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Analysis of the effectiveness of WUI shaded fuel breaks

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Abstract. The effectiveness of WUI fuel management practices aimed at protecting communities, infrastructures, and homes is analysed, specifically considering prescriptions for shaded fuel breaks of the regions of Catalonia (Spain) and Pyrénées-Orientales (France). Fire spread through fuel breaks is simulated under different environmental and wildfire exposure conditions in FDS (Fire Dynamics Simulator). The French regulated fuel breaks are simulated as 50 m wide areas with a density of 600 trees/ha, and the Catalan regulated breaks as 25 m wide areas with 300 trees/ha. The analysis allows a quantitative comparison of the fire protection provided by different fuel management regulations. Results show that the analysed shaded fuel breaks meet the objective of modifying fire behaviour and reducing emitted heat fluxes and temperatures, although, in some cases, not sufficiently, thus exposing assets to untenable environments, with possible direct flame contact or exposure to high heat fluxes and temperatures. Analysed scenarios also highlight that tree density within the fuel break can impact fire spread through surface fuels. Obtained results show that a 25 m wide break, as the one from the Catalan regulations, is not sufficient in several scenarios; additionally, when exposed to high wind speeds (7.8 m/s), a 50 m wide fuel break (French regulations) is also insufficient.

1. Introduction

The wildfire exposure of a WUI area can be reduced by applying fuel reduction strategies at the interface between the assets to be protected and the forested area. The primary objective of fuel treatments is to modify fire behavior from a crown fire to a surface fire and to reduce the emitted heat flux [1]. At the interface between communities and forested areas, the creation of shaded fuel breaks is often a prescribed fire prevention strategy. These are areas with variable width, in which overstory trees are thinned, the canopy base height is raised, dead vegetation is removed and the surface fuel load is reduced. Countries have adopted different regulations and guidelines for the creation of these fuel breaks around WUI settlements, especially when it comes to their width. With the increasing intensity of fires that reach the WUI, there is a need to quantify the effectiveness of current regulations and guidelines, as in the past years WUI communities have experienced fires in which prescribed fuel breaks have been ineffective (e.g., El Pont de Vilomara fire, Spain).

This paper presents a quantitative analysis, performed with FDS, of the effectiveness of the prescriptions for shaded fuel breaks of the regions of Catalonia (Spain) [2] and Pyrénées-Orientales (France) [3], described in Table 1. The exposure of the fuel break to two different fireline intensities and wind speeds is analysed to estimate the influence of these prescriptions.



Table 1: Fuel break characteristics of the Catalan and French regulations

Catalan regulations	Pyrénées-Orientales regulations
<ul style="list-style-type: none"> • 25 m distance of fuel break around WUI settlement • Tree coverage should be less than 35% • Minimum distance between tree trunks is 6 m • Trees pruned at 1/3 of their height • Shrub coverage should be less than 15% • Minimum distance between shrubs is 3 m, no vertical continuity with trees • No dead vegetation 	<ul style="list-style-type: none"> • 50 m distance of fuel break around WUI buildings • Minimum distance between tree crowns is 3 m • Trees pruned up to 2 m for trees over 6 m high, and up to 1/3 of the height for other tree heights • Ornamental shrub coverage should be less than 20% and distanced at least 3 m from tree crown base, natural shrubs should be removed • No dead vegetation

