Factors influencing fire behaviour in shrublands of different stand ages and the implications for using prescribed burning to reduce wildfire risk

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Received 20 June 2001; accepted 7 December 2001

Fire behaviour under experimental conditions is described in nine Mediterranean gorse shrublands ranging from 3–12 years of age with different fuel loads. Significant differences in the fire-line intensity, fuel load and rate of fire spread have been found to be related to the stage of development of the communities. Fire spread is correlated with fuel moisture using multiple regression techniques. Differences in fuel moisture between mature and young communities under moderate weather conditions have been found. The lower moisture content identified in the mature shrubland is due both to the decreasing moisture content of senescent shrubland in some species, mainly in live fractions of Ulex parvi¯orus Pourr. fuel, and to a substantial increase in dead fuel fractions with low percentages of moisture content. The result is that the older the shrubland is, the greater will be the decrease in the total moisture content of the vegetation. In these moderate weather conditions, the fire intensity of the mature community was as high as the maximum intensity recommended for prescribed fires. This fact seems to indicate that, even under moderate conditions, prescribed burning as an alternative management tool in the mature shrubland must always take into account fuel control; on the other hand, this technique could be applied more easily when the shrubland is at an intermediate growth stage (4–5 years of age). Therefore, more frequent low-intensity prescribed fires are indicated to abate the risk of catastrophic fire.

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Keywords: fire behaviour, fuel and weather variables, Mediterranean-type shrubland, Ulex parvi¯orus Pourr., East Spain.

Introduction

The countries of the Mediterranean Basin have undergone intensive land use for millennia, and this has resulted in a significant fragmentation of the landscape. Since 1950, this trend has been reversed in many areas with the abandoning of marginal agricultural lands, the decrease in the grazing pressure and the shift to sources of energy other than wood (Le Houérou, 1993). Current land conditions thus depend strongly on recurrent disturbances (Naveh, 1994).

In the Spanish Mediterranean coastal strip, the main disturbance process is the forest fire. In recent years, both climate factors (Bessie and Jonhson 1995; Rambal and Hoff, 1998; Piñol et al., 1998; Millán et al., 1997) and land use changes (Vallejo, 1997; Moreno et al., 1998) have produced an increase in the number and extension of these fires. The Valencia Region represents a good example of this increase. In the last 30 years (1968–2000), of a
total cumulative area of 1 200 000 ha, the surface burned has been approximately 680 000 ha. Wildfires have affected approximately the same area of forest as of shrubland (Vallejo and Alloza, 1998). Similarly to other countries of the Mediterranean Basin, a substantial percentage of the forest burned corresponds to Pinus halepensis Mill. (Corona et al., 1998), which in turn represents 70% of the forests in the Valencia Region (MAPA, 1994).

Most of the forest and shrubland areas of the region are the result of old-field abandonment or afforestation activity. In this area, tree and shrub sprouters have been historically eliminated (Abad et al., 1997), and after fire, shrub obligate seeder species (Ulex parviflorus, Rosmarinus officinalis, several species of Cistus, etc.) are the most frequently found (Vallejo and Alloza, 1998). Thus, a consequence of the increase in fire frequency is that this type of shrubland community has significantly extended its dominance in the Spanish Mediterranean coastal strip. In the Valencia Region, the most common shrubland community is dominated by Mediterranean gorse (Ulex parviflorus Pourr.).

A few years after fire, gorse shrublands reach a homogeneous vertical and horizontal structure with a high amount of standing necromass mainly in fine fuel fractions (Baeza et al., 1998), resulting in high combustibility and a natural fire risk. Fine fuels react faster to weather changes, particularly if these fuels are dead, and they play a major role in the initial stages of all fires and in the propagation of most of them (Papió and Trabaud, 1990; Vélez-Muñoz, 1995; Montoya-Oliver, 1995; Viegas, 1998). On the other hand, given the unpalatable leaves of Ulex parviflorus, increases in pasture burning represent an unplanned fire risk that sometimes affects the surrounding ecosystems (Moreno et al., 1998). Under these conditions, management strategies to reduce the current extension of gorse communities are one of the prime necessities in vast areas of the western Mediterranean.

In fire-risk reduction strategies, the structural factors are always known in advance and can sometimes be modified, as opposed to the meteorological factors. Management actions can help to reduce vulnerability in most critical areas, thus lowering the fire risk and/or the extinction difficulty (Bardaji et al., 1998). In this context, in other countries, several management practices such as herbicides, grazing animals or cutting with manual or heavy equipment have been used to reduce the extension of similar undesirable species (Etienne et al., 1996; Henkin et al., 1998; Wagner et al., 1998). As previously mentioned, some of these (e.g. grazing) are inapplicable for mature gorse shrublands and others (e.g. the use of herbicides) kill individuals but do not eliminate them, thus increasing both necromass accumulation and fire risk (Engle and Stritzeke, 1995).

