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Changes in Fuel Structure and Fire Behavior with Heathland Aging in Northern Portugal

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Abstract. Heathland dominated by *Chamaespartium tridentatum* and *Erica umbelatta* in the mountains of Northern and Central Portugal is a valuable range resource, as well an important fire hazard that demands the settling of rational management strategies. Fuel structural parameters sampled along an age gradient of 1 to 21 years displayed dramatic modifications in a relatively short period of time. The finer fuels (< 2.5 mm) represent more than 70% of total biomass at all ages, and dead material in this size class increases 10% in a 4 years interval. Canopy bulk density peaks at 5-7 years and fuel accumulates linearly at a rate of 2 t ha^{-1} $year^{-1}$ in the first 3 years after fire, then slows down progressively and stabilizes around 14 t ha^{-1} in the older stands. Fire behaviour was simulated with the BEHAVE system following the temporal fuel patterns. Fire hazard is predicted to be low until 8 years of age but will rise to uncontrollable levels in stands older than 13 years. Some considerations about fire regime and fire management in this vegetation type are drawn from the results.

Keywords: Fuels; fire behaviour; shrubs; fire management; Portugal.

Introduction

Information about how fuel changes with time can provide useful insights on the issues of plant senescence and the role of fire in ecosystems, while potential fire behaviour depends directly of fuel succession (Rundel & Parsons 1979). Each vegetation type displays a specific fire regime that is strongly related with fuel dynamics, whose knowledge is necessary, since the definition of a convenient fire regime is essential when designing fire management strategies (Sapsis & Martin 1993). Dynamic fire situations occur as a response to the changing nature of vegetation and require flexible management practices (Chandler et al. 1983). An obvious feature of temporal fuel dynamics is the increase of fuel loads, but considerable modifications can be experienced by other structural parameters of the fuel complex. However, few studies quantify those changes (McNab et al. 1978, Rundel & Parsons 1979) or their consequences on fire behaviour (Rothermel & Philpot 1973, Hough & Albini 1978, Agee & Huff 1987, Marsden-Smedley & Catchpole 1995a).

Low heathland dominated by the shrubs *Chamaespartium tridentatum* and *Erica umbelatta* covers large areas of Northern and Central Portugal mountains. These plant communities develop under sub-atlantic climatic conditions in oligotrophic siliceous soils, growing as nearly continuous even-aged stands. Deforestation caused by wildfires is leading to their expansion, and changes in land use are now disrupting the natural fuel cycle, with increasing fuel buildup and decrease in grazing and conservation values, which makes these areas the subject of a growing management concern. The objective of this study, as a part of a larger fuel and fire modeling program, was to evaluate the structural fuel modifications induced by *Chamaespartium tridentatum /Erica umbelatta* shrubland aging, both at the species and community levels, and to assess their effects on fire behaviour.

Methods

This study was conducted in Serra da Padrela (Northern Portugal), where total annual precipitation and mean annual temperature are approximately 1,000 mm and 11° C respectively. Soils are shallow, stony and derived from schists. Non-grazed *Chamaespartium tridentatum/Erica umbelatta* formations within a elevation range of 800-970 m were sampled at the ages of 1, 4, 6, 8, 14, 18 and 21 years; communities older than this are not representative. Age, or the time since last disturbance, was dated by counting stem annual growth rings. Sampling intended to cover the structural variability of each stand. The two dominant species were individually measured for height and cover in 0.25 m^2 quadrats, and all the aerial biomass within their vertical projections was clipped; remaining fuel from the last fire was not collected. Litter was harvested using 0.07

m^2 quadrats and registering its depth. Data describing stand structure was recorded, namely cover and height by species, litter depth and cover. Before oven-drying and weighing, biomass was splited by dead and live condition, according to the standard diameter classification for fuel inventories (0-6 and 6-25 mm diameters). An additional size class was considered and privileged in the analysis, due to the dominant role it plays in fire spread, the very fine fuels with less than 2.5 mm diameter.