2. Methodology

The Computational Fluid Dynamics software FDS (6.8.0) is used to simulate fire spread through the fuel break for both the Catalan and the French cases. The domain (with a δx of 25 cm and a Monin-Obukhov wind profile) includes a wildland area of $10 \times 20 \text{ m}^2$, represented as a vent with an assigned HRRPUA (Heat Release Rate Per Unit Area), spread rate and residence time [4], and the shaded fuel break area, in which the vegetation is simulated as Lagrangian particles (Fig. 1). The HRRPUA is assigned according to the fireline intensity [5] and flame depth [6], which are a function, respectively, of the rate of spread of the fire (considered as 10% of the wind speed [7]) and the wind speed, as well as the fuel consumption. Two different fireline intensities and wind speeds are analysed; details for each scenario are given in Table 2. These parameters are intended to simulate conservative wildfire intensities under an average and high wind speed, based on expected wind in the considered geographical regions. Ignition of the wildland area is set at 10 s, which allows for the wind profile development and stabilization. The vegetation located in the fuel break is divided into two categories: surface fuels and overstory (respectively in brown and in green in Fig. 1). Table 3 shows the assigned properties for each category. Test cases with different fuel moisture content were conducted before full-scale simulations to choose most appropriate one that still allows FDS software to simulate fire. In all scenarios, the trees (overstory) are 11 m tall, but the height of the crown base and the distancing between trees varies according to the rules given in Table 1, while the height of the treated surface fuels is of 25 cm in both scenarios. Based on the spacing rules, the tree density for the French case (~ 600 trees/ha) is double the one of the Catalan case (~ 300 trees/ha). Due to the limitations of FDS, scenarios are analysed on flat terrain, therefore the effect of slope on fire spread is not considered.

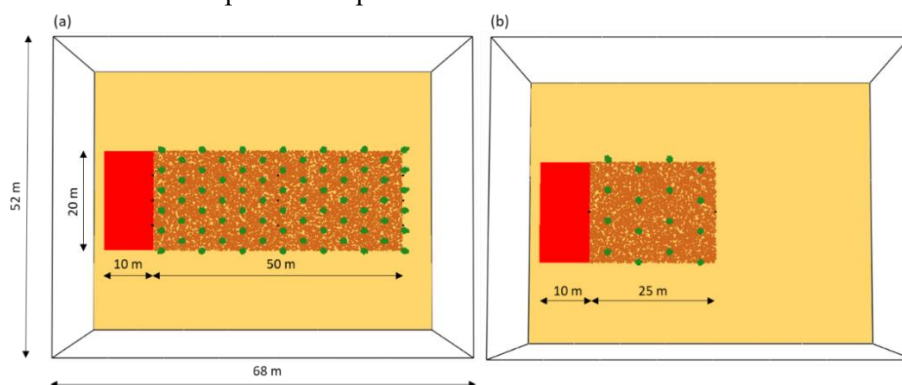


Fig. 1: Simulated domain for the French (a) and Catalan (b) scenarios

As the main objective is to identify whether a shaded fuel break can sufficiently reduce the thermal effects of fire onto assets located on the other side of the break, devices measuring temperatures and radiative heat fluxes are placed at the end of the fuel break (25 and 50 m) at a height of 1.5 m. To verify whether the fuel break is able to reduce the emitted heat flux and temperatures, devices are also located at the end of the simulated wildland area (at 0 m). Furthermore, the mass of the vegetation throughout the simulation is recorded to characterise fire spread through the fuel break.

Table 2: Calculated values for simulation inputs for the chosen fireline intensities

Scenario	Fireline intensity of untreated wildland [kW/m]	Wind speed [m/s]	Rate of spread [m/s]	Fuel consumption [kg/m ²]	Flame depth [m]	Residence time [s]	HRRPUA [kW/m ²]
FI10 4.2 m/s	10000	4.2	0.42	1.3	3.6	45	2778
FI10 7.8 m/s		7.8	0.78	0.7	7.9		1266
FI30	30000	4.2	0.42	4	4.8		6250

Table 3: Simulation properties. Cat.: Catalan case, Fr.: French case

Simulation Parameters	Surface fuels (treated)	Overstory	Reference
Moisture fraction	0.7		-
Surface to volume ratio	6629 m ⁻¹	6719 m ⁻¹	[8]
Heat of combustion	15600 kJ/kg	17425 kJ/kg	
Density	512 kg/m ³	500 kg/m ³	[9,10]
Conductivity	0.1 W/mK	0.2 W/mK	
Specific heat capacity	1.5 kJ/kgK		[9]
Bulk Density	0.8 kg/m ³	1.7 kg/m ³	[8]
Number of particles	155000 (Cat.) 310000 (Fr.)	14000	-

3. Results

The impact of the wildland fire onto the fuel break is shown in Fig. 2a for one of the French cases, where it is possible to see how the wind tilts the flames towards the vegetation located in the fuel break. Therefore, the combustion of part of the fuel break vegetation contributes to the Heat Release Rate (HRR) within the time frame of the combustion of the wildland vegetation, which lasts up to 75 s for the cases with a wind speed of 7.8 m/s, and up to 90 s for the cases with a wind speed of 4.2 m/s. This can be seen in Fig. 2b as well, as the mass loss of the particles located within the first 20 m of the fuel break in the French case FI10 4.2 m/s is due to the simulated wildfire exposure, and negligible self-sustained burning happens within the fuel break for this case.

