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Fireline production rate assessment under Mediterranean conditions

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Abstract

Global change is raising the occurrence and simultaneity of large wildfires. However, increasing the number of suppression resources is not necessarily the way to manage it and even less if suppression resource assignment is determined based on the experience of the incident commander or incident management team.

This research focuses on the estimation of fireline production rate in wildfires of different size under Mediterranean conditions. Fireline production rate was defined as the expected length of fireline that can be built by a firefighting crew in a period. Their most important explanatory variables were fuel model type, attack type, fire size, working time and support of aerial resources. Fuel models with the highest fireline production rate are those corresponding to grassland. Fireline production rate in indirect attack is lower than in direct attack regardless of fuel model. Fireline production rate decreased with increasing wildfire size. Firefighter production rate was decreased by 41.79% after three hours of work, due to fatigue in stress conditions next to the fire front. Aerial support increased fireline production rate between 8.14% and 20.63%. Finally, according to the findings obtained, the most efficient crew is made up of 7-9 firefighters.

The assessment of the average firefighter production rates based on easily identifiable variables from an incident command post, provides objective information for decision making about the type and number of resources required in wildfires suppression activities. An efficient allocation of suppression resources would reduce crew fatigue and increase the effectiveness of operational plans.

1. Introduction

Although large wildfires constitute less than 2% of the total forest fires (Donovan and Brown, 2005), they are the most severe causing the greatest ecological and socio-economic impacts. Due to their greater virulence and suppression difficulty, large wildfires require the highest suppression costs (Rodríguez y Silva et al., 2020). Moreover, Holmes and Calkin (2013) have indicated that in large wildfires, differences between the standard fireline production rates and estimated rates could be observed.

Fireline production rate was defined as the expected length of fireline that can be built by a firefighting crew in a period (Broyles, 2011). There is a lack of information regarding the productivity and efficiency of wildfires suppression resources (Thompson et al., 2018). Katuwal et al. (2016) used a Stochastic Frontier Analysis to model the production of the suppression resources, including the variability and inefficiency in suppression operations. Rodríguez y Silva (2017) and Rodríguez y Silva and Hand (2018) have generated productivity models based on the combination of suppression resources using econometric techniques.

The main goal of this research is to assess the fireline production rate developed by firefighters in wildfires of different size in Mediterranean ecosystems. Despite difficulties in generating the dataset (Plucinski, 2019a), this research was created through direct observations on active fires. In contrast, other studies estimated rates in firefighter trainings and burn areas and over-estimate fireline production rate (Plucinski, 2019b). Although some studies (Chico, 2001; Jiménez, 2014) have established production rates for fuel models in Mediterranean ecosystems, we try to cover gaps in relation to new psychological and working variables. Firefighter production rate estimated in different wildfire scenarios would constitute a useful and necessary tool for decision-making at two planning level. Before the wildfire, knowing terrestrial firefighting efficiency afford land managers optimize firefighting resources and design crews with an efficient number of firefighters. During a wildfire, it provides a scientific basis on which making technical decisions for the efficient suppression planning and resources assignment to contain a wildfire. Comparison of production rates based on the use of different suppression resources is a very useful tool for fire managers (Plucinski, 2019b).

2. Material and methods

2.1. Study area

The study area is limited to three spanish regions in southern Iberian Peninsula (Andalucia, Castilla La Mancha and Valencia), which cover a total of 190.000 km^2. Official statistics indicate an annual average of 1,993 fires and an annual burned area of 21,983 ha for them during 2008-2018. The climate of these regions are typically Mediterranean, with dry and hot summers making them fireprone areas.

2.2. Database creation

This study database was generated from direct observation during the firefighting crew work of three Spanish region wildfire agencies during the period 2013-2018. Fire technician or foreman filled in a report for each fire operation. A total of 229 reports were collected, 204 of which were used for this study. Fireline production rate was calculated by the ratio between fireline length and working time per number of firefighters. Fireline effectiveness is defined as the successful containment of the fire in the hand line build during firefighting. In addition to administrative information of each wildfire, the data gathered was (Table 1):

Table 1. Range of the variables gathered.

