Fuel-break assessment using expert appraisement approach

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ABSTRACT: In the French Mediterranean region wildfire hazard reduction is based on forest compartmentalisation by fuel-break networks. Areas of reduced fuels to decrease fire ignition events, fire effects on people and human resources, separate fire prone forests from the entire burnt area.

Existing fuel break networks have shown some limitations; therefore, it has been necessary to assess fuel break effectiveness including the point of view of the professionals involved in wildfire prevention and suppression. To compare potential costs to benefits of the fuel-break construction policy, we need quantitative knowledge of the fuel-breaks efficiency for stopping wildfires.

In the present study, I sought to identify fuel-break planning principals, which maximised effectiveness and to determine operational thresholds for the main parameters of fire-break design. The study was done at a scale of a hundredth of meters and the final objective was to give decision support for fire-breaks managers.

The methodology was an expert appraisement approach consisting of expert evaluations by firefighters and foresters skilled in wildfire suppression. Experts were visiting field sites with different fuel-break configurations and told to consider various wildfire severity scenarios. For each scenario of fuel-break condition-severity, they were asked to fill-out a questionnaire. Thirty one fuel-break segments were assessed in contrasting woodland and shrubland stands under different fuel-break configurations. Dimensions of the fuel-break, vegetation composition and structure, fire suppression infrastructure and topography of each segment and of the nearby untreated stand were described according to methods detailed by Cohen *et al*. (submitted).

Data was processed using multivariate descriptive statistical analysis, which enabled me to select the best criteria for fuel break effectiveness. The most discriminating criteria were fuel-break width, shrub volume and tree cover. A logistic model was fitted to predict the probability of a fuel-break stopping a fire as a function of its main characteristics. Model behaviour showed significant compensating interactions between certain variables contributing to fuel-break efficiency. An important conclusion was that the treatment of the tree component was extremely important; a finding that contrasts with the previously held belief that fuel-break construction should focus mostly on control of the shrub layer. Practical implications of these results are discussed.

1 INTRODUCTION

Forest compartmentalisation by fuel-break networks is one of the major components of wildfire hazard reduction in the French Mediterranean region. Green (1977) defines a fuel-break as “a strategically located wide block, or strip, on which a cover of dense, heavy, or flammable vegetation has been permanently changed to one of lower volume or reduced flammability”. Fuel reduction on fuel-breaks has always been focused on the shrub layer control. But recent works have underlined the need to consider all the vegetation strata which may contribute to fire spreading namely litter layer (Rigolot and Etienne, 1996), herbaceous layer (Etienne *et al*., 1996) and tree layer (Agee *et al.,* 2000; Guiton and Kmiec, 2000).
Duché and Rigolot (2000) distinguish three main objectives that a fuel-break can achieve: (i) to decrease fire ignition events, (ii) to decrease total area burnt and (iii) to decrease fire effects on people and human resources. The last objective is the only one where the fuel-break can sometimes be effective by itself, without any fire suppression effort. However, generally, fuel-break are designed to help fire fighters to develop suppression actions in the safest conditions (Agee *et al.,* 2000). Therefore, starting from Green’s general definition (1997) of a fuel-break, it may be necessary to add other infrastructure and equipment like forest roads for access and water points for vehicles supply. Vegetation treatment standards themselves may be different to prevent fire ignition and to reduce fire intensity on a fuel-break designed to help fire-fighters to stop a wildfire.

Existing fuel-breaks have shown some limitation, namely during the 1989 and 1990 fire seasons in France. The behaviour of large wildfires of that period showed that some fuel-breaks were not properly designed, and/or were not properly maintained, and occasionally not properly used by suppression forces or even not used at all (Cochelin, 1992). Absolute standards for fuel-break design and maintenance are difficult to define because of the variety of fuel-break objectives, of terrain situations, and fire fighting strategy and means (Agee, 2000). Nevertheless, there is no doubt about the necessity of field preparation for fire fighting in order to achieve suppression forces security and efficiency (Rigolot, 2000). Therefore, it has been necessary to assess fuel break effectiveness including the point of view of the professionals involved in wildfire prevention and suppression. To compare potential costs to benefits of the fuel-break construction policy, we need quantitative knowledge of the efficiency of fuel-breaks for stopping wildfires.