Aerial biomass partition by size class, % of dead material on each class and bulk densities at the species and community levels, and aboveground biomass (fuel load) at the stand level were calculated from the data. Time-dependent functions were fitted to a data set comprising the average values of fuel parameters for each stand, using weighted non-linear regression. The changes in fire behaviour with age were examined through the BEHAVE system (Andrews 1986) based on the fire spread model of Rothermel (1972). Fuel dynamics equations were used to derive the input data for fuel models development (Burgan & Rothermel 1984) at time steps of 2 years, starting at 3 years (the threshold for fire spread) and ending at 21 years. Additional static information on surface area-to-volume ratios and heat contents came respectively from Fernandes (non-published data) and Gomes (1982).

Results

The major differences between the two species relate to partition by size class and dead fuel percentage. Rates of structural modification are faster in *Chamaespartium tridentatum* (CHTR) and have a higher range. The relative amount of very fine fuel decreases with age, and is always lower in CHTR, reaching near 40% of the total biomass at 21 years, while *Erica umbelatta* (EUMB) doesn't drop below 75%. The increase of larger (> 6 mm) fuels with age has also distinct patterns, making up more than 30% of total biomass in CHTR above 18 years but reaching only 10% in EUMB. Dead fuel accumulation is quite impressive in CHTR, and half of its <2.5 mm canopy biomass is dead by the age of 8 years, further stabilizing at 60%, in a marked contrast with EUMB that only attains 20% after a almost linear growth. > 6 mm % dead fuels increase very similarly in the two shrubs, in a strong alometric fashion until reaching 50% at 21 years. Bulk density, as an expression of <2.5 mm canopy biomass concentration, peaks earlier (4-5 years) and higher (3.5 kg m^{-3}) in CHTR than in EUMB (7-9 years, 3 kg m^{-3}), but after 8 years is lower in the first species, reaching finally 1.5 and 2.0 kg m^{-3}

Fuel dynamics at the stand level (Table 1 and Fig. 1) result of the balance between CHTR and EUMB. < 2.5 mm biomass remains above 70% of the total at all ages, and the more dramatic changes arise in dead fuel % and bulk density, the parameters that express shrub decadence. Dead fuel increases approximately 10% at 4 years intervals in the finer class, and it is strongly non-linear in the other classes. < 2.5 mm bulk density reaches a maximum of 3.2 kg m^{-3} at 5-7 years and a minimum of 1.8 kg m^{-3} at 21 years; bulk density of the remaining fuels never exceeds 1.2 kg m-3.

Stand fuel load accumulates linearly at a rate of 2 t ha^{-1} year-1 in the first 3 years, but this rate slows down progressively. Data evidenced some decrease in the older ages, but a conservative approach was taken and fuel loads modeled as a function of (1-exp(-b AGE)). This function is frequently used (e.g. Kessel et al. 1984, Fensham 1992, Catchpole & Marsden-Smedley 1995b) and considered the most coherent to describe fuel accumulation with time from an ecological viewpoint, resulting in a curve that flattens out to a plateau - the maximum fuel load at equilibrium (14 t/ha in this study). Fuel load growth after 12 years is essentially accounted by the larger fuels.

The evolution of predicted fire behaviour with age showed a clear sigmoidal trend, which is not surprising, given the fact that energy stored on landscapes is likely to follow a logistic function (Sapsis & Martin 1993). Shape of the fitted logistic models is analogous to the ones presented for California chaparral by Rothermel & Philpot (1973), but fire behaviour levels off earlier in the CHTR/EUMB fuel complex, at 15-20 years. The sharp rise in rate of spread and flame length that takes place between 8 and 14 years of age can essentially be accounted by the crescent availability of fine dead fuel. The lower bulk densities and fine fuel % that characterize old stands could be expected to diminish fire behaviour magnitude, but higher amounts of 1hr (both in litter and canopy) and 10hr dead fuels counteract those effects.

