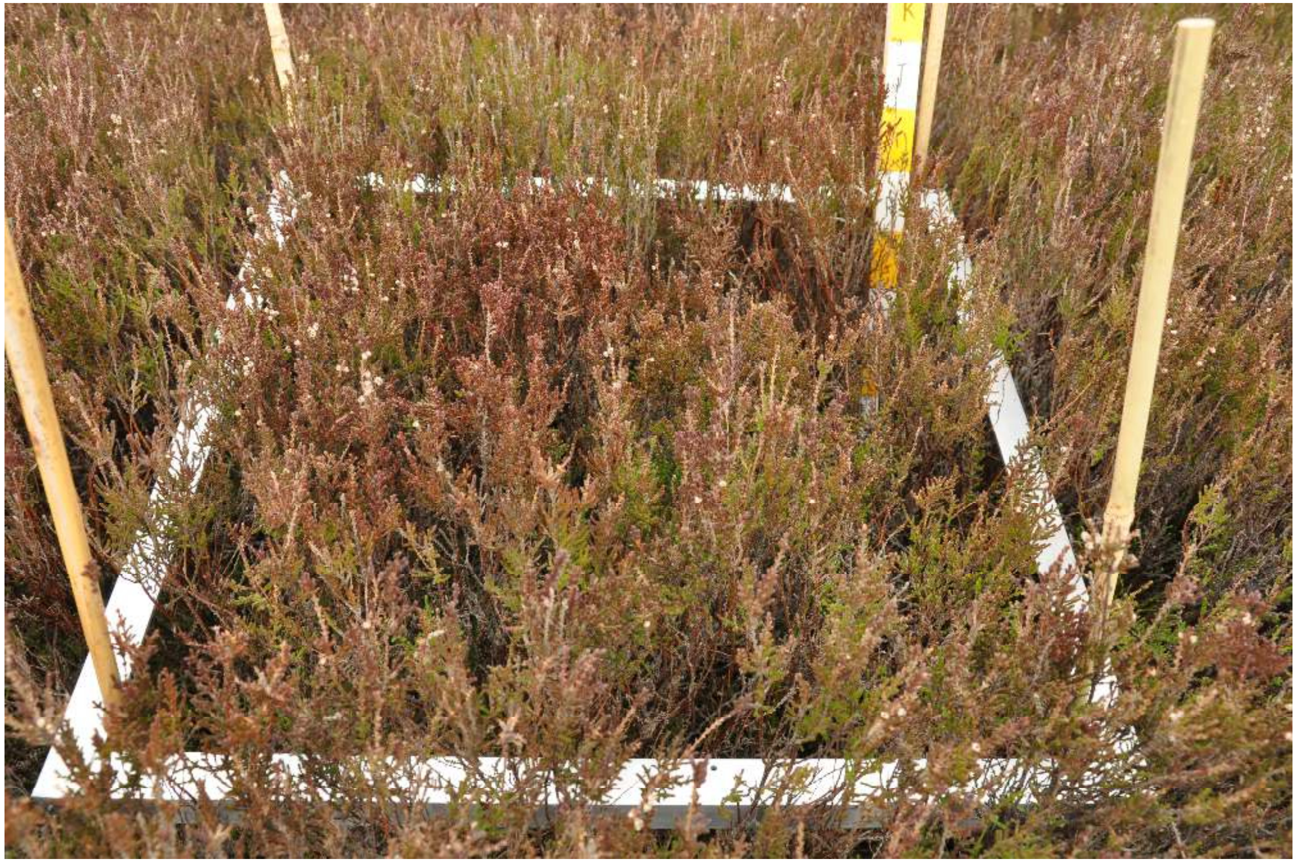
Moisture content hugely variable 13 – 500 (1600)

Response time greatly influenced by moss cover and species present

Response time buffered due to canopy cover

Comparison between shrub and grassland fuels and represented fuels in CFWI system

Shrub layer



Fuel load strongly influenced by management, age, slope, altitude

Comparison between shrub and grassland fuels and represented fuels in CFWI system

