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Forest Flammability Modelling to evaluate the fire flammability on different fire severity in Buangor Forest

Yanxiang Yang

Melbourne School Design (MSD), University of Melbourne, Melbourne, Australia

Abstract: *The vegetation type is the critical factor in evaluating how a wildfire will behave on-site at the burning time. Plant flammability is tested in a wide range of experiments in a laboratory in Creswick campus to visualize the ability of plants' ignitability and combustibility, as well as the ability to sustain combustion. In this case, based on an exploration of plant flammability and structure of forest stratum, forest flammability model is used to assess the influence of historical flammability in Buangor Forest following the 2010 fire. This research aims to find how fire severity effects predicted flammability using the Forest Flammability Model. The investigators analyse the data collected in different severity types in Buangor Forest from site study and compare their main features. Across three severity types, in Eucalyptus-dominated damp and dry forest, we measured Fuel Hazard Scores and Fuel Weights on-site, dimensions of different species (base height, top height, width). We estimated the spacing and density of them. The study in the essay mainly demonstrates flame height and flame length as referred data to analyse the effect of flammability. However, specific leaf area or bulk density may promote cumulative effects in some instances, or they could create counteractive effects because of high moisture content. Comparing with plant traits in different fire severity in both mild and severe weather condition will be necessary to identify important contributions to forest flammability from the composition of species.*

Keywords: *Forest Flammability Model, flame height, flame length, plant traits*

1. Introduction

Australian Bushfire consistently happens through millions of years and Landscape pattern in some ways is shaped by it. When there is a sharp light in the forest, fires are most likely to start. Black Saturday in March 2010 presented severe Bushfire burning about 1356 hectares from Mount Buangor State Park to Mount Cole State Forest. Fortunately, it was not a devastating catastrophe, and fuel loads can be sampled to the research of large blackened and charred area after fire issue. Over a long period, Bushfire becomes a natural part of the landscape. When it gradually recovers, original plants and vegetation can be collected as samples to analyze potential contributor and connector of fire based on their biological traits. In addition, some interesting things could happen during the process of recovery. For example, aboriginal people previously use fire as a tool to promote the growth of grassland, and they enhance hunting by maintaining the extent of grass. In some ways, fire helps to keep vegetation from being too dense to walk through by reducing levels of fuel. Theoretically, vegetation and individual plants can essentially control forest fire behavior by quantity and density of different fuel loads, flammability of surface fuel, the live parts after a fire, as well as the dimension in each section of forest structure (e.g., the height of the canopy, mid-canopy, elevated). Historical records from past Bushfire help us gain information about duration, the rate of spread and affected area in each stage. Potential fire contributor and connector can be estimated through the expansion map of Bushfire. In order to make fire prediction more accurately and improve fire management in the future, it is necessary to examine the influence of fire history, and this examination needs to be combined with the different weather condition and geographical feature such as slope if possible.

2. Aim

Because there are few studies to verify the potential contributor of bushfire in Buangor, comprehensive analysis with multiple forest fire severity types is needed to evaluate the historical fire behavior in this paper. Besides the role of species, the significance of forest structure, as well as weather condition, cannot be ignored to determine fire behavior. This research is trying to collect comprehensive

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data to do analysis and understand how fire severity affect flammability prediction with the help of Forest Flammability Model. Each fire severity type we also take some variations in fuels (if any) into consideration to see how these variations could influence fire behavior. Potentially the study can contribute to effective suppression plan and fire management for Buangor Forest in the future.

3. Methods

3.1 Study Area

Buangor is a region located in the west Victoria in south-eastern Australia, characterized by large natural area with a few small towns, covering about 181 kilometers west of the state capital, Melbourne. Species in the forest of Buangor is dominated by sclerophyll eucalypt, which makes the natural woodland easier to be ignited [5]. In some special seasons, a large amount of rainfall improves the moisture content of forest and decrease the possibility of wildfires. But periodic conditions of extreme hot weather still make this region prone to incur bushfire with a large area of forest covered by ignitable dry eucalypt and high dense acacia on elevated stratum. As for climate, average annal humidity is about 52% and wind blows at 11km/h with SW direction. Since it is located inland and far from coast, it is less likely to be influenced by coastal climate. According to historical records, Bushfire in 2010 burned approximately 1356 hectares between Mount Buangor State Park and Mount Cole State Forest. Many of the tree trunks were scorched, the canopies had stayed largely intact and there were signs of green leaves and shoots [6].

Based on our site excursion, canopy height in forest ranges from 10 to 40m, most of bars are ribbon bars and they show the low rates of mortality. Mid-canopy is at the height of 8m to 15m, and the elevated, domain by Acacia and PEA, almost grows to 1.2 to 2.5m(manual measurement).

Figure 1: Map of Buargon, west Victoria

3.2 Data Collection

Comprehensive data including location, topography, fuel weight, fuel moisture and fuel hazard scores of all stratum are collected from 12 sites in Mt Buangor State Park, with 3 different fire severities, Low severity (fig 2), Control severity (fig 3) and High severity (fig 4).

In each fire severity site, the types of data and approaches to collecting them are listed below:

-Location: take the name from 'what3words' app based on GPS signal. record longitude and latitude as well.

-Photos: 2 photos of each site

-Date, name, and assessors

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-Aspect and slope: using compass, clinometer.

-Fuel Hazard Score: referring to fuel hazard guide.

-Minimum radius to capture 15 trees.

-Dimension of canopy: top height, base height and width manually measuring with tapeline or using 'Arboreal' app to estimate the height, especially for canopy top height.

-Dimension of mid-canopy: top height, base height and width manually measuring with tapeline or using 'Arboreal' app to estimate the height, especially for canopy top height.

-Dimension of elevated: manually measuring height and width with tapeline.

These data were collected in 4 sites of low-fire severity, 4 sites of control-fire severity and 4 sites of high-fire severity. We manage data in 2 sections, table 1 show an overall environmental data about fuel hazard scores in each site. table 2 show the information of species in different stratum and we calculated their density and spacing.

Low Severity	FHS			
Location	L(1)	L(2)	L(3)	L(4)
Bark	High	Very High	Very High	High
(fuel weight)	2	5	5	2
Elevated	High	Middle	Middle	Low
(fuel weight)	2.5	1.5	1.5	1
Near Surface	High	Very High	Very High	Extreme
(fuel weight)	3.5	5	5	7
Surface	High	Middle	Middle	Extreme
(fuel weight)	11	7	7	25
S-NS	Very High	Very High	Very High	Extreme
(fuel weight)	14.5	12	12	32
OHS	Very High	Extreme	Extreme	High
(fuel weight)	33.5	18.5	18.5	35

Control Severity	FHS			
Location	C(1)	C(2)	C(3)	C(4)
Bark	Extreme	Extreme	Extreme	Extreme
(fuel weight)	0	7	7	7
Elevated	Low	Low	Low	Middle
(fuel weight)	0	1	0.5	1.5
Near Surface	High	High	Low	High
(fuel weight)	4	3	1.5	3.5
Surface	Middle	Middle	Extreme	Low
(fuel weight)	5	6	18	3
S-NS	High	High	Extreme	Middle
(fuel weight)	9	9	19.5	6.5
OHS	Very High	Very High	Extreme	Very High
(fuel weight)	9	17	27	15

High Severity	FHS			
Location	H(1)	H(2)	H(3)	H(4)
Bark	High	Middle	Extreme	High
(fuel weight)	2	1	7	2
Elevated	High	High	Extreme	Extreme
(fuel weight)	2.5	3	6.5	6.5
Near Surface	Very High	High	Extreme	Very High
(fuel weight)	5	4	7	5
Surface	High	High	Very High	Very High
(fuel weight)	11	7.68	16	16
S-NS	High	High	Extreme	Low
(fuel weight)	16	11.68	23	0
OHS	Very High	High	Extreme	Extreme
(fuel weight)	20.5	15.68	36.5	29.5

Table 1: Fuel Hazard Scores (FHS) of selected 12 sites in all levels of fire severity

This score is evaluated according to 'Overall fuel hazard assessment guide'. Information of location should be presented by 3 words or quantified latitude or longitude but because data is collected from different groups and not all groups successfully find accurate data, so this is replaced by simplified code.

Low Severity	Species			
Location	L(1)	L(2)	L(3)	L(4)
Canopy				
Species	Blue gum	Ribbon	Eucalypetus	Ribbon Gum
Radius	25	25	25	25
Total count	51	30	16	12
Density	38.5	65.4	122.7	163.6
Spacing	10.6	13.8	18.9	21.8
Mid-Canopy				
Species	Silver Wattle	Eucalyptus	Acacia	Black Wood
Radius	25	25	10	25
Total count	76	11	19	3
Density	25.8	178.5	16.5	654.5
Spacing	8.7	22.8	6.9	43.7
Elevated				
Species	Prickly Moses	Acacia	Bracken	Acacia
Radius	25	25	10	25
Total count	37	5	79	3
Density	53.1	392.7	4.0	654.5
Spacing	12.4	33.8	3.4	43.7
Near surface				
Species	Braken	Bracken	Grasstuft	Poa
Radius	25	15	5	2.5
Total count	30	10	31	75
Density	65.4	70.7	2.5	0.3
Spacing	13.8	14.4	3.7	0.9

Control Severity	Species			
Location	C(1)	C(2)	C(3)	C (4)
Canopy				
Species	Stringy bark	Stringy bark	Eucalypetus	Stringy bark
Radius	25	25	25	25
Total count	29	14	47	15
Density	67.7	140.2	41.8	130.9
Spacing	14.0	20.2	11.0	19.5
Mid-Canopy				
Species	n/a	n/a	n/a	Ribbon bark
Radius	n/a	n/a	n/a	25
Total count	n/a	n/a	n/a	3
Density	n/a	n/a	n/a	654.5
Spacing	n/a	n/a	n/a	43.7
Elevated				
Species	n/a	Ribbon bark	n/a	Acacia
Radius	n/a	25	n/a	25
Total count	n/a	1	n/a	3
Density	n/a	392.7	n/a	392.7
Spacing	n/a	33.8	n/a	33.8
Near surface				
Species	Braken	Poa	Grasstuft	Fern
Radius	7.2	7.5	10	1
Total count	23	74	240	15
Density	7.1	2.4	1.3	0.2
Spacing	4.5	2.6	1.9	0.8