Since the two dominant species are structurally very different, some degree of variation in fire behaviour is expected to occur, depending on the relative importance

Table 1. Equations describing fuel structural changes with age (t) at the stand level.

Parameters	Function	b_0	b_1	b_2	R^2	s_{yx}
< 2.5 mm size class						
% of the total	$y = b_0 t^{b_1}$	99.339	-0.123	-	0.96	2.5
% dead	$y = b_0 t^{b_1}$	3.388	0.875	-	0.89	6.5
bulk density, kg m^{-3}	$b_0 t^{b_1} e^{-b_2 t}$	2.621	0.372	-0.075	0.74	0.4
Fuel loads						
< 2.5 mm		9.796	-0.224	-	0.62	2.6
< 6.0 mm	$y = b_0 (1 - e^{b_1 t})$	12.384	-0.203	-	0.65	3.2
total		14.434	-0.175	-	0.67	3.7

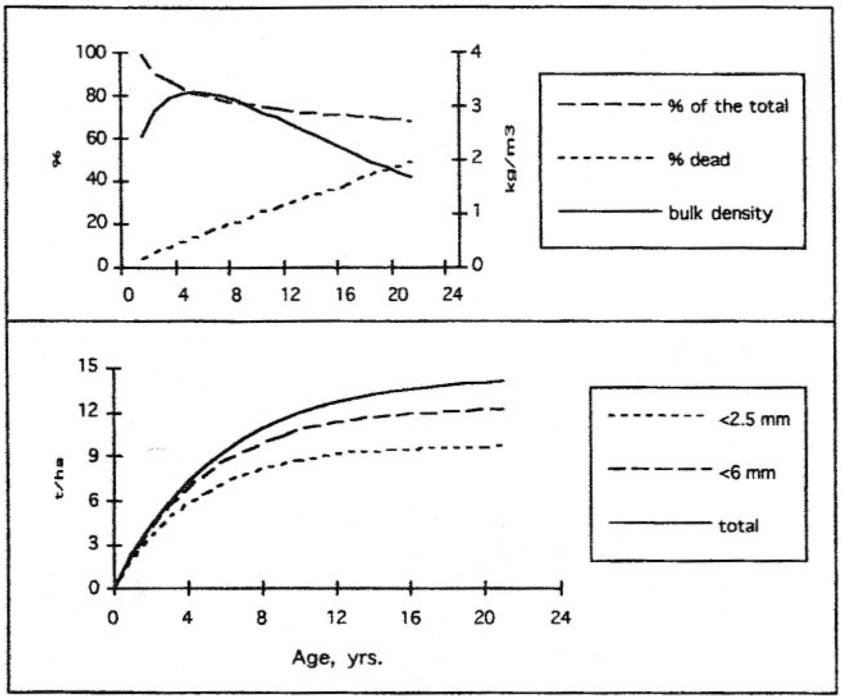

Figure 1. Fuel dynamics in CHTR/EUMB stands, < 2.5 mm size class (above) and fuel load (below) .

of each species in a given community. The estimated fire behaviour curves for an extreme situation of a fuel bed entirely made up by CHTR illustrate this point: higher fire hazard since the beginning and a sooner stabilization.

Implications

This vegetation type has been shown to be stable and adapted to recurrent disturbance (Rego et al. 1988a, 1991). The results now obtained are complementary to previous knowledge, allowing to conclude that fire in CHTR/EUMB heathland is not entirely exogenous, and matching the hypothesis of Mutch (1970) about the interconnection between fire dependency and high flammability. Fuel cycle in this shrubland is relatively short (15-20 years), with senescence already apparent at 14 years of age, indicating the necessity of periodical burning or other disturbances to maintain the system's sustainability and prevent high levels of fire behaviour. Fire behaviour can be interpreted in terms of supression difficulty. A wildfire taking place in this vegetation type under "normal"