There are different methods for fuel-break effectiveness assessment. Post-fire analysis can be organised when a wildfire affects a fuel-break (Lambert *et al*., 1999). To be relevant, this approach needs to get direct observers of the events and free contribution of the different operational partners. Fire behaviour models can be used to simulate fuel-break efficiency against different wildfire scenarios (Finney, 1998; Dupuy, 2000). This approach will be currently applied at the wildland urban interface in the frame of the European research project Fire Star (Valette *et al.,* 2002). Experimental fires can be set for appraising the probability of fuel-break crossing according to fire intensity (Davidson, 1988) or for assessing fuel-break appropriate width (Wilson, 1988). Davis (1965) underlines the difficulty to carry out this kind of experimental fires. Finally, the expert appraisement approach, used in this study, consists of expert evaluations by fire-fighters and foresters skilled in wildfire suppression.

For this study, experts were visiting field sites with different fuel-break conditions and told to consider various wildfire severity scenarios. For each scenario of fuel-break condition-severity, they were asked to fill-out a questionnaire. The study was done at a scale of a hundredth of meters. Fuel-breaks were assessed in contrasting woodland and shrubland stands under different fuel-break configurations. Expert appraisements were then studied against fuel-break segment and nearby untreated stand characteristics. These characteristics included local dimensions, vegetation composition and structure, fire suppression infrastructure and topography. Fuel-break assessment with an expert appraisement approach is so far the single operational method that can give results on a wide range of situations.

In the present study, we sought to identify fuel-break planning principals, which maximised effectiveness, and to determine operational thresholds for the main parameters of fire-break design. The final objective was to give decision support for managers in charge of designing and maintaining fire-breaks.

2 METHODS

2.1 *Fuel-break segments sampling*

The study was based on existing fire management operations realised in the French Mediterranean region. Vegetation characteristics were the first fuel break segment sampling criteria. Dominant species, tree density on the fuel-break and forest management type were taken into account as sampling criteria for tree layer. Shrub encroachment was taken into account for shrub layer.

In a second step, we considered fuel-break characteristics like local width, topographic position and forest road localisation.

Finally, 18 sites were selected, distributed in three natural regions namely defined on a geologic point of view inducing different forest stands: calcareous Provence (Gard, Vaucluse, Bouches-du-Rhône and Western Var), crystalline Provence (Eastern Var) and Corsica (Corse du Sud). These sites encompassed a wide range of fuel-break types (strategic fuel-breaks, wildland urban interfaces, fuel-breaks along public roads, …). Sites including two modalities of the same parameter were selected in priority (low and high shrub encroachment, low and high tree density, …). On the whole, 31 segments were selected among the 18 sites. Dominant tree species in the selected forest stand were *Pinus halepensis*, *Pinus pinaster*, *Quercus ilex* and *Quercus suber*.

2.2 *Expert appraisement realisation*

The expert appraisement approach consisted in submitting a pre-established questionnaire to a panel of about ten people gathered on a fuel-break segment in order to collect their expertise on different points. Groups' composition could differ among sites according to expert professional origin. Experts could be either foresters who are in charge of fire prevention in France or fire-fighters who are in charge of fire suppression. The first ones realise the fuel-breaks and the second ones use them. Appraisements were preferably realised at the beginning or at the end of the fire season.

Experts could freely move along the fuel-break segment, and along the nearby-untreated stand before and after the fuel-break. The questionnaire included appraisements of the expected characteristics of the wildfire just close to the fuel-break and then on the fuel-break itself (flame geometry, vegetation layers involved in fire propagation, …). It included also appraisements of the fighting difficulties on the fuel-break (access, smoke, …) and of the security feeling of the fire-fighter (security feeling, starting fighting, …). Finally the expert was ask to give a prognostic for fuel-break crossing probability and the way it could occur (surface fire, crown fire, spotting).