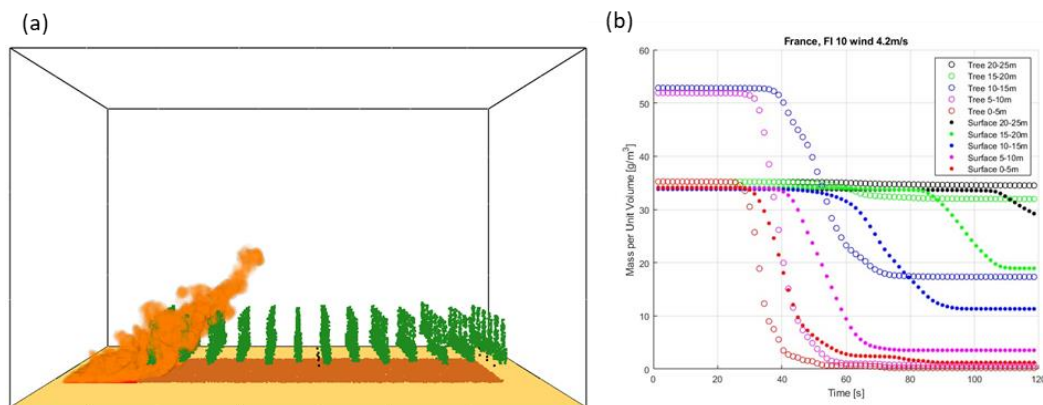


Fig. 2: French FI10 scenario with a wind speed of 4.2 m/s at 40s (a) and mass loss of the vegetation over time (b)

HRR curves for all analysed cases are given in Fig. 3. Average HRR values within the fuel break, after the extinction of the wildland fire, are higher (reaching approximately 9 MW) in the cases with the higher wind speed, and they are higher in the Catalan fuel break compared to the French one for the lower wind speed. Mass Loss Rate (MLR) curves for the simulated scenarios are given in Fig. 4. The combustion of tree particles happens during the time frame in which the wildland area is burning, and there is no combustion of the overstory after that, while surface fuels continue burning. As reflected by

the HRR, higher MLRs are recorded for the scenarios with a higher wind speed (7.8 m/s). When exposed to a higher fireline intensity, fuels in the Catalan break show higher MLR values compared to the French case because the fire spreads farther, reaching the end of the fuel break (25 m), while in the French case the fire stops within 20 m from the wildland area.

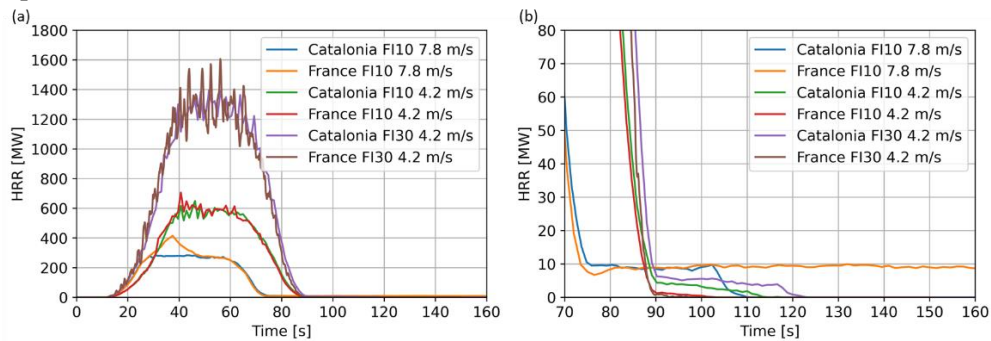


Fig. 3: Heat Release Rate curves for each scenario (a) with a zoom-in of the HRR in the fuel break (b). FI10 and FI30 indicate a fireline intensity of respectively 10000 kW/m and 30000 kW/m.