Currently, one of the dominant management techniques to reduce fuel loads is prescribed, burning early in the dry season in order to limit the extent and severity of fires that might occur later in summer. This technique is commonly used in Mediterranean-type ecosystems: California, Australia and South Africa (Minnich, 1998; Gill and Bradstock, 1994; Davis, 1998), but its applicability is being hotly debated from different viewpoints ranging from the nature of constraints to the use of fire as a management practice in vegetation (Bond and van Wilgen, 1996).

On the one hand, its costs are largely dependent on the structural composition of the selected community given that even in moderate weather conditions the fire intensity can be high and its control overly expensive (Gonzalez-Cabán, 1997). Thus, prescribed fires are recommended only for expected fire-line intensities of lower than 1000 Kw/m (Budd et al., 1997). On the other hand, designing and establishing priorities for prescribed burning to control fuel loads requires predicting the ecosystem response and the associated environmental risks (Budd et al., 1997; Bradstock et al., 1998; Cain et al., 1998).

Due to the increasing occurrence of wildfires in Spanish Mediterranean coastal areas, Mediterranean gorse communities are very prevalent. Because of this and of the scant information available on fire behaviour, it is necessary to search for fuel control techniques in this type of shrubland. Due to the fast occupation of some near gorse stands by an urban population, wildfires are not only an ecological problem sensu stricto but a more global one concerning maxim when often wildfires on this region cause losses on human life.

Our concern is to reduce the fire risk in fire-prone shrublands by using prescribed burning techniques. For this purpose, we have used fire-line intensity (Byram, 1959) to determine the potential applicability of prescribed burning in Mediterranean gorse. Given that for management purposes the age of the shrubland could be an appropriate indicator of the developmental stage of the gorse community (Johnson, 1992; Minnich, 1998), we have chosen communities of three different ages (3, 9 and 12 years old) in order to cover a wide range of developmental stages.

This paper reports the results of an experiment designed to analyse fire behaviour in...
Ulex parvi¯orus shrublands. The specific objectives of the experiment were: (1) to evaluate fire-line intensity in Mediterranean gorse communities of different ages in order to determine the potential for using prescribed burning and (2) to identify and evaluate the importance of their different components, especially those related to fuel properties, in order to generate managerial alternatives.

Methods

Study area and experimental design

To perform the experiment, gorse communities of different ages (3, 9 and 12 years old) were chosen. Each of them was replicated 3 times. The nine sites were located between the provinces of Alicante and Valencia in Eastern Spain (38°35′N–0°39′W). Summer wildfires had burnt six of them in 1985 and the other 3 in 1991. All the sites range between 800–900 m above sea level with the exception of Guadalest (450 m). The mean annual rainfall ranges between 500 and 600 mm and the mean annual temperatures between 13.8 and 14.5°C. Bedrock is marl and soils are Calcaric Cambisol (FAO, 1988). Sites were dry land crops until the 1950s. Table 1 shows descriptive characteristics of the stands.

Before the experimental fires, vegetation was homogeneous shrubland dominated by obligate seeder species: Ulex parvi¯orus, Rosmarinus of®ci nalis, Thymus piperella and several species of the Cistaceae family (Tutin et al., 1964/1980). The herbaceous stratum comprised perennial species, mainly Brachypodium retusum and B. phoenicoides. There were only a few small isolated individuals of Pinus halepensis and Quercus rotundifolia.

Burning procedures and weather variables

We carried out experimental burnings in nine 33 × 33 m plots. Five of them took place in the spring of 1994, one in the autumn of 1994, and the other three in the autumn of 1996. Before experimental burning, a fuelbreak of 6–8 m of mineral soil was bulldozed around each plot. A meteorological station was located near each experimental site. Air temperature and relative humidity were measured at a height of 2 m every 15 minutes. It is amply accepted that wind speed is the most important factor in determining fire behaviour because wind speed strongly affects heat transfer and increases fire spread. Thus, all the experimental fires were conducted on days with wind speeds under 5 Km/h. These weather conditions (Table 2) represent the range of conditions under which experimental fires are recommended (van Wilgen et al., 1985). On the 3-year-old gorse shrublands, we applied headfires whereas on 9 and 12 stands the ignition technique was backfires.

Fuel characteristics

Before the experimental burning, the vegetation cover was recorded by the point-intersect method (Greig-Smith, 1983). All the species were recorded along 5 parallel line transects of 5 m in length. Measurements were taken every 10 cm with a metal rod to record the contact between each species. A total of 250 points were recorded per site.