Variable	Range
Fireline production rate	0.1 - 2.85 m/min*firefighter
Fuel model (Anderson, 1982)	1-10
Fire size	0.5 - 3,400 ha
Working time	10 - 445 min
Temperature	21 - 41.5 ºC
Relative humidity	8 - 52%
Wind speed	2.5 - 60 km/h
Slope	0- 15% (value 1) - > 45% (value 4)
Stoniness	Low (value 1) - Very high (value 4)
Number of firefighters	5-27 firefighters
Type of attack	Direct (value 0) and Indirect (value 1)
Air resources support	No (value 0) and Yes (value 1)
Time interval between releases	3-15 min
Fireline effectiveness	No (value 0) and Yes (value 1)

2.3. Statistical analysis

Statistical analyses were performed by SPSS© software. Kolmogorov-Smirnov test was used to check the normal distribution. Krustal-Wallis and Mann-Whitney tests were used to identify significant differences ($p < 0.05$).

3. Results

In direct attack (Table 2), the highest production rate of firefighting crews was observed working in timber-litter fuel models, however, the lowest rate was found in chaparral fuel models. Fireline production rate in indirect attack (Table 2) was significantly increased in grassland and brushland fuel models in relation to timber fuel models.

Table 2. Fireline production rate for each fuel model group based on type of attack.

<table>
<tr><th>Fuel model type</th><th>Fireline production rate (m/min*firefighter)
Direct attack</th><th>Fireline production rate (m/min*firefighter)
Indirect attack</th></tr>
<tr><td>Grassland</td><td>0.87(±0.45)^a</td><td>0.40(±0.16)^a</td></tr>
<tr><td>Chaparral</td><td>0.33(±0.19)^b</td><td rowspan="2">0.31(±0.12)^a</td></tr>
<tr><td>Brushland</td><td>0.67(±0.34)^c</td></tr>
<tr><td>Timber-understory</td><td>0.44(±0.17)^b</td><td rowspan="2">0.16(±0.04)^b</td></tr>
<tr><td>Timber-litter</td><td>1.06(±0.1)^d</td></tr>
</table>

Mean values in a column followed by the same letter are not significantly different ($p < 0.05$).

Aerial resources support increased fireline production rate between the 8.14% (grassland fuel models) and the 20.63% (brushland fuel models) (Table 3).

Table 3. Fireline production rate based on air resources support.

Fuel model type	Fireline production rate (m/min*firefighter) with support of aerial resources	Fireline production rate (m/min*firefighter) without support of aerial resources
Grassland	0.87(±0.30)[a]	0.79(±0.45)[a]
Brushland	0.63(±0.39)[a]	0.51(±0.20)[b]

Mean values in a raw followed by the same letter are not significantly different ($p < 0.05$).

Statistical analysis of production rate did not provide significant differences ($p < 0.05$) according to meteorological conditions and environmental characteristics. However, fireline production rate decreased with increasing wildfire size (Table 4).

Table 4. Fireline production rate based on fire size.

Fire size (ha)	Fireline production rate (m/min*firefighter)
< 1	0.67(±0.55)[a]
1-50	0.55(±0.43)[a]
> 50	0.41(±0.25)[b]

Mean values in a column followed by the same letter are not significantly different ($p < 0.05$).

In addition, in brushland fuel models, fireline production rate was decreased by 41.79% after three hours of work (Table 5).

Table 5. Fireline production rate based on working time.

Working time (min)	Fireline production rate (m/min*firefighter)
< 60	0.67(±0.54)[a]
60-180	0.52(±0.28)[a]
> 180	0.39(±0.27)[b]

Mean values in a column followed by the same letter are not significantly different ($p < 0.05$).

The successful containment increased fireline production rate in both grassland and brushland fuel models (Table 6). The production rate was increased by 84.84% due to a successful containment of the fire perimeter.