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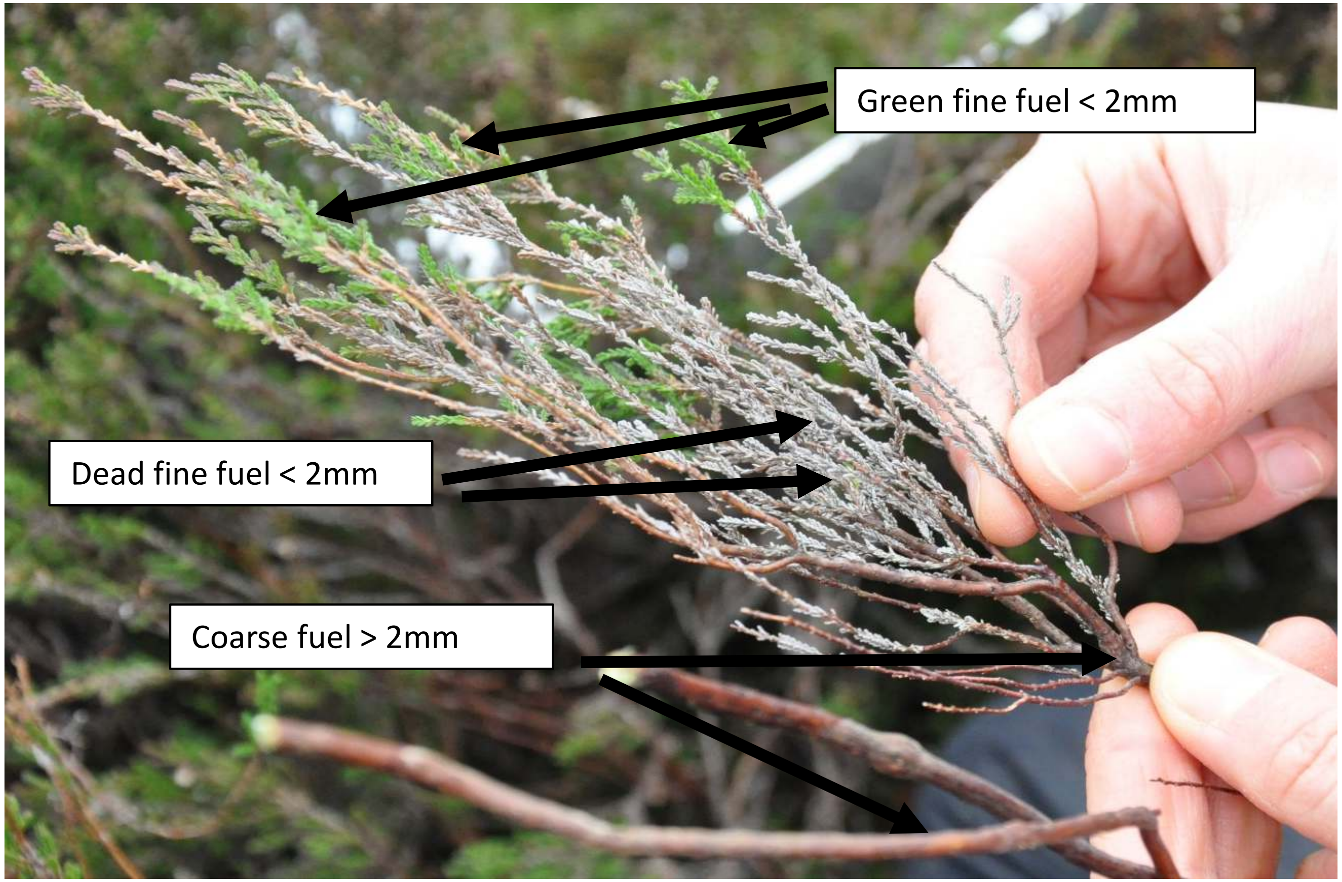
Shrub layer



Varying proportions of fine and coarse, live and dead – all of which differ in their responsiveness to available moisture, annual phenology, and life cycle stage

Comparison between shrub and grassland fuels and represented fuels in CFWI system

Conclusion

The fuel types in Scottish heather moorlands and grasslands are structurally and responsively different from those in the original forest fire scenarios in which the system was developed.