High Severity	Species			
Location	H(1)	H(2)	H(3)	H(4)
Canopy				
Species	Blue Gum	Ecucalps	Ribbon bark	Ribbon bark
Radius	25	5	25	25
Total count	48	40	42	10
Density	40.9	2.0	46.7	196.3
Spacing	15.9	2.4	11.7	23.4
Mid-Canopy				
Species	Blue Gum	Ecucalps	Acacia	Ribbon bark
Radius	25	5	25	25
Total count	18	45	67	10
Density	109.1	1.7	29.3	196.3
Spacing	17.8	2.3	9.2	23.4
Elevated				
Species	Blue Gum	Pea	Gum	Ribbon Gum
Radius	25	2.5	25	1
Total count	12	35	145	10
Density	163.6	0.6	13.5	0.3
Spacing	21.8	1.3	6.3	0.9
Near surface				
Species	Bracken	Tufty Grass	Grass	Bracken/Poa
Radius	25	5	2	1
Total count	10	30	19	10
Density	196.3	2.6	0.7	0.3
Spacing	23.9	2.8	1.4	0.9

Table 2: Species information of selected 12 sites in all levels of fire severity

All data is collected by manual measurement with tapeline and calculated by fire model. The scale of study area is determined by surveyor, but it is representative enough

The species information shown above is generalized from a large amount of information of individual plants, to help build an impression on composition and distribution of plants. The density and spacing influence fire depth as well as the fire intensity when bushfire happens [4].

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Figure 2: Low severity site. Location- L3

Figure 3: Control severity site. Location- C2

Figure 4: High severity site. Location- H1

4. FFM (Forest Flammability Model)

Forest fire behavior needs to be quantified with key factors to infer the influence of composition of plant species and forest structure. Currently, Forest Flammability Model has been verified to be able to quantify the way that plant influence it, which help us better understand fire behavior and make prediction, leading to better management ultimately[1].

According to (Gill and Zylstra 2005), The FFM models behavior mechanistically and there are 3 components to determine flammability-ignitability, combustibility, and sustainability. This study tends to focus on analysis of outputs from model to identify the leaf traits with significant determinants of fire behavior. Some leaf traits may have accumulative effects to intensify the influence of fire.

The FFM predicts fire behavior is based on plant structure and leaf traits and it is used to test their effects on flame expansion and dimensions. The principle is shown as follows:

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1) A leaf ignites as the heat donor, and it creates a convective plume which fall in temperature as it flows along a flame angle defined vector to a distance from original heat source. In this process combustibility, the heat output from a burning leaf determines the scale of plume and temperature.

2) As the function of the leaf ignitability and temperature in the plume, leaves ignite when the duration of flame created by the donor leaf is beyond the time to ignition for the receiver.

3) Repeating process 1&2 in one-second time steps vertically from leaf to branch, plant, and plant stratum.

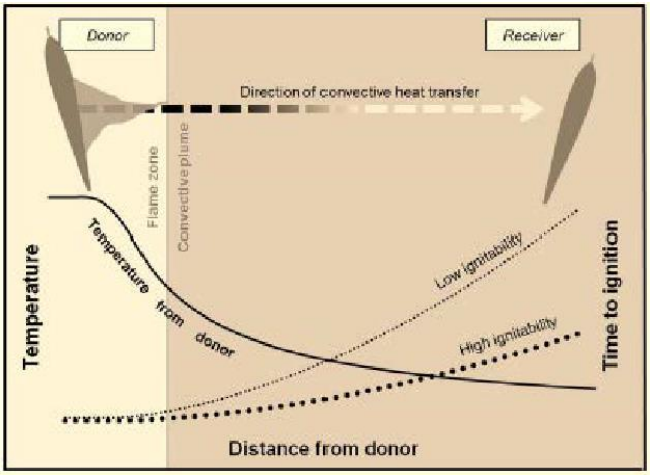

Figure 5: Diagram about Ignition from a donor to a receiver

Similarly, we can summarize that a convective plume of the flame from the donor substance follows a direction with controlled by the angle of the flame (dashed arrow). And the air temperature in the plume gradually decreases as it flows far from the donor (solid line). Thus, heating time to make receiver ignite increases at a rate depending on the leaf ignitability.

To determine the flame depth, combustibility and ignitability interact with each other. The number of leaves ignited in an area determine the density of foliage. A plume pattern or potential depth of ignited foliage can be figured out by the angle at which the burning plume intersects a plant stratum. However, the angle can be changed at each time step with the influence of wind speed and flame dimensions, correspondingly, plume pattern changes over time.

We can get the number of leaves in burning by the formular below:

N (leaves burning in a time step) =

N (the sum of leaves burning in the previous step) + N (newly ignited leaves) - N (extinguished leaves determined by sustainability properties)

As a result, flame length for that step is determined by the collaborative function of the amount of burning leaves and their combustibility, as well as physical process of heat transfer and air entrainment between them.

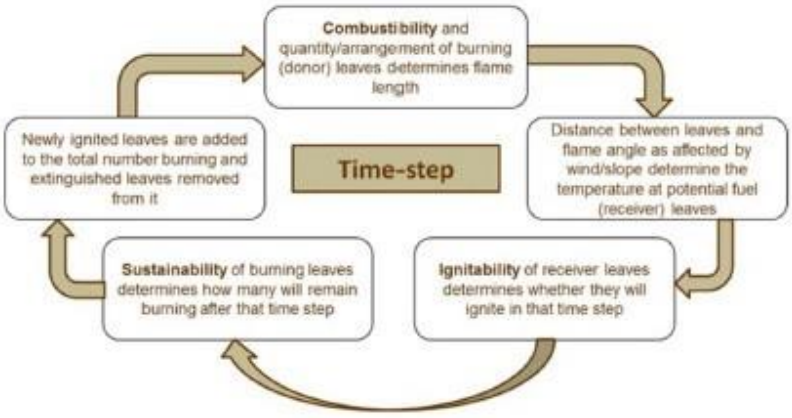

Figure 6: Processes involved in one time-step of FFM operation

The flame capacity to ignite strata above can determine the combustion height in each stratum, which

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reflect the fire severity in vegetation with multiple stratums. Fire severity overall is determined by both the heat produced from the donor strata and that required for the receiver stratum ignition. However, it must be influenced by the spacing relationship between donor and receiver because convective heat can lose through heat-transfer process. on the other hand, if plants in higher strata above a flame but is not burned, the speed and direction of wind in burning strata may cause fire behavior on strata at higher level[2].

In the FFM, Leaf Area Index (LAI) can model such effects with a function of the shelter formed by the foliage overhead. This index is combined with key factors including leaf size, density and spacing of branches, as well as physical size and spacing of plant crowns. Moreover, wind in turn, works on the heat plume and further affect the plume pattern, possibly making a difference of the distance and the angle to receiver fuel loads. Therefore, the flammability of donor and the ignitability of receiver contribute to evolving flame dimensions (angle & height) and propagation affected by leaf traits. Environmental effects from overstorey sheltering also make a difference as well. Both exogenous and endogenous factors are simulated in the Forest Flammability Model, and we can effectively figure out not only flame characteristics, but the propagation of fire[3].

There is a dominated environmental wind with a greater speed and a convective heat plume flow near the cluster of plants in each scenario,

Scenario a: Donor plants created a convective plume, intersecting with the receiver plants, but the condition is not strong enough support ignition for receiver.

Scenario b: The flammability of donor increases and gives a larger flame to ignite the receiver.

Scenario c: Receiver ignitability is greater on the condition that the flammability of donor keeps the same in that of scenario b.

Scenario d: The same flammability of plants as that in scenario a, wider tree spacing, wind speed is greater at the flame level. the flame depth goes up. Larger flame contributes to the ignition of receiver.

Scenario e: The same pre-condition as scenario d. Flame dimensions remain unchanged as the heat plume dissipates in the long distance between donor and receiver. The stratum above is less likely to be ignited comparing with scenario a.

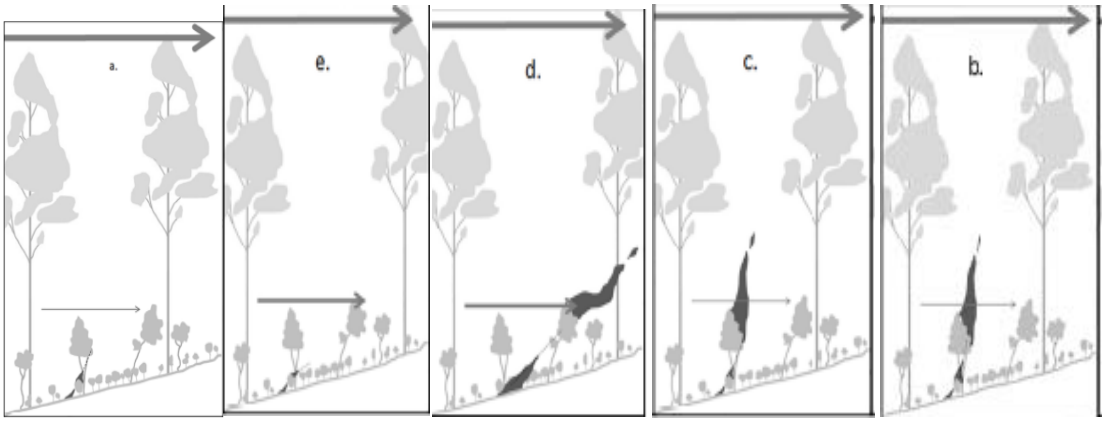

Figure 8: Effects of donor flammability, receiver ignitability and overstorey sheltering on fire severity

4.1 Model Operation

FFM works as a C++ based exe file. It uses Notepad for inputs and runs in the Windows command prompt. Based on our collected data, we refer to Monte Carlo parameter to run our model in process, which can be used to create probabilistic results by a csv output file.