Experts were asked to fill the questionnaire in one of the three following wildfire scenarios of decreasing severity:

Scenario 1 (extreme): strong wind (60 km/h) and head fire

Scenario 2 (moderate): moderate to strong wind (20 to 60 km/h) and flank fire

Scenario 3 (moderate): moderate wind (20km/h) and head fire

Not all the scenarios were proposed on each segment. Scenarios 1 and 3 were proposed more frequently. On the whole, crossing the three level of sampling (sites, experts, scenarios), 385 questionnaires were filled up.

2.3 *Fuel-break segments description*

The fuel-break segment description was based on a belt-transect perpendicular to the main fuel-break direction, by mean of dominant species cover, height and aggregation, assessed on 25 m x 25 m elementary squares (Cohen *et al*,. this volume). Two juxtaposed series of squares were described included the nearby untreated stand before and after the fuel-break. Thereafter all the described segments were 50 m wide, but their length depended on the local width of the fuel-break. Among the four vegetation strata (litter, herbs, shrub and trees) several height classes were distinguished in order to specify fuel description (Cohen *et al*,. this volume). Litter was measured according to Rigolot and Etienne (1996). Herb layer was described as a whole without distinguishing species. For shrub and tree layers, the three dominant species were considered together with a global assessment of the layer. For tree layer, a complete inventory was also realised.

Within each height classes of each herb, shrub and tree layers, aggregation of individuals or clumps were assessed according to Folk (1951).

2.4 *Data analysis*

In a first step, questionnaires were analysed thanks to a Multiple Correspondence Analysis (Dervin, 1988). Questions of the form were transformed in the 12 following variables. The different possible answers to a given question represented the modalities of the corresponding variable. The modalities were coded (-, =, +) according to the corresponding effectiveness of the fuel-break segment.

1. Tree crowning out of fuel-break [generalised (1-); localised (1=); no (1+)]
2. Tree crowning on the fuel-break [generalised (2-); localised (2=); no (2+)]
3. Fire halting without fire fighting [yes (3-); no (3+)]
4. Accessibility of the forest road [low (4-); medium (4=); high (4+)]
5. Accessibility for pedestrians on the fuel-break [low (5-); medium (5=); high (5+)]
6. Accessibility for vehicles on the fuel-break [low (6-); medium (6=); high (6+)]
7. Smokes [untenable (7-); uncomfortable (7=); slightly uncomfortable (7+)]
8. Spotting on the fuel-break [likely (8-); unlikely (8+)]
9. Spotting over the fuel-break [likely (9-); unlikely (9+)]
10. Security feeling [no (10-); may be (10=); yes (10+)]
11. Start fighting [no (11-); may be (11=); yes (11+)]
12. Stop fire [no (12-); may be (12=); yes (12+)]

When some questions had no answer, the corresponding questionnaire was not included in the analysis. Finally, the analysis was made on 308 questionnaires.

Variables describing fuel-break dimensions and fuel characteristics were built using segment descriptions. On each segment, the value of each variable was calculated on every 625 m^2 elementary square. The mean value of each variable was then calculated on the whole fuel-break and on the nearby untreated stand. The descriptive variables built for the analysis are listed in table 1.