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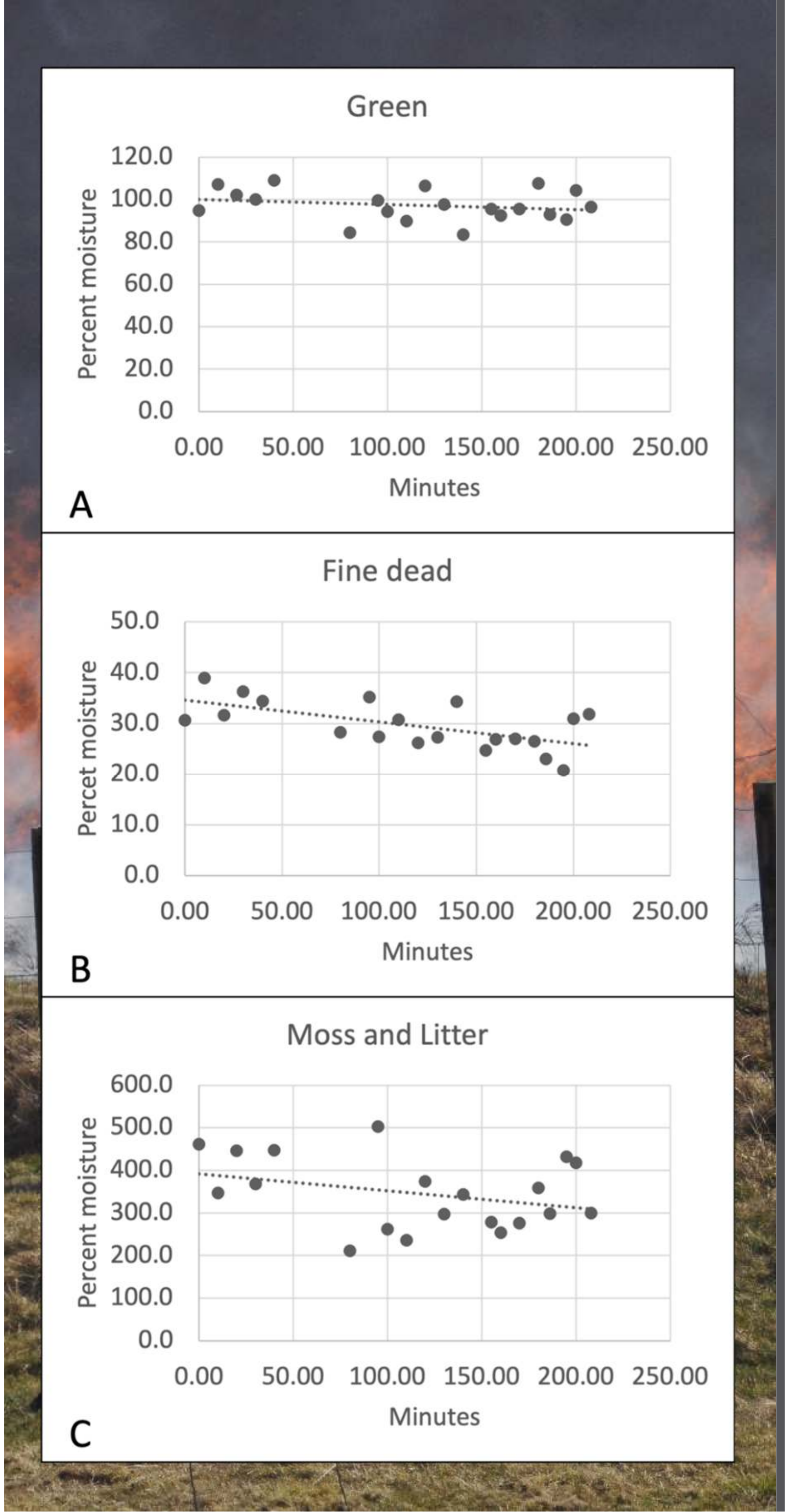
Wildfire in New Galloway, SW Scotland, April 2020

The way forward

Short-term (12 months)

- A workshop to share research results, stimulate conceptual thinking about fire danger rating system issues and develop a focused research and development programme.
- Optimise the current situation by creating a reliable wildfire intelligence decision support system for Scotland using existing evidence, infrastructure, and other capabilities.
- Further develop collaborations with related research and development work on similar fuel types.
- Maintain fire-related field work to retain a core research skills base in Scotland.