The process makes each record represent one run in process and provide detailed level information, although it is not a deterministic result, but it can be referred to make comparison in different condition of fuel types and climate change. The output file contains overall information of flame length and angles at basic level. The flame height is defined not clearly and an original flame above the ground is possible to grow higher than the flame tip so this factor is divided into tip heights and original heights (Fig. 9).

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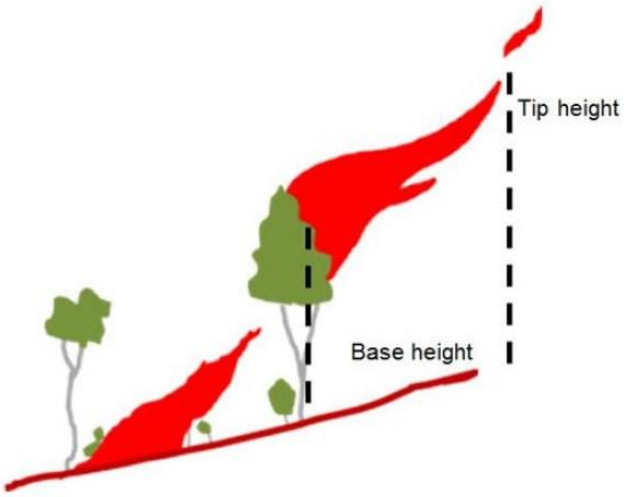

Figure 9: Origin and tip height in flames

We use our required input file and ffm.exe to run the model in the Window command. The steps are listed below:

1) Set a director to place the exe and input file (information about table 1&2).
2) Copy the address information.
3) Open a Windows Command Prompt window.
4) Type 'cmd' into windows search bar.
5) Type cd-[space]-right click in the window- paste - [Enter].
6) Type ffm [input file name].txt-[Enter]. Run the model within cmd.
7) Type ffm [input file name].txt-[output file name].txt/csv. Save the results in a txt file.

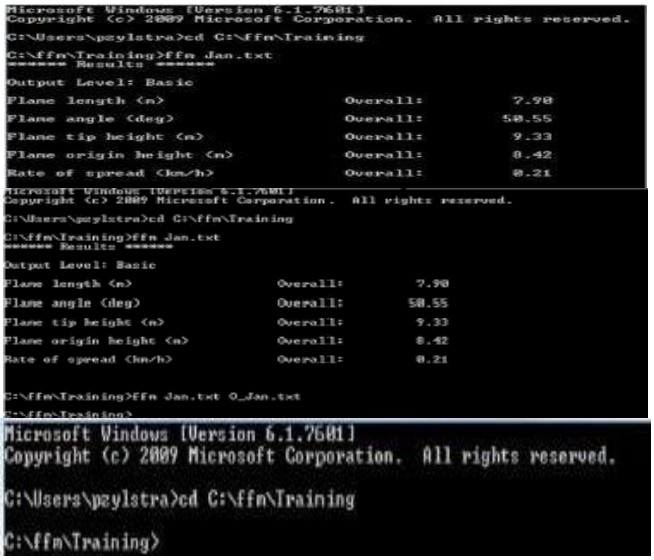

Figure 10: Process to run the model

4.2 Comparison between different fire severity classes

Model each severity site and we can get a variety of information in terms of flame height and flame angle. We even model the site under two different weather condition, Prescribed burning weather (PB)- mild weather conditions; Black Saturday weather (BS)- severe weather conditions. The comparison is done in two different ways:

1) In the same fire severity sites (4 sites in each severity), compare flame height, length and angle the with each other to generalize main features.
2) In the same fire severity (low, control and high), compare flame height, length, and angle under different weather conditions (PB & BS) respectively. Figure out how the weather can influence overall fire behavior.

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3) Under the same weather condition, compare flame height, length, and angle in different fire severity sites, generalize the main traits in each severity level.

4) Combine with the above two comparisons, comparing with their changing rate and if possible, try to figure out whether extreme weather condition (BS) would affect more in some severity sites than others (e.g. flame height will change more in high severity sites than that in low severity sites, probably).

5. Results

Under mild weather condition, fire behaviors in each fire severity are shown below:

Table 4: Fire behavior in Control-severity sites calculated by Forest Flammability Model under the condition of prescribed weather

Mild weather condition		Stratum	Site	L(1)	L(2)	L(3)	L(4)
Low fire severity	Input	Surface	Species	Acacia dealbata	n/a	n/a	n/a
			Plant seperation	22.8	n/a	n/a	n/a
			Leaf mositure	0.79	n/a	n/a	n/a
			Igition temperature(℃)	220	n/a	n/a	n/a
		Near-Surface	Species	Pteridium esculentum	Bracken	n/a	Poa tenera
			Plant seperation	14.35	0.873	n/a	2.72
			Leaf mositure	0.89	0.52	n/a	0.52
			Igition temperature(℃)	260	260	n/a	260
		Elevated	Species	Eucalyptus obliqua	n/a	Pteridium esculentum	Pteridium esculentum
			Plant seperation	22.8	n/a	13.8	3.4
			Leaf mositure	0.78	n/a	0.89	0.89
			Igition temperature(℃)	220	n/a	260	260
		Mid-Storey	Species	Eucalyptus obliqua	n/a	Acacia dealbata	Eucalyptus obliqua
			Plant seperation	2.47	n/a	8.7	6.94
			Leaf mositure	0.78	n/a	0.79	0.78
			Igition temperature(℃)	220	n/a	220	220
		Canopy	Species	Eucalyptus obliqua	Ribbon gum	Blue gum	Eucalyptus obliqua
			Plant seperation	13.8	21.837	10.6	18.91
			Leaf mositure	0.78	0.78	0.78	0.78
			Igition temperature(℃)	220	220	220	220
	Output	Surface	Flame length(m)	1.07	1.12	0.49	2
			Flame angle(deg)	65.55	60.37	47.01	12.08
			Flame tip height(m)	0.96	0.94	0.34	0.32
			Flame orginal height(m)	0	0	0	0
			Species flame tip heights (m)	n/a	Poa 1.50	n/a	n/a
		Near-Surface	Flame length(m)	1.77	2.19	n/a	0.85
			Flame angle(deg)	75.32	74.62	n/a	4.8
			Flame tip height(m)	1.71	2.11	n/a	0.42
			Flame orginal height(m)	1.07	1.34	n/a	0.46
			Species flame tip heights (m)	Pteridium esculentum 1.71	Bracken 2.74	n/a	Poa tenera 0.42
		Elevated	Flame length(m)	3.95	n/a	1.6	1.29
			Flame angle(deg)	69.82	n/a	63.5	4.92
			Flame tip height(m)	5.32	n/a	1.44	0.54
			Flame orginal height(m)	3.8	n/a	0.91	0.69
			Species flame tip heights (m)	Eucalyptus obliqua 7.42	n/a	Pteridium esculentum 1.44	Pteridium esculentum 0.54
		Mid-Storey	Flame length(m)	8.33	n/a	n/a	0
			Flame angle(deg)	74.8	n/a	n/a	0
			Flame tip height(m)	10.01	n/a	n/a	0
			Flame orginal height(m)	4.66	n/a	n/a	0
			Species flame tip heights (m)	Eucalyptus obliqua 10.01	n/a	n/a	Eucalyptus obliqua 0.00
		Canopy	Flame length(m)	15.01	0	0	0
			Flame angle(deg)	72.12	0	0	0
			Flame tip height(m)	22.14	0	0	0
			Flame orginal height(m)	14.13	0	0	0
			Species flame tip heights (m)	Eucalyptus obliqua 22.14	Stringy Bark 0.00	Blue Gum 0.00	Eucalyptus obliqua 0.00
		Overall	Flame length(m)	21.32	2.19	1.6	2.23
			Flame angle(deg)	72.52	69.8	59.62	8.36
			Flame tip height(m)	22.14	2.11	1.44	0.54
			Flame orginal height(m)	14.13	1.34	0.91	0.69
Mild weather condition		Stratum	Site	C(1)	C(2)	C(3)	C(4)
Control fire severity	Input	Surface	Species	n/a	n/a	n/a	n/a
			Plant seperation	n/a	n/a	n/a	n/a
			Leaf mositure	n/a	n/a	n/a	n/a
			Igition temperature(℃)	n/a	n/a	n/a	n/a
		Near-Surface	Species	Lomandra filiformis	Poa	Lomandra filiformis	Pteridium esculentum
			Plant seperation	0.78	2.638	1.9	0.78
			Leaf mositure	0.52	0.52	0.52	0.89
			Igition temperature(℃)	260	260	260	260
		Elevated	Species	n/a	n/a	n/a	Acacia dealbata
			Plant seperation	n/a	n/a	n/a	33.83
			Leaf mositure	n/a	n/a	n/a	0.79
			Igition temperature(℃)	n/a	n/a	n/a	220
		Mid-Storey	Species	n/a	n/a	n/a	n/a
			Plant seperation	n/a	n/a	n/a	n/a
			Leaf mositure	n/a	n/a	n/a	n/a
			Igition temperature(℃)	n/a	n/a	n/a	n/a
		Canopy	Species	Eucalyptus obliqua	Stringy Bark	Eucalyptus obliqua	Eucalyptus obliqua
			Plant seperation	14	20.216	11	19.53
			Leaf mositure	0.78	0.78	0.78	0.78
			Igition temperature(℃)	220	220	220	220
	Output	Surface	Flame length(m)	0.92	2	2	0.91
			Flame angle(deg)	43.25	37.15	28.98	39.38
			Flame tip height(m)	0.53	0.63	0.66	0.49
			Flame orginal height(m)	0	0	0	0
			Species flame tip heights (m)	n/a	n/a	n/a	n/a
		Near-Surface	Flame length(m)	1.14	1.81	1.21	0.93
			Flame angle(deg)	49.85	34.16	17.76	40.25
			Flame tip height(m)	0.8	0.62	0.21	0.68
			Flame orginal height(m)	0.58	0.94	0.27	0.49
			Species flame tip heights (m)	Lomandra filiformis 0.66	Poa 0.54	Lomandra filiformis 0.21	Pteridium esculentum 0.68
		Elevated	Flame length(m)	n/a	n/a	n/a	n/a
			Flame angle(deg)	n/a	n/a	n/a	n/a
			Flame tip height(m)	n/a	n/a	n/a	n/a
			Flame orginal height(m)	n/a	n/a	n/a	n/a
			Species flame tip heights (m)	n/a	n/a	n/a	n/a
		Mid-Storey	Flame length(m)	n/a	n/a	n/a	0
			Flame angle(deg)	n/a	n/a	n/a	0
			Flame tip height(m)	n/a	n/a	n/a	0
			Flame orginal height(m)	n/a	n/a	n/a	0
			Species flame tip heights (m)	n/a	n/a	n/a	Acacia dealbata 0.00
		Canopy	Flame length(m)	0	0	0	0
			Flame angle(deg)	0	0	0	0
			Flame tip height(m)	0	0	0	0
			Flame orginal height(m)	0	0	0	0
			Species flame tip heights (m)	Eucalyptus obliqua 0.00	Stringy Bark 0.00	Eucalyptus obliqua 0.00	Acacia dealbata 0.00
		Overall	Flame length(m)	1.14	2.02	2.05	0.94
			Flame angle(deg)	46.9	35.73	24.76	39.82
			Flame tip height(m)	0.8	0.63	0.66	0.68
			Flame orginal height(m)	0.58	0.94	0.27	0.49