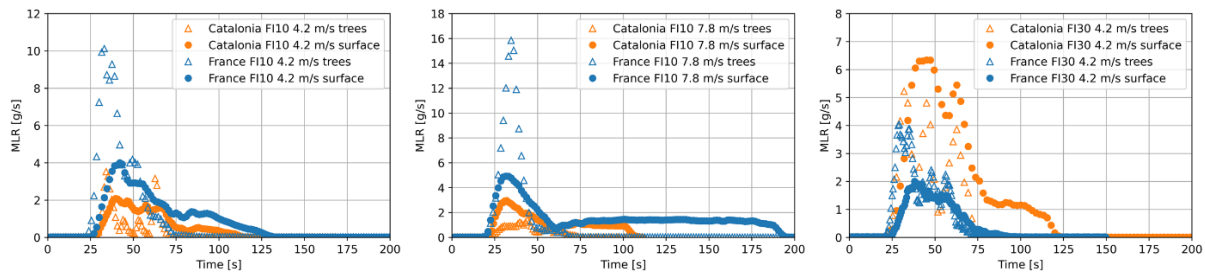


Fig. 4: Mass Loss Rate curves of the analysed scenarios

A summary of the results is presented in Table 4. For each scenario, it was possible to identify the distance reached by the fire inside the fuel break within 5 m intervals, the percentage of mass lost within the 5 m interval where the burning stopped and of the overall mass loss, the burning time of the overstory and surface fuels within the fuel break, the mass loss rate, the HRR within the fuel break and the peak temperature and radiative heat flux received at the end of the wildland area and at a distance of 25 m and 50 m (for the French scenarios).

Table 4: Summary of results. Veg.: vegetation; Fr.: France; Cat.: Catalonia; S.: surface; T.: trees.

Analysed data	Veg. type	Fr.	Fr.	Fr.	Cat.	Cat.	Cat.
		FI10 7.8 m/s	FI10 4.2 m/s	FI30 4.2 m/s	FI10 7.8 m/s	FI10 4.2 m/s	FI30 4.2 m/s
Distance from wildland boundary [m]	S.	45-50	10-15	15-20	20-25	10-15	20-25
	T.	20-25	10-15	15-20	20-25	10-15	20-25
Mass lost where burning stops [%]	S.	41	21	17	47	32	30
	T.	17	41	30	15	16	15
Burning time [s]	S.	174	77	73	87	94	100
	T.	41	51	51	51	51	51
Peak mass loss rate [g/s]	S.	19	2	2	5	2	3.5
	T.	42	6	4	1	4	3.5
Overall mass loss percentage [%]	S.	30	20	57	60	43	72
	T.	31	25	33	39	54	77
Average HRR in fuel break [MW]		9	1	1	9	3	5

Peak radiative heat flux at wildland boundary [kW/m ²]	123	240	330	129	265	268
Peak temperature at wildland boundary [°C]	830	1170	1327	865	1212	1158
Peak radiative heat flux at 25m [kW/m ²]	11	0.6	3.8	11	0.8	4.2
Peak radiative heat flux at 50m [kW/m ²]	11	0.02	0.16	-	-	-
Peak temperature at 25m [°C]	234	28	79	133	44	127
Peak temperature at 50m [°C]	210	23	72	-	-	-

4. Discussion

The percentage of mass burned within 5 m intervals inside the fuel break (Table 4) shows that less than half of the available particles were burnt within the interval where the fire stopped. For the overstory, the mass loss within this interval is mainly due to the loss of moisture, as the particles dry, but are not ignited. The cases with higher wind speed (7.8 m/s) present higher mass loss percentage values for the surface fuels within the last 5 m interval, as the fire reaches the end of the fuel break. The overall mass loss percentage is higher for the Catalan cases because the French fuel break is double its size, therefore containing double the amount of surface particles. Within the fuel breaks exposed to the same wind and intensity, the fire spreads until the same location in both the Catalan and French cases, with the exception of the FI30 scenarios. Here, the Catalan fuel break experiences farther fire spread, possibly due to its lower tree density, which allows for the wind to contribute more to the fire spread along surface fuels.