The way forward

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Medium term (1-5 years)

Research focus

- Establish a dedicated Scottish wildfire research group within existing higher education and Scottish government infrastructure
- Application of existing landscape mapping tools for assessing fuel type and loads
- Detailed investigations of the interactions between the different fuel layers and fire behaviours
- Determine moisture dynamics of different fuel layers.
- Model real-time effects of weather on fire behaviour.

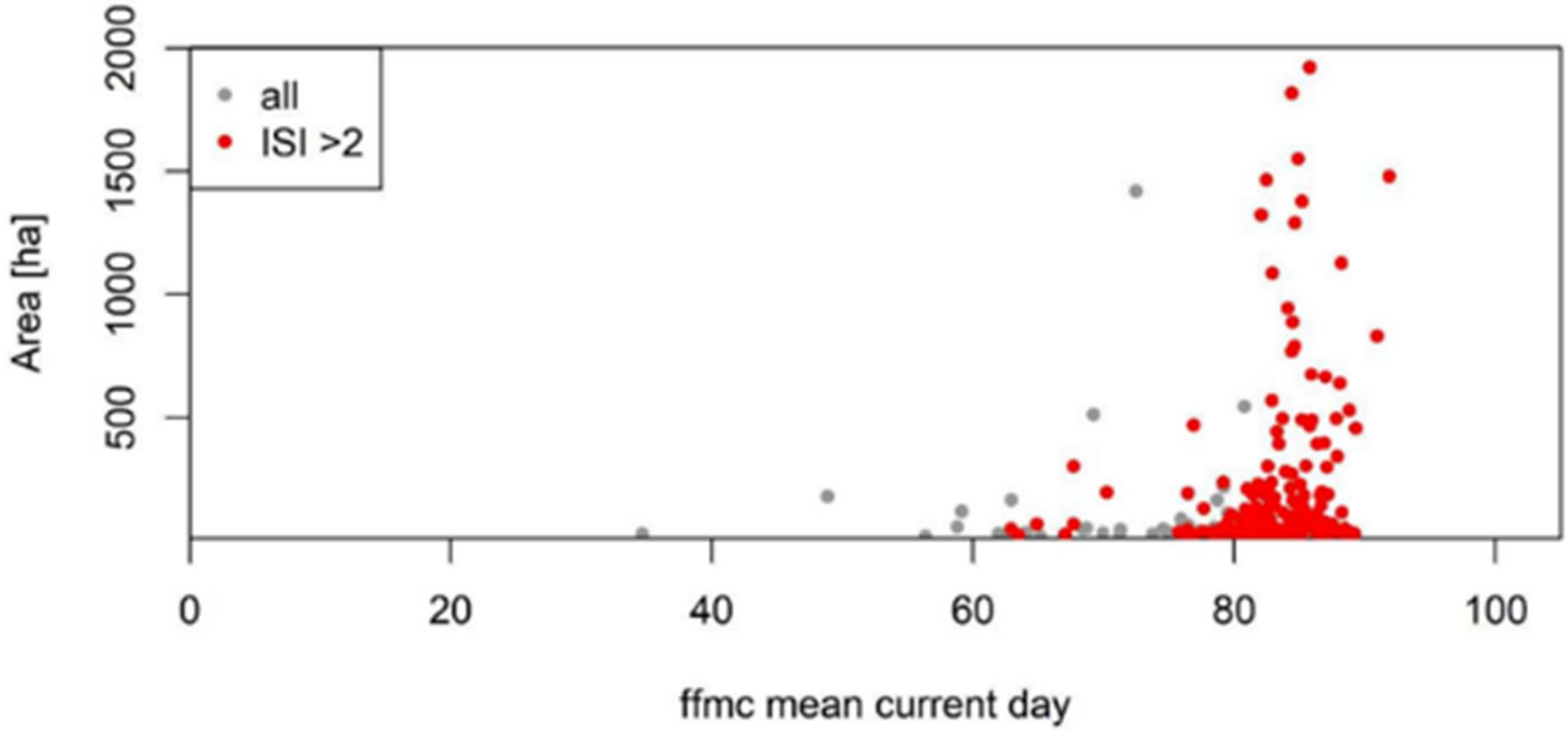