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Table 5: Fire behavior in High-severity sites calculated by Forest Flammability Model under the condition of prescribed weather

Mild weather condition		Stratum	Site	L(1)	L(2)	L(3)	L(4)
High fire severity	Input	Surface	Species	n/a	n/a	n/a	n/a
			Plant seperation	n/a	n/a	n/a	n/a
			Leaf mositure	n/a	n/a	n/a	n/a
			Igition temperature(℃)	n/a	n/a	n/a	n/a
		Near-Surface	Species	Pteridium esculentum	Poa tenera	Lomandra filiformis	n/a
			Plant seperation	23.921	2.76	1.4	n/a
			Leaf mositure	0.89	0.52	0.52	n/a
			Igition temperature(℃)	260	260	260	n/a
		Elevated	Species	Eucalyptus	Acacia dealbata	n/a	Pteridium esculentum
			Plant seperation	21.837	1.28	n/a	0.96
			Leaf mositure	0.78	0.79	n/a	0.89
			Igition temperature(℃)	220	220	n/a	260
		Mid-Storey	Species	Eucalyptus obliqua	Eucalyptus obliqua	n/a	n/a
			Plant seperation	17.8295	2.26	n/a	n/a
			Leaf mositure	0.78	0.78	n/a	n/a
			Igition temperature(℃)	220	220	n/a	n/a
		Canopy	Species	Eucalyptus obliqua	Eucalyptus obliqua	Eucalyptus obliqua	Ribbon Gum
			Plant seperation	2.47	2.39	11.7	23.9
			Leaf mositure	0.78	0.78	0.78	0.78
			Igition temperature(℃)	220	220	220	220
	Output	Surface	Flame length(m)	0.6	0.35	1.77	0.65
			Flame angle(deg)	34.69	80.6	54.25	33.62
			Flame tip height(m)	0.32	0.34	1.25	0.33
			Flame orginal height(m)	0	0	0	0
			Species flame tip heights (m)	n/a	n/a	n/a	n/a
		Near-Surface	Flame length(m)	1.47	0.66	0.91	n/a
			Flame angle(deg)	61.18	85.22	33.94	n/a
			Flame tip height(m)	1.48	0.66	0.4	n/a
			Flame orginal height(m)	0.91	0.3	0.3	n/a
			Species flame tip heights (m)	Pteridium esculentum 1.48	Poa tenera 0.66	Lomandra filiformis 0.40	n/a
		Elevated	Flame length(m)	7.53	0.77	n/a	0.53
			Flame angle(deg)	82.84	62.89	n/a	25.92
			Flame tip height(m)	8.68	1.32	n/a	0.21
			Flame orginal height(m)	3.6	1.03	n/a	0.15
			Species flame tip heights (m)	Eucalyptus obliqua 8.68	Acacia dealbata 1.32	n/a	Pteridium esculentum 0.21
		Mid-Storey	Flame length(m)	11.33	0	n/a	n/a
			Flame angle(deg)	83.05	0	n/a	n/a
			Flame tip height(m)	15.39	0	n/a	n/a
			Flame orginal height(m)	9.01	0	n/a	n/a
			Species flame tip heights (m)	Eucalyptus obliqua 15.39	Eucalyptus obliqua 0.00	n/a	n/a
		Canopy	Flame length(m)	23.6	0	0	0
			Flame angle(deg)	81.59	0	0	0
			Flame tip height(m)	39.79	0	0	0
			Flame orginal height(m)	27.09	0	0	0
			Species flame tip heights (m)	Eucalyptus obliqua 39.79	Eucalyptus obliqua 0.00	Eucalyptus obliqua 0.00	Ribbon Gum 0.00
		Overall	Flame length(m)	35.81	0.77	1.8	0.67
			Flame angle(deg)	80.87	74.7	47.36	30.18
			Flame tip height(m)	39.79	1.32	1.25	0.33
			Flame orginal height(m)	27.09	1.03	0.3	0.15

Among the information in input file, we consider the species, plant separation(density), live leaf moisture are the most important variations to affect fire behavior. For output file, we select flame height, flame length and flame angle to reflect fire behaviors. Tip height and original height can help us to predict ordinary and extreme situation in bushfire. Serious condition is more likely to happen in low and high severity site.

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Considering historical bushfire in 2010, we collect environmental data from Black Saturday and put it into FFM. Each severity site has been remodeled and the results are collected as comparing groups (BS). The information on each site in different fire severity are shown as following tables.

Table 6: Comparable Fire behavior in Low-severity sites under the conditions of both mild and Severe weather

Low-severity Site		L(1)			Low-severity Site		L(2)		
Weather condition		PB	BS	Increment	Weather condition		PB	BS	Increment
Surface	Flame length(m)	1.07	2	0.93	Surface	Flame length(m)	1.12	2	0.88
	Flame angle(deg)	65.55	11.04	-54.51		Flame angle(deg)	60.37	20.09	-40.28
	Flame tip height(m)	0.96	0.35	-0.61		Flame tip height(m)	0.94	0.59	-0.35
	Flame orginal height(m)	0	0	0		Flame orginal height(m)	0	0	0
	Species flame tip heights (m)	n/a	n/a	n/a		Species flame tip heights (m)	Poa 1.50	n/a	n/a
lear-Surfac	Flame length(m)	1.77	1.83	0.06	Near-Surface	Flame length(m)	2.19	2.48	0.29
	Flame angle(deg)	75.32	10.02	-65.3		Flame angle(deg)	74.62	24.81	-49.81
	Flame tip height(m)	1.71	0.3	-1.41		Flame tip height(m)	2.11	0.96	-1.15
	Flame orginal height(m)	1.07	0.25	-0.82		Flame orginal height(m)	1.34	0.52	-0.82
	Species flame tip heights (m)	Pteridium esculentum 1.71	Pteridium esculentum 0.30	n/a		Species flame tip heights (m)	Bracken 2.74	Bracken 1.07	n/a
Elevated	Flame length(m)	3.95	0	-3.95	Elevated	Flame length(m)	n/a	n/a	n/a
	Flame angle(deg)	69.82	0	-69.82		Flame angle(deg)	n/a	n/a	n/a
	Flame tip height(m)	5.32	0	-5.32		Flame tip height(m)	n/a	n/a	n/a
	Flame orginal height(m)	3.8	0	-3.8		Flame orginal height(m)	n/a	n/a	n/a
	Species flame tip heights (m)	Eucalyptus obliqua 7.42	Acacia dealbata 0.00	n/a		Species flame tip heights (m)	n/a	n/a	n/a
Mid-Storey	Flame length(m)	8.33	0	-8.33	Mid-Storey	Flame length(m)	n/a	n/a	n/a
	Flame angle(deg)	74.8	0	-74.8		Flame angle(deg)	n/a	n/a	n/a
	Flame tip height(m)	10.01	0	-10.01		Flame tip height(m)	n/a	n/a	n/a
	Flame orginal height(m)	4.66	0	-4.66		Flame orginal height(m)	n/a	n/a	n/a
	Species flame tip heights (m)	Eucalyptus obliqua 10.01	Eucalyptus obliqua 0.00	n/a		Species flame tip heights (m)	n/a	n/a	n/a
Canopy	Flame length(m)	15.01	18.7	3.69	Canopy	Flame length(m)	0	0	0
	Flame angle(deg)	72.12	15.49	-56.63		Flame angle(deg)	0	0	0
	Flame tip height(m)	22.14	17.33	-4.81		Flame tip height(m)	0	0	0
	Flame orginal height(m)	14.13	14.47	0.34		Flame orginal height(m)	0	0	0
	Species flame tip heights (m)	Eucalyptus obliqua 22.14	Eucalyptus obliqua 17.33	n/a		Species flame tip heights (m)	Stringy Bark 0.00	Ribbon Gum 0.00	n/a
Overall	Flame length(m)	21.32	18.7	-2.62	Overall	Flame length(m)	2.19	2.48	0.29
	Flame angle(deg)	72.52	14.65	-57.87		Flame angle(deg)	69.8	22.71	-47.09
	Flame tip height(m)	22.14	17.33	-4.81		Flame tip height(m)	2.11	0.96	-1.15
	Flame orginal height(m)	14.13	14.47	0.34		Flame orginal height(m)	1.34	0.52	-0.82