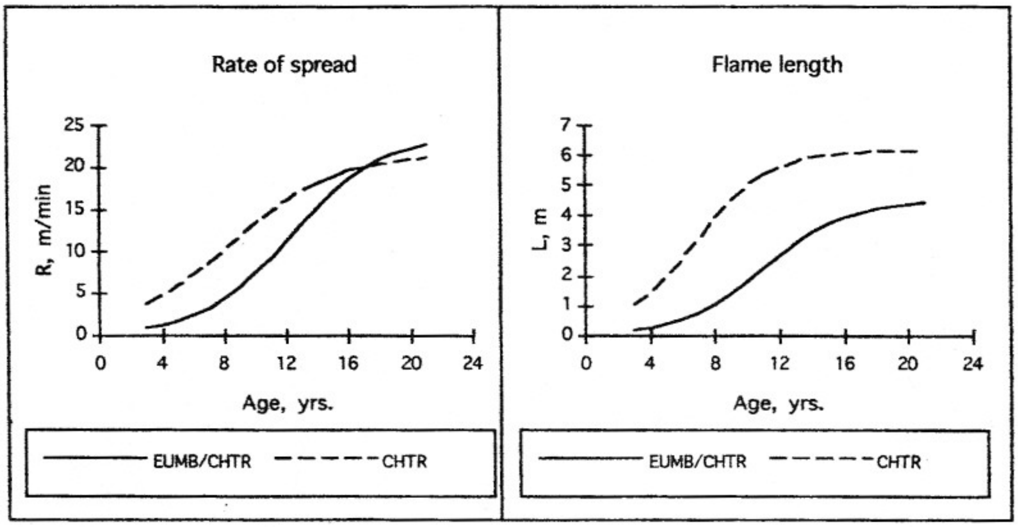

Figure 2. Fire behaviour dynamics in CHTR/EUMB stands and hypothetical CHTR stands as predicted by the BEHAVE system. Simulations for "normal" Summer conditions: midflame windspeed 10 km h^{-1}, slope 30%, and fuel moisture contents of 6% (1hr), 7% (10hr) and 80% (live vegetation).

Summer conditions is expected to be of low severity until 8 years of age, while frontal fire attack will be unsuccessful behind 13 years, according to the scale of Roussopoulos & Johnson (1975) cit. Andrews & Rothermel (1982). Therefore, burning CHTR/EUMB shrubland at a frequency of 8 years would be an appropriate target to maintain relatively safe fuel accumulation levels (fuels <2.5 mm below 8 t ha^{-1} and less than 20% dead). When the primary management objective is to supply the greatest amount of high quality forage, the traditional 3 to 7 years fire cycle is considered rational (Rego et al. 1988b) and ensures low fire hazard. However, vegetation is likely to become more flammable under this regime, because CHTR is a strong sprouter favored by frequent burning, while EUMB obligately regenerates from seed and will decline or disappear on sites that are burnt at those frequencies (Rego et al. 1988a); again, the links between fire adaptation and flammability are apparent.

Field work was confined to a small geographic area and only a reduced number of stands were sampled. Additionally, Rothermel's model has been considered inadequate do describe fire spread in shrubland (e.g. Lindenmuth & Davies 1973, Marsden-Smedley & Catchpole 1995b), and some preliminary testing of BEHAVE system in CHTR/EUMB heathland hints at the same conclusion (Fernandes 1996). Fuel models parameters tuning can improve the quality of fire behaviour predictions, but that was outside the scope of this study's purposes, and only moisture of extinction was adjusted to 35%. Therefore, the functions cannot be used for prediction and these results are merely relied upon to provide broad management guidelines. In spite of the limitations it is possible to conclude that vegetation senescence leads to severe fire behaviour in this heathland type, which illustrates the ecological and economical consequences of a fire exclusion policy and the necessity of establishing fuel rotation cycles to achieve age-class mosaics.

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