Tab. 1: Elementary statistics on fuel-break segments descriptive variables

Variables	Min	Mean	Max	Variance
Fuel-break width (m)	69	133	400	63,6
Distance between fuel-break edges and forest road (m)	0	92	350	67,9
Mean litter thickness (cm)	0	0,9	2,	0,7
Shrub cover (%)	0	33	74	22,8
Mean shrub volume (m^3/ha)	0	1364	4680	1239,6
Tree density (t/ha)	0	301	2771	481,6
Total height of tree dominant species (m)	0	8	15	3,9
Mean cover of dominant tree layer (%)	0	25	77	1239,6
Distance between tree crowns (m)	1	17	85	22,8

Among the various questions asked to the expert panels, the one summarising the best the fuel-break effectiveness was “Do you think you will be able to stop the fire on this fuel-break?” Then a model predicting the probability of halting the fire thanks to the fuel-break was built. This model should describe the relationship between variable to be explained, “stopping or not the fire”, and a set of explanatory variables describing the fuel-break. The variable to be explained is a binary variable (yes or not). “May be” responses were assimilated to “no” responses. Logistic distribution has been selected first because it is mathematically flexible of use, and then because it gives rich biological interpretations (Hosmer and Lemeshow, 1989). Explanatory variables which were selected were introduced in a logistic model $P(\text{halting fire}) = 1/(1+\exp(-bo + b1X1 + \dots + bnXn)))$ where P(halting fire) is the probability of halting the wildland fire on the fuel-break, X1, …,Xn are the independent variables, and b0, …, bn are the estimates coefficients.

Several models were fitted. In a first step, a general model was fitted, including the highest number of independent variables in order to illustrate the contribution of each selected variable in the expert decision making. In a second step, specific models were fitted for each single scenario.

The best explanatory variables for halting wildfire on a fuel-break were looked for.

To assess model stability, several data set were used. These data set were randomly selected among the whole data set, with a proportion of two third to build the model and one third to validate it.

In a second step, models were fitted for each scenario, and without distinguishing the professional origin of experts in order to give an average point of view of the expert panel. On the set of 372 questionnaires with a response to the question related with halting fire, 201 questionnaires were filled up in the frame of scenario 1, 37 with scenario 2 and 132 with scenario 3. In order to keep enough data in each sample, the whole data set was used to build the model in each case.

3 RESULTS

3.1 *Experts appraisement analysis*

The modalities of each variable were plotted on the three first axes of the factorial plan, which restituted 35% of the overall variance of the data matrix. The first axis opposed negative against the positive modalities of variables “halting fire”, “starting fighting” and “security feeling”. The second axis opposed the negative against the positive modalities of the variables describing the accessibility of the fuel-break.

This general analysis showed that “accessibility” is positively correlated with “security feeling” and “starting fire” variables but not with “halting fire”. It showed also that tree crowning (generalised or localised) and smoke production (untenable or uncomfortable) on the fuel-break, were negatively correlated with “security feeling”, “starting fire” and “halting fire” variables. It was finally noted that spotting over the fuel-break turned fuel-break breaching probable.

When analysing the influence of the professional origin of the expert within each geographical region, by projecting on the first factorial plan barycenters of their responses, it was observed that within each region, fire-fighters are more pessimistic than foresters are.

Tableau 2: Main characteristics of effective fuel-breaks in scenario 1

Segment	Fuel-break local width (m)	Phytovolume (m^3/ha)	Tree cover (%)
Avélans Fréjus	90	488	8
L'Ospedale - Pozzu Chiaru	117	320	29
Marguaritaghju au vent	125	0	3
Marguaritaghju contre-crête	125	64	3
Le Camp borne	131	1008	15
L’Ospedale – Diamente	170	310	23
Catalugno 171	173	1195	35
Catalugno 193	200	214	21
Gratadis	400	1892	4

3.2 *The “stop fire” model creation*

Tableau 3 : General “fire stop” model

Coefficients	Estimate	Std. error	Z value	Pr (>|z|)	
Constante	-4.2410528	0.8458993	-5.014	5.34e-07	***
Scenario	1.2319799	0.1972758	6.245	4.24e-10	***
Intercept	1.3121447	0.3106502	4.224	2.40e-05	***
Tree cover	-0.0270841	0.0085029	-3.185	0.00145	**
Shrub volume	-0.0002543	0.0001151	-2.209	.02716	*
Fuel-break local width	0.0146896	0.0052847	2.780	0.00544	**

Signif. Codes: *** 1‰ ** 1% * 5%

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