Low-severity Site		L(3)			Low-severity Site		L(4)		
Weather condition		PB	BS	Increment	Weather condition		PB	BS	Increment
Surface	Flame length(m)	0.49	2	1.51	Surface	Flame length(m)	2	2	0
	Flame angle(deg)	47.01	28.54	-18.47		Flame angle(deg)	12.08	12.08	0
	Flame tip height(m)	0.34	0.86	0.52		Flame tip height(m)	0.32	0.32	0
	Flame orginal height(m)	0	0	0		Flame orginal height(m)	0	0	0
	Species flame tip heights (m)	n/a	n/a	n/a		Species flame tip heights (m)	n/a	n/a	n/a
Near-Surface	Flame length(m)	n/a	n/a	n/a	Near-Surface	Flame length(m)	0.85	0.85	0
	Flame angle(deg)	n/a	n/a	n/a		Flame angle(deg)	4.8	4.8	0
	Flame tip height(m)	n/a	n/a	n/a		Flame tip height(m)	0.42	0.42	0
	Flame orginal height(m)	n/a	n/a	n/a		Flame orginal height(m)	0.46	0.46	0
	Species flame tip heights (m)	n/a	n/a	n/a		Species flame tip heights (m)	Poa tenera 0.42	Poa tenera 0.42	n/a
Elevated	Flame length(m)	1.6	3.71	2.11	Elevated	Flame length(m)	1.29	1.29	0
	Flame angle(deg)	63.5	28.9	-34.6		Flame angle(deg)	4.92	4.92	0
	Flame tip height(m)	1.44	1.7	0.26		Flame tip height(m)	0.54	0.54	0
	Flame orginal height(m)	0.91	0.78	-0.13		Flame orginal height(m)	0.69	0.69	0
	Species flame tip heights (m)	Pteridium esculentum 1.44	Pteridium esculentum 1.70	n/a		Species flame tip heights (m)	Pteridium esculentum 0.54	Pteridium esculentum 0.54	n/a
Mid-Storey	Flame length(m)	n/a	n/a	n/a	Mid-Storey	Flame length(m)	0	0	0
	Flame angle(deg)	n/a	n/a	n/a		Flame angle(deg)	0	0	0
	Flame tip height(m)	n/a	n/a	n/a		Flame tip height(m)	0	0	0
	Flame orginal height(m)	n/a	n/a	n/a		Flame orginal height(m)	0	0	0
	Species flame tip heights (m)	n/a	n/a	n/a		Species flame tip heights (m)	Eucalyptus obliqua 0.00	Eucalyptus obliqua 0.00	n/a
Canopy	Flame length(m)	0	0	0	Canopy	Flame length(m)	0	0	0
	Flame angle(deg)	0	0	0		Flame angle(deg)	0	0	0
	Flame tip height(m)	0	0	0		Flame tip height(m)	0	0	0
	Flame orginal height(m)	0	0	0		Flame orginal height(m)	0	0	0
	Species flame tip heights (m)	Blue Gum 0.00	Blue gum 0.00	n/a		Species flame tip heights (m)	Eucalyptus obliqua 0.00	Eucalyptus obliqua 0.00	n/a
Overall	Flame length(m)	1.6	3.71	2.11	Overall	Flame length(m)	2.23	2.23	0
	Flame angle(deg)	59.62	28.78	-30.84		Flame angle(deg)	8.36	8.36	0
	Flame tip height(m)	1.44	1.7	0.26		Flame tip height(m)	0.54	0.54	0
	Flame orginal height(m)	0.91	0.78	-0.13		Flame orginal height(m)	0.69	0.69	0

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Table 7: Comparable Fire behavior in Control-severity sites under the conditions of both mild and Severe weather

Control-severity Site		C(3)			Control-severity Site		C(4)		
Weather condition		PB	BS	Increment	Weather condition		PB	BS	Increment
Surface	Flame length(m)	2	2	0	Surface	Flame length(m)	0.91	2	1.09
	Flame angle(deg)	28.98	11	-17.98		Flame angle(deg)	39.38	12.11	-27.27
	Flame tip height(m)	0.66	0.04	-0.62		Flame tip height(m)	0.49	0.18	-0.31
	Flame orginal height(m)	0	0	0		Flame orginal height(m)	0	0	0
	Species flame tip heights (m)	n/a	n/a	n/a		Species flame tip heights (m)	n/a	n/a	n/a
Near-Surface	Flame length(m)	1.21	1.11	-0.1	Near-Surface	Flame length(m)	0.93	2.77	1.84
	Flame angle(deg)	17.76	11	-6.76		Flame angle(deg)	40.25	17.01	-23.24
	Flame tip height(m)	0.21	0.06	-0.15		Flame tip height(m)	0.68	0.68	0
	Flame orginal height(m)	0.27	0.1	-0.17		Flame orginal height(m)	0.49	0.97	0.48
	Species flame tip heights (m)	Lomandra filiformis 0.21	Lomandra filiformis 0.06	n/a		Species flame tip heights (m)	Pteridium esculentum 0.68	Pteridium esculentum 0.68	n/a
Elevated	Flame length(m)	n/a	n/a	n/a	Elevated	Flame length(m)	n/a	1.96	n/a
	Flame angle(deg)	n/a	n/a	n/a		Flame angle(deg)	n/a	8	n/a
	Flame tip height(m)	n/a	n/a	n/a		Flame tip height(m)	n/a	2.22	n/a
	Flame orginal height(m)	n/a	n/a	n/a		Flame orginal height(m)	n/a	2.51	n/a
	Species flame tip heights (m)	n/a	n/a	n/a		Species flame tip heights (m)	n/a	Acacia dealbata 2.22	n/a
Mid-Storey	Flame length(m)	n/a	n/a	n/a	Mid-Storey	Flame length(m)	0	n/a	n/a
	Flame angle(deg)	n/a	n/a	n/a		Flame angle(deg)	0	n/a	n/a
	Flame tip height(m)	n/a	n/a	n/a		Flame tip height(m)	0	n/a	n/a
	Flame orginal height(m)	n/a	n/a	n/a		Flame orginal height(m)	0	n/a	n/a
	Species flame tip heights (m)	n/a	n/a	n/a		Species flame tip heights (m)	Acacia dealbata 0.00	n/a	n/a
Canopy	Flame length(m)	0	0	0	Canopy	Flame length(m)	0	0	0
	Flame angle(deg)	0	0	0		Flame angle(deg)	0	0	0
	Flame tip height(m)	0	0	0		Flame tip height(m)	0	0	0
	Flame orginal height(m)	0	0	0		Flame orginal height(m)	0	0	0
	Species flame tip heights (m)	Eucalyptus obliqua 0.00	Eucalyptus obliqua 0.00	n/a		Species flame tip heights (m)	Acacia dealbata 0.00	Eucalyptus obliqua 0.00	n/a
Overall	Flame length(m)	2.05	2	-0.05	Overall	Flame length(m)	0.94	2.89	1.95
	Flame angle(deg)	24.76	11	-13.76		Flame angle(deg)	39.82	12.93	-26.89
	Flame tip height(m)	0.66	0.06	-0.6		Flame tip height(m)	0.68	2.22	1.54
	Flame orginal height(m)	0.27	0.1	-0.17		Flame orginal height(m)	0.49	2.51	2.02

Control-severity Site		C(1)			Control-severity Site		C(2)		
Weather condition		PB	BS	Increment	Weather condition		PB	BS	Increment
Surface	Flame length(m)	0.92	2	1.08	Surface	Flame length(m)	2	2	0
	Flame angle(deg)	43.25	9	-34.25		Flame angle(deg)	37.15	12	-25.15
	Flame tip height(m)	0.53	0.04	-0.49		Flame tip height(m)	0.63	0.04	-0.59
	Flame orginal height(m)	0	0	0		Flame orginal height(m)	0	0	0
	Species flame tip heights (m)	n/a	n/a	n/a		Species flame tip heights (m)	n/a	n/a	n/a
lear-Surfac	Flame length(m)	1.14	0.93	-0.21	Near-Surface	Flame length(m)	1.81	1.25	-0.56
	Flame angle(deg)	49.85	9	-40.85		Flame angle(deg)	34.16	12	-22.16
	Flame tip height(m)	0.8	0.05	-0.75		Flame tip height(m)	0.62	0.06	-0.56
	Flame orginal height(m)	0.58	0.12	-0.46		Flame orginal height(m)	0.94	0.13	-0.81
	Species flame tip heights (m)	Lomandra filiformis 0.66	Lomandra filiformis 0.05	n/a		Species flame tip heights (m)	Poa 0.54	Bracken 0.06	n/a
Elevated	Flame length(m)	n/a	n/a	n/a	Elevated	Flame length(m)	n/a	n/a	n/a
	Flame angle(deg)	n/a	n/a	n/a		Flame angle(deg)	n/a	n/a	n/a
	Flame tip height(m)	n/a	n/a	n/a		Flame tip height(m)	n/a	n/a	n/a
	Flame orginal height(m)	n/a	n/a	n/a		Flame orginal height(m)	n/a	n/a	n/a
	Species flame tip heights (m)	n/a	n/a	n/a		Species flame tip heights (m)	n/a	n/a	n/a
Mid-Storey	Flame length(m)	n/a	n/a	n/a	Mid-Storey	Flame length(m)	n/a	n/a	n/a
	Flame angle(deg)	n/a	n/a	n/a		Flame angle(deg)	n/a	n/a	n/a
	Flame tip height(m)	n/a	n/a	n/a		Flame tip height(m)	n/a	n/a	n/a
	Flame orginal height(m)	n/a	n/a	n/a		Flame orginal height(m)	n/a	n/a	n/a
	Species flame tip heights (m)	n/a	n/a	n/a		Species flame tip heights (m)	n/a	n/a	n/a
Canopy	Flame length(m)	0	0	0	Canopy	Flame length(m)	0	0	0
	Flame angle(deg)	0	0	0		Flame angle(deg)	0	0	0
	Flame tip height(m)	0	0	0		Flame tip height(m)	0	0	0
	Flame orginal height(m)	0	0	0		Flame orginal height(m)	0	0	0
	Species flame tip heights (m)	Eucalyptus obliqua 0.00	Eucalyptus obliqua 0.00	n/a		Species flame tip heights (m)	Stringy Bark 0.00	Stringy Bark 0.00	n/a
Overall	Flame length(m)	1.14	2	0.86	Overall	Flame length(m)	2.02	2	-0.02
	Flame angle(deg)	46.9	9	-37.9		Flame angle(deg)	35.73	12	-23.73
	Flame tip height(m)	0.8	0.05	-0.75		Flame tip height(m)	0.63	0.06	-0.57
	Flame orginal height(m)	0.58	0.12	-0.46		Flame orginal height(m)	0.94	0.13	-0.81