Table 6. Fireline production rate based on fire successful containment.

Fuel model type	Unsuccessful fire containment	Successful fire containment
Grassland fuel models	1.09(±0.15)[a]	1.16(±0.42)[a]
Brushland fuel models	0.33(±0.09)[a]	0.61(±0.29)[b]

Mean values in a raw followed by the same letter are not significantly different ($p < 0.05$).

No significant differences in grassland fuel models were observed according to the number of firefighters (Table 7). In the case of brushland fuel models, significant differences were observed from 9 firefighters.

Table 7. Fireline production rate based on crew size.

Fire crew (firefighters)	Fireline production rate in grasslands (m/min*firefighter)	Fireline production rate in brushlands (m/min*firefighter)
< 7	1.02(±0.65)[a]	0.68(±0.47)[a]
7-9	0.77(±0.57)[a]	0.55(±0.35)[a]
> 9	0.90(±0.42)[a]	0.33(±0.26)[b]

Mean values in a column followed by the same letter are not significantly different ($p < 0.05$).

4. Discussion

Fuel models with the highest fireline production rate are those corresponding to grassland. Fireline production rate in indirect attack is lower than in direct attack regardless of fuel model. The fireline production rate estimated in this study is lower than those obtained in other Iberian studies (Chico, 2001; Chico and Poza, 2009; Jiménez, 2014). They overestimated fireline production rate values from simulated conditions or trainings while we consider direct observations on active fires. In active fires, the working demands, thermal stress conditions and smoke inhalation are different (Rodríguez-Marroyo et al., 2011, 2012). The main differences between our findings and other studies (Chico, 2001; Chico and Poza, 2009; Jiménez, 2014) are found in chaparral and timber-litter fuel models. With regards to chaparral fuel models, the rate is almost half in our study, due to longer periods of work. The timber-litter fuel models have a higher rate due to the absence of tree cutting. Besides, as a finding of this study, it is worth highlighting the production rate increases with the support of aerial resources according to other authors (Holmes and Calkin, 2013; Florec et al., 2019).

Although some studies (Jiménez, 2014) have pointed out that slope and stoniness are important variables in fireline production rates, they have not been identified as representative variables in our research. Similarly, differences in meteorological conditions did not provide significant changes, except for wind speed above 50-60 km/h that reduces production rates. Further studies have highlighted the decline in fireline production rates under extreme fire conditions (Holmes and Calkin, 2013). Moreover, production rate decreased by 45.9% on unsuccessful containment operations. This fact seems to support the idea that productivity models must incorporate psychological variables.

The availability of a reliable dataset for estimating the productivity of fire crews expands wildfire suppression knowledge (Katuwal et al., 2016; Thompson et al., 2018). This study affords to reduce uncertainty about the productivity of suppression resources based on working conditions. As a result, efficiency in the suppression operations will improve (Thompson and Calkin, 2011; Rodríguez y Silva and González-Cabán, 2016).

Further studies should analyse and modelling the effects of aerial resources and the working time in fireline production rate. In this sense, time intervals between releases below 5 minutes greatly increase the productivity of fire crews.

5. Conclusions

Despite the difficulties in generating a fireline production rate dataset, supporting statistical analysis provides us accurate data under Mediterranean Basin conditions. Our findings show that firefighter productivity is lower under active fires than under simulated conditions or trainings. The methodological framework is very flexibility enabling an extrapolation to other territories and fire crew structures. However, more precise information of some variables, such as fuel models, slope and stoniness, is needed.

Several factors were identified as statistically significant to determinate fireline production rates. We emphasize in the idea that productivity models must incorporate working and psychological variables, such as working time, fire size and successful containment. Fire crew productivity increases with the support of aerial resources according to the time interval between releases. Direct attack increases the operational effectiveness of suppression resources. Fireline production rates provide a useful tool for fire managers to assign the right type and number of fire resources, mainly in simultaneous large fires occurrence. Fire managers could quickly predict and evaluate spatial and temporal allocation resources.

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