Results in Table 4 show that the higher the wind speed, the farther the fire spreads through the fuel break, the higher the HRR and therefore the higher the radiant heat fluxes and temperatures that assets located behind the fuel break are exposed to. With a wind speed of 7.8 m/s, both analysed regulations fail to protect these assets, as there could be direct flame contact. Additionally, the heat flux values recorded at the end of the Catalan fuel break (25 m) and of the French break (50 m) are very high (reaching 11 kW/m² in both cases), considering that 1.7 kW/m² is the minimum value at which humans feel pain [11] and piloted ignition of wood happens at 12 kW/m² [12]. Temperatures in these scenarios also reach untenable conditions (over 200°C) at both 25 m and 50 m.

The scenarios with a higher fireline intensity experience larger overall mass loss percentage, as particles exposed to the flames coming from the simulated wildland area burn more in comparison with the FI10 scenarios. The exposure to a higher fireline intensity also implies a farther fire spread.

Average rates of spread, fuel consumption values and fireline intensities are calculated for each scenario (Table 5). The fireline intensity in the shaded fuel break area where the fire extinguishes is also calculated. The average fireline intensity for the scenarios with a wind speed of 7.8 m/s is the same for both the Catalan and the French fuel breaks; these are also the scenarios that present the highest average rate of spread. The FI30 French scenario presents a higher average intensity compared to the Catalan one, due to a slightly faster rate of spread through the surface fuels, although the fire stops earlier, and with a much lower intensity (almost 1/3 of the Catalan one). This shows how tree density impacts fire spread through surface fuels by having a shading effect, as previously mentioned. Results presented in Table 5 show that the simulated fuel breaks are able to modify fire behaviour, presenting much lower fireline intensities compared to those they were exposed to, and the fire only spreads through surface fuels. The shaded fuel break is also able to reduce radiative heat fluxes and temperatures (Table 4).

Table 5: Average computed values of rate of spread, fuel consumption and fireline intensity for the analysed cases, with the fireline intensity in the zone where the fire extinguishes.

Scenario	Average rate of spread [m/s]	Average fuel consumption [kg/m ²]	Average intensity [kW/m]	Intensity at final location [kW/m]
Fr. FI10 7.8 m/s	0.18	0.18	505	495 at 45-50 m ^a
Fr. FI10 4.2 m/s	0.15	0.17	398	207 at 10-15 m
Fr. FI30 4.2 m/s	0.16	0.22	549	104 at 15-20 m
Cat. FI10 7.8 m/s	0.18	0.18	505	486 at 20-25 m ^a

Cat. FI10 4.2 m/s	0.12	0.19	356	215 at 10-15 m
Cat. FI30 4.2 m/s	0.14	0.22	480	292 at 20-25 m ^a

^a End of fuel break

A comparison was also made between the treated fuel breaks and a non-treated scenario simulated with particles exposed to the FI10 4.2 m/s scenario (results not shown). The bulk density of the particles in the untreated scenario is much higher compared to the treated ones [8], therefore fire spread is much slower and the mass loss rate is higher, with peaks of 144 g/s. The HRR within the untreated fuel break is 20 MW, much higher than all of the treated cases.

5. Conclusions

The analysis of the effectiveness of fuel treatments as a fire prevention strategy for the protection of WUI communities with FDS shows that shaded fuel breaks meet the objective of modifying fire behavior and reducing emitted heat fluxes and temperatures. However, prescriptions for the regions of Catalonia and Pyrénées-Orientales are found to not be sufficient under high wildfire intensity and wind speed conditions. The length of the Catalan fuel break (25 m) is not sufficient to protect assets when exposed to a wildfire with a fireline intensity of 30000 kW/m, which indicates extreme fire behavior, or when experiencing high wind speed (7.8 m/s). On the contrary, the length of the French fuel break (50 m) is sufficient to protect assets in both analysed cases with a wind speed of 4.2 m/s, while it is not sufficient under high wind speeds. Results show that longer fuel break lengths (50 m) with higher tree density compared to Catalan regulations can provide higher protection from wildfire exposure. The proposed methodology can be used for the development of a model for the design of fuel breaks in which the particular conditions of each case (e.g., wind, wildfire intensity, etc.) can be considered.

Acknowledgments

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