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Table 8: Comparable Fire behavior in High-severity sites under the conditions of both mild and Severe weather

High-severity Site		H(1)		
Weather condition		PB	BS	Increment
Surface	Flame length(m)	0.6	2	1.4
	Flame angle(deg)	34.69	15.77	-18.92
	Flame tip height(m)	0.32	0.44	0.12
	Flame orginal height(m)	0	0	0
	Species flame tip heights (m)	n/a	n/a	n/a
lear-Surfac	Flame length(m)	1.47	3.94	2.47
	Flame angle(deg)	61.18	30.54	-30.64
	Flame tip height(m)	1.48	2	0.52
	Flame orginal height(m)	0.91	0.91	0
	Species flame tip heights (m)	Pteridium esculentum 1.48	Pteridium esculentum 2.00	n/a
Elevated	Flame length(m)	7.53	9.53	2
	Flame angle(deg)	82.84	48.73	-34.11
	Flame tip height(m)	8.68	8.18	-0.5
	Flame orginal height(m)	3.6	3.6	0
	Species flame tip heights (m)	Eucalyptus obliqua 8.68	Eucalyptus obliqua 8.18	n/a
Mid-Storey	Flame length(m)	11.33	12.57	1.24
	Flame angle(deg)	83.05	45.5	-37.55
	Flame tip height(m)	15.39	12.71	-2.68
	Flame orginal height(m)	9.01	9.01	0
	Species flame tip heights (m)	Eucalyptus obliqua 15.39	Eucalyptus obliqua 12.71	n/a
Canopy	Flame length(m)	23.6	27.3	3.7
	Flame angle(deg)	81.59	41.28	-40.31
	Flame tip height(m)	39.79	33.56	-6.23
	Flame orginal height(m)	27.09	25.87	-1.22
	Species flame tip heights (m)	Eucalyptus obliqua 39.79	Eucalyptus obliqua 33.56	n/a
Overall	Flame length(m)	35.81	44.03	8.22
	Flame angle(deg)	80.87	41.84	-39.03
	Flame tip height(m)	39.79	33.56	-6.23
	Flame orginal height(m)	27.09	25.87	-1.22

High-severity Site		H(2)		
Weather condition		PB	BS	Increment
Surface	Flame length(m)	0.35	0.47	0.12
	Flame angle(deg)	80.6	42.48	-38.12
	Flame tip height(m)	0.34	0.29	-0.05
	Flame orginal height(m)	0	0	0
	Species flame tip heights (m)	n/a	n/a	n/a
Near-Surface	Flame length(m)	0.66	0.8	0.14
	Flame angle(deg)	85.22	58.45	-26.77
	Flame tip height(m)	0.66	0.66	0
	Flame orginal height(m)	0.3	0.3	0
	Species flame tip heights (m)	Poa tenera 0.66	Poa tenera 0.66	n/a
Elevated	Flame length(m)	0.77	0.5	-0.27
	Flame angle(deg)	62.89	7.75	-55.14
	Flame tip height(m)	1.32	0.66	-0.66
	Flame orginal height(m)	1.03	0.8	-0.23
	Species flame tip heights (m)	Acacia dealbata 1.32	Acacia dealbata 0.66	n/a
Mid-Storey	Flame length(m)	0	0	0
	Flame angle(deg)	0	0	0
	Flame tip height(m)	0	0	0
	Flame orginal height(m)	0	0	0
	Species flame tip heights (m)	Eucalyptus obliqua 0.00	Eucalyptus obliqua 0.00	n/a
Canopy	Flame length(m)	0	0	0
	Flame angle(deg)	0	0	0
	Flame tip height(m)	0	0	0
	Flame orginal height(m)	0	0	0
	Species flame tip heights (m)	Eucalyptus obliqua 0.00	Eucalyptus obliqua 0.00	n/a
Overall	Flame length(m)	0.77	0.8	0.03
	Flame angle(deg)	74.7	39.92	-34.78
	Flame tip height(m)	1.32	0.66	-0.66
	Flame orginal height(m)	1.03	0.8	-0.23

High-severity Site		H(3)		
Weather condition		PB	BS	Increment
Surface	Flame length(m)	1.77	2	0.23
	Flame angle(deg)	54.25	11	-43.25
	Flame tip height(m)	1.25	0.04	-1.21
	Flame orginal height(m)	0	0	0
	Species flame tip heights (m)	n/a	n/a	n/a
Near-Surface	Flame length(m)	0.91	0.8	-0.11
	Flame angle(deg)	33.94	11	-22.94
	Flame tip height(m)	0.4	0.04	-0.36
	Flame orginal height(m)	0.3	0.06	-0.24
	Species flame tip heights (m)	Lomandra filiformis 0.40	Lomandra filiformis 0.04	n/a
Elevated	Flame length(m)	n/a	n/a	n/a
	Flame angle(deg)	n/a	n/a	n/a
	Flame tip height(m)	n/a	n/a	n/a
	Flame orginal height(m)	n/a	n/a	n/a
	Species flame tip heights (m)	n/a	n/a	n/a
Mid-Storey	Flame length(m)	n/a	n/a	n/a
	Flame angle(deg)	n/a	n/a	n/a
	Flame tip height(m)	n/a	n/a	n/a
	Flame orginal height(m)	n/a	n/a	n/a
	Species flame tip heights (m)	n/a	n/a	n/a
Canopy	Flame length(m)	0	0	0
	Flame angle(deg)	0	0	0
	Flame tip height(m)	0	0	0
	Flame orginal height(m)	0	0	0
	Species flame tip heights (m)	Eucalyptus obliqua 0.00	Eucalyptus obliqua 0.00	n/a
Overall	Flame length(m)	1.8	2	0.2
	Flame angle(deg)	47.36	11	-36.36
	Flame tip height(m)	1.25	0.04	-1.21
	Flame orginal height(m)	0.3	0.06	-0.24

High-severity Site		H(4)		
Weather condition		PB	BS	Increment
Surface	Flame length(m)	0.65	2	1.35
	Flame angle(deg)	33.62	14.01	-19.61
	Flame tip height(m)	0.33	0.48	0.15
	Flame orginal height(m)	0	0	0
	Species flame tip heights (m)	n/a	n/a	n/a
Near-Surface	Flame length(m)	n/a	n/a	n/a
	Flame angle(deg)	n/a	n/a	n/a
	Flame tip height(m)	n/a	n/a	n/a
	Flame orginal height(m)	n/a	n/a	n/a
	Species flame tip heights (m)	n/a	n/a	n/a
Elevated	Flame length(m)	0.53	0.47	-0.06
	Flame angle(deg)	25.92	2.72	-23.2
	Flame tip height(m)	0.21	0.02	-0.19
	Flame orginal height(m)	0.15	0.06	-0.09
	Species flame tip heights (m)	Pteridium esculentum 0.21	Pteridium esculentum 0.02	n/a
Mid-Storey	Flame length(m)	n/a	n/a	n/a
	Flame angle(deg)	n/a	n/a	n/a
	Flame tip height(m)	n/a	n/a	n/a
	Flame orginal height(m)	n/a	n/a	n/a
	Species flame tip heights (m)	n/a	n/a	n/a
Canopy	Flame length(m)	0	0	0
	Flame angle(deg)	0	0	0
	Flame tip height(m)	0	0	0
	Flame orginal height(m)	0	0	0
	Species flame tip heights (m)	Ribbon Gum 0.00	Ribbon gum 0.00	#VALUE!
Overall	Flame length(m)	0.67	2.03	1.36
	Flame angle(deg)	30.18	11.87	-18.31
	Flame tip height(m)	0.33	0.48	0.15
	Flame orginal height(m)	0.15	0.06	-0.09

The last column on each table illustrates Increments, which are calculated by 'BS minus PB'. This factor, however, is only available in items with quantified and comparable data. In this case, increments

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can be referred to assess the extent of impact caused by severe weathers.

Table 9: Summarized Fire behavior in all severity sites under the prescribed burning weather condition