The way forward

Medium term (1-5 years)

- Develop fire behaviour models that allow fuel, weather and terrain conditions to be related to time-dependent assessments of fire intensity and fire severity
- Refinement of fire danger classes, that are related to the thresholds of control for fire suppression, and can be used as triggers for fire prevention activities and thresholds for prescribed fires

Possible use of sub-indices for fire danger intelligence purposes

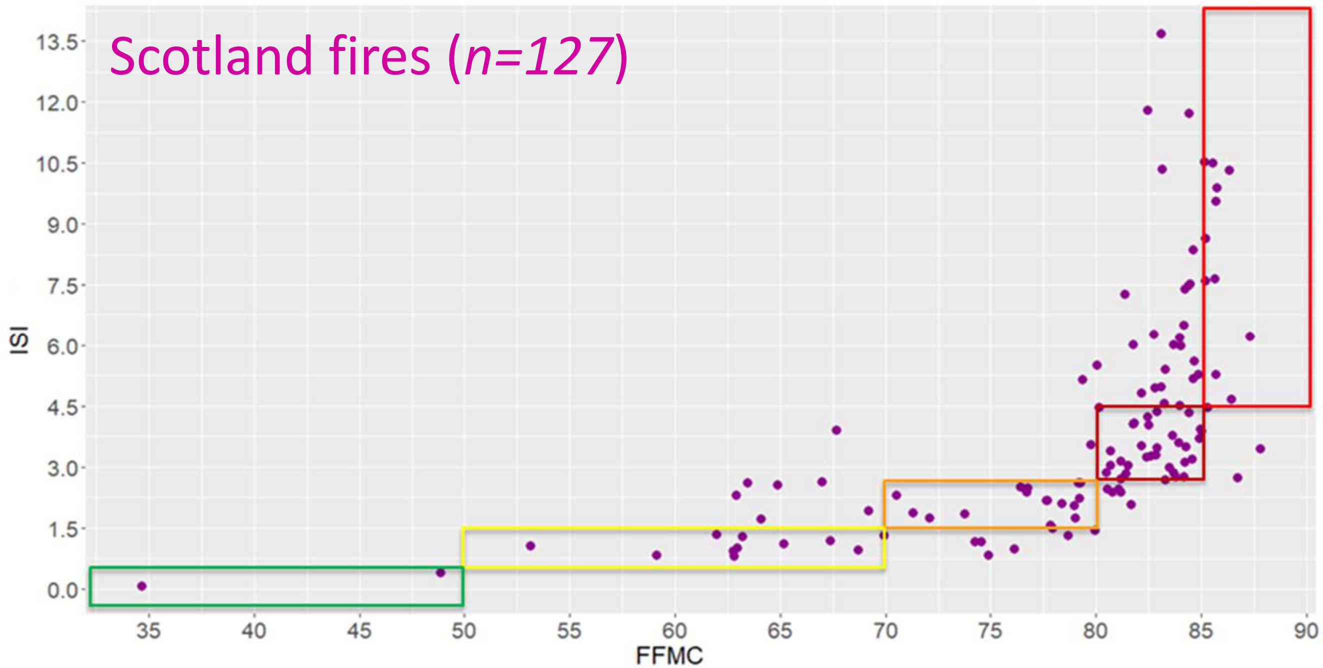
- Relationships between ISI and FFMC (UK data)