Prescribed Burning weather(PB)		Low severity				Control severity				High severity				Average score		
Stratum	Site	L(1)	L(2)	L(3)	L(4)	C(1)	C(2)	C(3)	C(4)	H(1)	H(2)	H(3)	H(4)	Low	Control	High
Surface	Flame length(m)	1.07	1.12	0.49	2	0.92	2	2	0.91	0.6	0.35	1.77	0.65	1.17	1.46	0.84
	Flame angle(deg)	65.55	60.37	47.01	12.08	43.25	37.15	28.98	39.38	34.69	80.6	54.25	33.62	46.25	37.19	50.79
	Flame tip height(m)	0.96	0.94	0.34	0.32	0.53	0.63	0.66	0.49	0.32	0.34	1.25	0.33	0.64	0.58	0.56
	Flame orginal height(m)	0	0	0	0	0	0	0	0	0	0	0	0	0.00	0.00	0.00
	Species flame tip heights (m)	n/a	Poa 1.50	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Near-Surface	Flame length(m)	1.77	2.19	n/a	0.85	1.14	1.81	1.21	0.93	1.47	0.66	0.91	n/a	1.60	1.27	1.01
	Flame angle(deg)	75.32	74.62	n/a	4.8	49.85	34.16	17.76	40.25	61.18	85.22	33.94	n/a	51.58	35.51	60.11
	Flame tip height(m)	1.71	2.11	n/a	0.42	0.8	0.62	0.21	0.68	1.48	0.66	0.4	n/a	1.41	0.58	0.85
	Flame orginal height(m)	1.07	1.34	n/a	0.46	0.58	0.94	0.27	0.49	0.91	0.3	0.3	n/a	0.96	0.57	0.50
	Species flame tip heights (m)	Pteridium esculentum 1.71	Bracken 2.74	n/a	Poa tenera 0.42	Lomandra filiformis 0.66	Poa 0.54	Lomandra filiformis 0.21	Pteridium esculentum 0.68	Pteridium esculentum 1.48	Poa tenera 0.66	Lomandra filiformis 0.40	n/a	n/a	n/a	n/a
Elevated	Flame length(m)	3.95	n/a	1.6	1.29	n/a	n/a	n/a	n/a	7.53	0.77	n/a	0.53	2.28	n/a	2.94
	Flame angle(deg)	69.82	n/a	63.5	4.92	n/a	n/a	n/a	n/a	82.84	62.89	n/a	25.92	46.08	n/a	57.22
	Flame tip height(m)	5.32	n/a	1.44	0.54	n/a	n/a	n/a	n/a	8.68	1.32	n/a	0.21	2.43	n/a	3.40
	Flame orginal height(m)	3.8	n/a	0.91	0.69	n/a	n/a	n/a	n/a	3.6	1.03	n/a	0.15	1.80	n/a	1.59
	Species flame tip heights (m)	Eucalyptus obliqua 7.42	n/a	Pteridium esculentum 1.44	Pteridium esculentum 0.54	n/a	n/a	n/a	n/a	Eucalyptus obliqua 8.68	Acacia dealbata 1.32	n/a	Pteridium esculentum 0.21	n/a	n/a	n/a
Mid-Storey	Flame length(m)	8.33	n/a	n/a	0	n/a	n/a	n/a	0	11.33	0	n/a	n/a	4.17	n/a	5.67
	Flame angle(deg)	74.8	n/a	n/a	0	n/a	n/a	n/a	0	83.05	0	n/a	n/a	37.40	n/a	41.53
	Flame tip height(m)	10.01	n/a	n/a	0	n/a	n/a	n/a	0	15.39	0	n/a	n/a	5.01	n/a	7.70
	Flame orginal height(m)	4.66	n/a	n/a	0	n/a	n/a	n/a	0	9.01	0	n/a	n/a	2.33	n/a	4.51
	Species flame tip heights (m)	Eucalyptus obliqua 10.01	n/a	n/a	Eucalyptus obliqua 0.00	n/a	n/a	n/a	Acacia dealbata 0.00	Eucalyptus obliqua 15.39	Eucalyptus obliqua 0.00	n/a	n/a	n/a	n/a	n/a
Canopy	Flame length(m)	15.01	0	0	0	0	0	0	0	23.6	0	0	0	3.75	0.00	5.90
	Flame angle(deg)	72.12	0	0	0	0	0	0	0	81.59	0	0	0	18.03	0.00	20.40
	Flame tip height(m)	22.14	0	0	0	0	0	0	0	39.79	0	0	0	5.54	0.00	9.95
	Flame orginal height(m)	14.13	0	0	0	0	0	0	0	27.09	0	0	0	3.53	0.00	6.77
	Species flame tip heights (m)	Eucalyptus obliqua 22.14	Stringy Bark 0.00	Blue Gum 0.00	Eucalyptus obliqua 0.00	Eucalyptus obliqua 0.00	Stringy Bark 0.00	Eucalyptus obliqua 0.00	Acacia dealbata 0.00	Eucalyptus obliqua 39.79	Eucalyptus obliqua 0.00	Eucalyptus obliqua 0.00	Ribbon Gum 0.00	n/a	n/a	n/a
Overall	Flame length(m)	21.32	2.19	1.6	2.23	1.14	2.02	2.05	0.94	35.81	0.77	1.8	0.67	6.84	1.54	9.76
	Flame angle(deg)	72.52	69.8	59.62	8.36	46.9	35.73	24.76	39.82	80.87	74.7	47.36	30.18	52.58	36.80	58.28
	Flame tip height(m)	22.14	2.11	1.44	0.54	0.8	0.63	0.66	0.68	39.79	1.32	1.25	0.33	6.56	0.69	10.67
	Flame orginal height(m)	14.13	1.34	0.91	0.69	0.58	0.94	0.27	0.49	27.09	1.03	0.3	0.15	4.27	0.57	7.14

Table 10: Summarized Fire behavior in all severity sites under the Black Saturday weather condition

Black Saturday weather(BS)		Low severity				Control severity				High severity				Average score		
Stratum	Site	L(1)	L(2)	L(3)	L(4)	C(1)	C(2)	C(3)	C(4)	H(1)	H(2)	H(3)	H(4)	Low	Control	High
Surface	Flame length(m)	2	2	2	2	2	2	2	2	2	0.47	2	2	2.00	2.00	1.62
	Flame angle(deg)	11.04	20.09	28.54	12.08	9	12	11	12.11	15.77	42.48	11	14.01	17.94	11.03	20.82
	Flame tip height(m)	0.35	0.59	0.86	0.32	0.04	0.04	0.04	0.18	0.44	0.29	0.04	0.48	0.53	0.08	0.31
	Flame orginal height(m)	0	0	0	0	0	0	0	0	0	0	0	0	0.00	0.00	0.00
	Species flame tip heights (m)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Near-Surface	Flame length(m)	1.83	2.48	n/a	0.85	0.93	1.25	1.11	2.77	3.94	0.8	0.8	n/a	1.72	1.52	1.85
	Flame angle(deg)	10.02	24.81	n/a	4.8	9	12	11	17.01	30.54	58.45	11	n/a	13.21	12.25	33.33
	Flame tip height(m)	0.3	0.96	n/a	0.42	0.05	0.06	0.06	0.68	2	0.66	0.04	n/a	0.56	0.21	0.90
	Flame orginal height(m)	0.25	0.52	n/a	0.46	0.12	0.13	0.1	0.97	0.91	0.3	0.06	n/a	0.41	0.33	0.42
	Species flame tip heights (m)	Pteridium esculentum 0.30	Bracken 1.07	n/a	Poa tenera 0.42	Lomandra filiformis 0.05	Bracken 0.06	Lomandra filiformis 0.06	Pteridium esculentum 0.68	Pteridium esculentum 2.00	Poa tenera 0.66	Lomandra filiformis 0.04	n/a	n/a	n/a	n/a
Elevated	Flame length(m)	0	n/a	3.71	1.29	n/a	n/a	n/a	1.96	9.53	0.5	n/a	0.47	1.67	1.96	3.50
	Flame angle(deg)	0	n/a	28.9	4.92	n/a	n/a	n/a	8	48.73	7.75	n/a	2.72	11.27	8.00	19.73
	Flame tip height(m)	0	n/a	1.7	0.54	n/a	n/a	n/a	2.22	8.18	0.66	n/a	0.02	0.75	2.22	2.95
	Flame orginal height(m)	0	n/a	0.78	0.69	n/a	n/a	n/a	2.51	3.6	0.8	n/a	0.06	0.49	2.51	1.49
	Species flame tip heights (m)	Acacia dealbata 0.00	n/a	Pteridium esculentum 1.70	Pteridium esculentum 0.54	n/a	n/a	n/a	:ia dealbata2	Eucalyptus obliqua 8.18	Acacia dealbata 0.66	n/a	Pteridium esculentum 0.02	n/a	n/a	n/a
Mid-Storey	Flame length(m)	0	n/a	n/a	0	n/a	n/a	n/a	n/a	12.57	0	n/a	n/a	0.00	n/a	6.29
	Flame angle(deg)	0	n/a	n/a	0	n/a	n/a	n/a	n/a	45.5	0	n/a	n/a	0.00	n/a	22.75
	Flame tip height(m)	0	n/a	n/a	0	n/a	n/a	n/a	n/a	12.71	0	n/a	n/a	0.00	n/a	6.36
	Flame orginal height(m)	0	n/a	n/a	0	n/a	n/a	n/a	n/a	9.01	0	n/a	n/a	0.00	n/a	4.51
	Species flame tip heights (m)	Eucalyptus obliqua 0.00	n/a	n/a	Eucalyptus obliqua 0.00	n/a	n/a	n/a	n/a	Eucalyptus obliqua 12.71	Eucalyptus obliqua 0.00	n/a	n/a	n/a	n/a	n/a
Canopy	Flame length(m)	18.7	0	0	0	0	0	0	0	27.3	0	0	0	4.68	0.00	6.83
	Flame angle(deg)	15.49	0	0	0	0	0	0	0	41.28	0	0	0	3.87	0.00	10.32
	Flame tip height(m)	17.33	0	0	0	0	0	0	0	33.56	0	0	0	4.33	0.00	8.39
	Flame orginal height(m)	14.47	0	0	0	0	0	0	0	25.87	0	0	0	3.62	0.00	6.47
	Species flame tip heights (m)	Eucalyptus obliqua 17.33	Ribbon Gum 0.00	Blue gum 0.00	Eucalyptus obliqua 0.00	Eucalyptus obliqua 0.00	Stringy Bark 0.00	Eucalyptus obliqua 0.00	Eucalyptus obliqua 0.00	Eucalyptus obliqua 33.56	Eucalyptus obliqua 0.00	Eucalyptus obliqua 0.00	Ribbon gum 0.00	n/a	n/a	n/a
Overall	Flame length(m)	18.7	2.48	3.71	2.23	2	2	2	2.89	44.03	0.8	2	2.03	6.78	2.22	12.22
	Flame angle(deg)	14.65	22.71	28.78	8.36	9	12	11	12.93	41.84	39.92	11	11.87	18.63	11.23	26.16
	Flame tip height(m)	17.33	0.96	1.7	0.54	0.05	0.06	0.06	2.22	33.56	0.66	0.04	0.48	5.13	0.60	8.69
	Flame orginal height(m)	14.47	0.52	0.78	0.69	0.12	0.13	0.1	2.51	25.87	0.8	0.06	0.06	4.12	0.72	6.70

Table 11: Overall Fire behavior summarized in all severity sites under both prescribed burning and Black Saturday weather condition

Low severity	L1			L2			L3			L4		
Overall	PB	BS	Increment	PB	BS	Increment	PB	BS	Increment	PB	BS	Increment
Flame length(m)	21.32	18.7	-2.62	2.19	2.48	0.29	1.6	3.71	2.11	2.23	2.23	0
Flame angle(deg)	72.52	14.65	-57.87	69.8	22.71	-47.09	59.62	28.78	-30.84	8.36	8.36	0
Flame tip height(m)	22.14	17.33	-4.81	2.11	0.96	-1.15	1.44	1.7	0.26	0.54	0.54	0
Flame orginal height(m)	14.13	14.47	0.34	1.34	0.52	-0.82	0.91	0.78	-0.13	0.69	0.69	0

Control severity	C1			C2			C3			C4		
Overall	PB	BS	Increment	PB	BS	Increment	PB	BS	Increment	PB	BS	Increment
Flame length(m)	1.14	2	0.86	2.02	2	-0.02	2.05	2	-0.05	0.94	2.89	1.95
Flame angle(deg)	46.9	9	-37.9	35.73	12	-23.73	24.76	11	-13.76	39.82	12.93	-26.89
Flame tip height(m)	0.8	0.05	-0.75	0.63	0.06	-0.57	0.66	0.06	-0.6	0.68	2.22	1.54
Flame orginal height(m)	0.58	0.12	-0.46	0.94	0.13	-0.81	0.27	0.1	-0.17	0.49	2.51	2.02

High severity	H1			H2			H3			H4		
Overall	PB	BS	Increment	PB	BS	Increment	PB	BS	Increment	PB	BS	Increment
Flame length(m)	35.81	44.03	8.22	0.77	0.8	0.03	1.8	2	0.2	0.67	2.03	1.36
Flame angle(deg)	80.87	41.84	-39.03	74.7	39.92	-34.78	47.36	11	-36.36	30.18	11.87	-18.31
Flame tip height(m)	39.79	33.56	-6.23	1.32	0.66	-0.66	1.25	0.04	-1.21	0.33	0.48	0.15
Flame orginal height(m)	27.09	25.87	-1.22	1.03	0.8	-0.23	0.3	0.06	-0.24	0.15	0.06	-0.09

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Last, all data about fire behavior in all severity sites under both weather conditions are summarized below. In addition, average scores of flame height and flame degree in the same fire severity level are calculated to provide reference data to assess overall fire behaviors and these average figures can be compared among different fire severity.

6. Discussion

Further research mainly focuses on overall fire behavior in each severity site. Comparisons of Flame height, flame length and flame degree between different fire severity are illustrated in two diagrams (fig 11 & 12), and the increment factor reflects the impact on fire from weather change. Obviously, the degree of flame is quite sensitive to environmental effect and is easier to change comparing with flame height and length. It may be because wind speed and direction may control the expansion of fire. As statistics below, increment correspond-dingly increases when flame tip height goes up. By comparing input and output, the analysis in this study can figure out how plant composition in different forest stratum can influence fire behavior. Most area in Buangor Forest does not show high flammability as flame height and length is not too high and flame does not reach canopy in most areas.

7. Conclusion

Buangor Forest is a highly sensitive forest site in terms of humidity and temperature, severe weather can easily improve the risk of ignition. Extreme fire behavior is more likely to happen in low and high severity sites. For those sites with more fuel loads or fuel weights, flame height is high enough in mild weather condition and fire tends to intensify faster when weather is hotter and drier.

Forest Fire Model promotes to make overall evaluation of fire behavior but how fire expand with time and duration of different stage is unable to figure out. Simulation with time might be potential to develop FFM in the future. This model is mainly based on physical elements of environment, but individual species could make a difference in special biological reaction. Sometimes, not all data from input and output is effective or some of data is set default. Moreover, the results calculated by FFM could also be affected by extreme natural condition so analysis of fire behavior with FFM relies on a huge number of samples.

Acknowledgements

All data in this study is collected from real site excursion. The dimension of species is measured manually and partly combined with 'Arboreal' app, some data may not be quite accurate, but data recording is a collaborative work of different groups in the whole class and the analysis is based on most effective data.

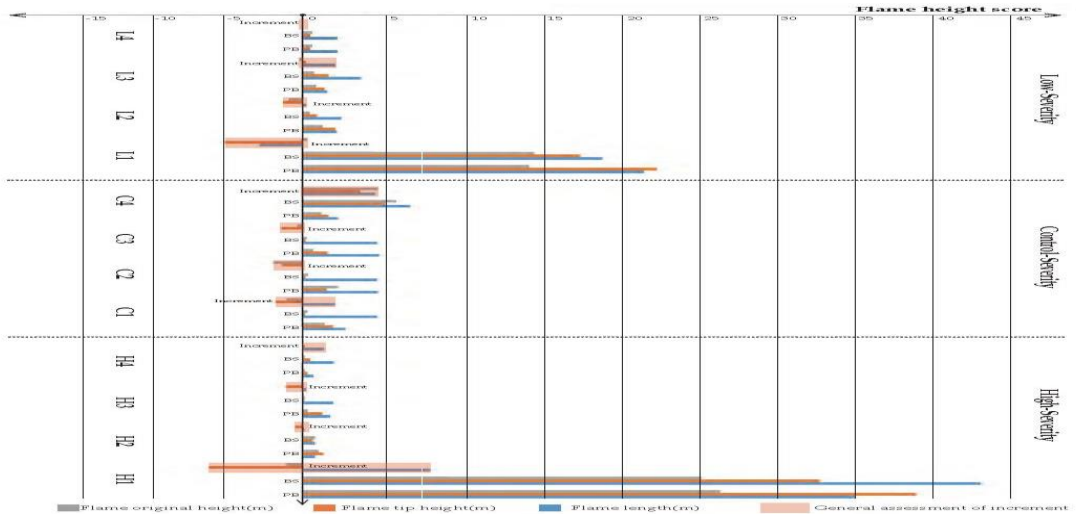

Figure 11: Diagrams to compare flame height & length in different severity sites under different weather condition. Increment varies in different scenarios

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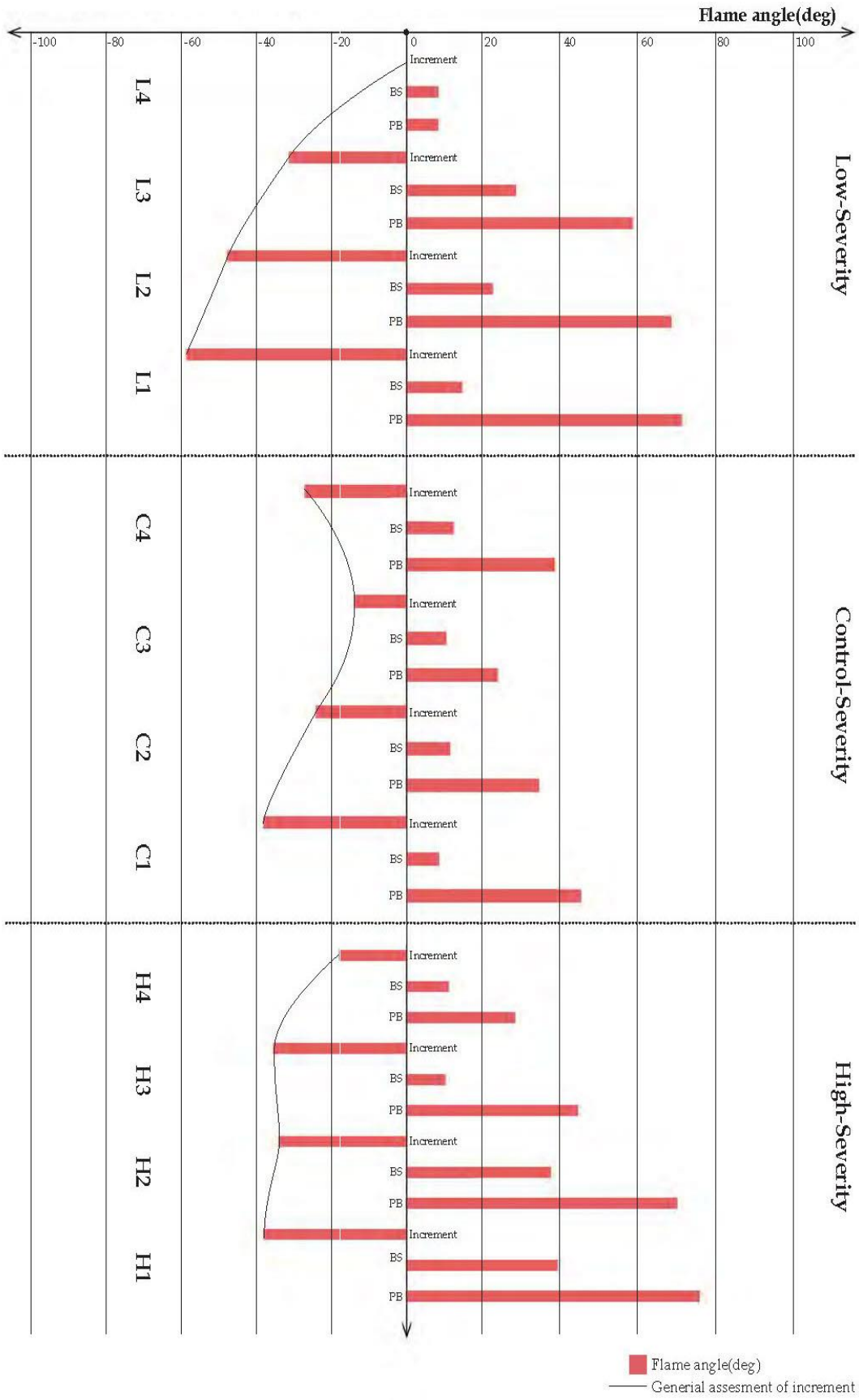

Figure 12: Diagrams to compare flame angle in different severity sites under different weather condition. Increment varies in different scenarios, Tendency line is to assess the overall impact on fire behaviour in terms of fire direction

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