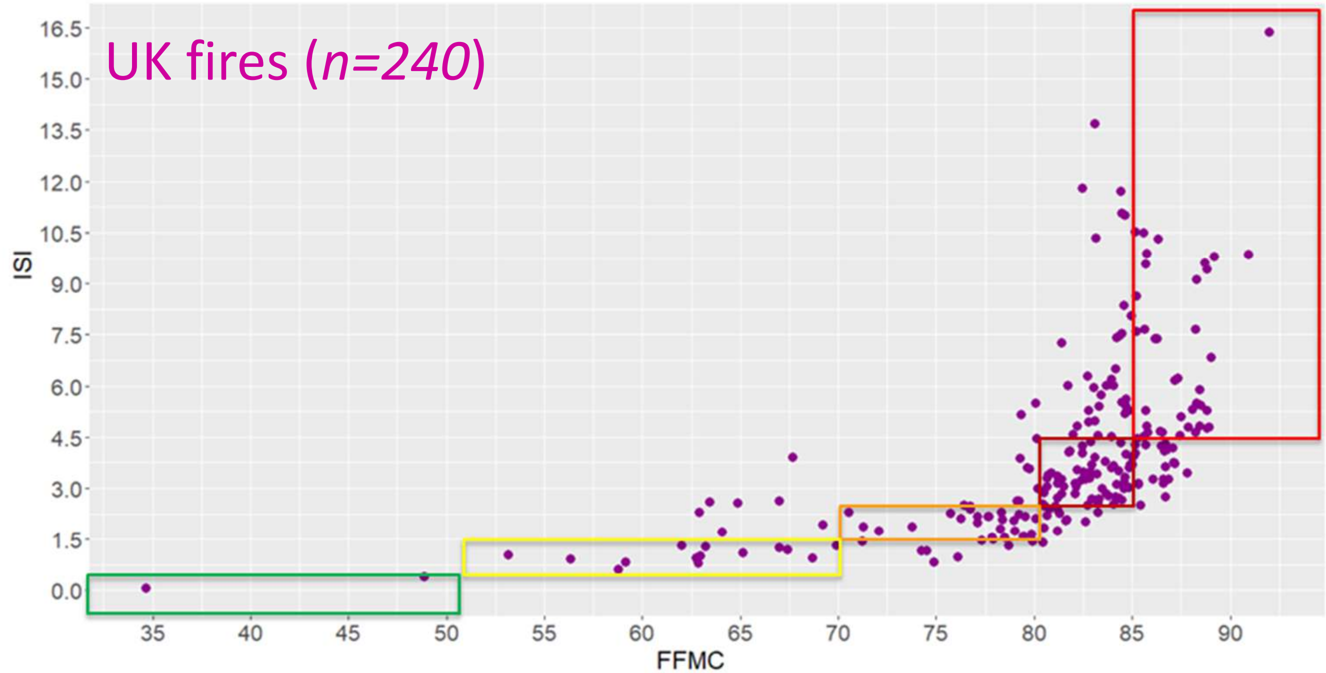


Fire Danger Classes: FFMC and ISI

Example of thresholds

Draft Fire Danger Class	FFMC	ISI
Low	<50	<0.5
Moderate	50 - 70	0.5 - <1.5
High	70 - 80	1.5> - <2.5
Very High	80 - 85	2.5 >- <4.5
Extreme	>85	4.5>





The way forward

Medium term (1-5 years)

Societal and organisational development

- Development of relevant government policies for fire awareness and prevention
- Stimulate co-operation between fire management agencies, research institutions and programmes through the Scottish Wildfire Forum, to set common standards for the use of fire danger information and disseminate this through awareness raising, and training initiatives.
- Work with end-users in government agencies, third sector and private organisations on the standards, presentation, descriptors, and communication of fire danger information

The way forward

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Long term (5-10 years)

- Continue the development of cost-sharing agreements between interested agencies and interests that will support a long-term multi-purpose, multi-stakeholder fire danger information platform.
- Continue the development of a suite of fire danger guidance material for fire and land managers to support training and decision making on the ground for fire management and suppression purposes.
- Continue fire danger rating system development in view of changing land-uses, climate, policy development, economic and social change.

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