The fuel load at each site was measured in eight 1 m quadrats adjacent to the experimental plots. These sites were selected in a random way to avoid subjective choice. In each quadrat the vegetation, including litter, was harvested. Clipped material

<table>
<thead>
<tr>
<th>Table 1. Descriptive characteristics of sites for experimental burnings. Site code corresponds to: B: Bañeres; C: Confrides; G: Guadalest; A: Alcoy; T: Torremanzanas; O: Onil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site code</td>
</tr>
<tr>
<td>Age*</td>
</tr>
<tr>
<td>Altitude (m)</td>
</tr>
<tr>
<td>Aspect</td>
</tr>
<tr>
<td>Slope (°)</td>
</tr>
<tr>
<td>Season</td>
</tr>
<tr>
<td>Days**</td>
</tr>
</tbody>
</table>

* Time since last fire (years).

1 Seasons: (S) spring; (A) autumn.

2 Number of days before burnings with accumulated rainfall of less than 15 mm.
Table 2. Fire characteristics, weather and fuel data for the experimental burnings in *Ulex parviflorus* shrubland of different ages

<table>
<thead>
<tr>
<th>Site code</th>
<th>B-3</th>
<th>C-3</th>
<th>G-3</th>
<th>O-9</th>
<th>A-9</th>
<th>T-9</th>
<th>O1-12</th>
<th>O2-12</th>
<th>O3-12</th>
</tr>
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<tr>
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<td>21</td>
<td>27</td>
<td>10</td>
<td>10</td>
<td>93</td>
<td>82</td>
<td>67</td>
<td>93</td>
</tr>
<tr>
<td>Air temperature (°C)</td>
<td>18</td>
<td>26</td>
<td>28</td>
<td>27</td>
<td>30</td>
<td>18</td>
<td>19</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
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<td>&lt;5</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td>&lt;5</td>
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<td>Fuel height (cm)</td>
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<td>49</td>
<td>58</td>
<td>91</td>
<td>104</td>
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<td>59</td>
<td>67</td>
<td>22</td>
<td>32</td>
<td>43</td>
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<td>70</td>
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<td>1043</td>
<td>1585</td>
<td>3474</td>
<td>3997</td>
<td>3981</td>
<td>2564</td>
<td>4308</td>
<td>4617</td>
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<tr>
<td>Vegetation cover (%)</td>
<td>77</td>
<td>89</td>
<td>52</td>
<td>100</td>
<td>82</td>
<td>100</td>
<td>98</td>
<td>100</td>
<td>99</td>
</tr>
<tr>
<td>Fire-line intensity (kW/m)</td>
<td>69</td>
<td>89</td>
<td>213</td>
<td>2310</td>
<td>873</td>
<td>1117</td>
<td>1290</td>
<td>931</td>
<td>860</td>
</tr>
<tr>
<td>Rate of spread (m/s)</td>
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<td>0.005</td>
<td>0.008</td>
<td>0.039</td>
<td>0.013</td>
<td>0.019</td>
<td>0.029</td>
<td>0.011</td>
<td>0.011</td>
</tr>
</tbody>
</table>

Standard errors are given in brackets.

was separated into different species. The samples were taken to the laboratory, oven-dried at 80°C for 24 h and weighed.

For *Ulex parviflorus* biomass a very detailed analysis was performed. Individuals of *Ulex parviflorus* provide spinifex fuel of both live and dead plant material (Baeza et al., 1998). Because fine material is the most flammable fuel, the spinifex fuel and twigs (live and dead) <6 mm in diameter were considered separately from the larger components. And since dead woody fuel was absent in the 3-year-old communities and very low in those of 9 and 12 years of age, live and dead woody fuel (branches >6 mm of diameter) was grouped into one class.

Moisture content of the vegetation was obtained from 10 samples of the most abundant species immediately before each burning. For *Ulex parviflorus* we carried out measurements for each of the above-mentioned fractions. Samples were oven-dried at 80°C for 24 h and the fuel moisture was expressed as a percentage of dried weight. For regression analysis, the mean moisture content for the communities was estimated by weighing species and fuel load to provide a single fuel moisture content value for each experimental burning (Table 2) (Hobbs and Gimingham, 1984; Catchpole and Catchpole, 1991; Hernando et al., 1993; Cheney et al., 1993; Vega et al., 1998).

**Fire-line intensity**

The fire-line intensity (*I*) (kW/m) was calculated by using Byram’s equation (1959):

\[ I = H \times W \times R \]

where *H* is the fuel heat of combustion in kJ/kg, *W* is the weight of fuel consumed per unit area (kg/m²) and *R* is the rate of spread in m/s. The annual average of high heat combustion, 21 050 kJ/kg, was used for *Ulex parviflorus* (Elvira and Hernando, 1989). For the other species, a high heat combustion of 19500 kJ kg was used (Heim, 1974). The fuel load heat content (low heat of combustion, *H*) was obtained by adjusting the high heat of combustion for fuel moisture and the heat of vaporisation (Alexander, 1982). Fire spread was calculated twice for each experimental fire with the use of a metal rod separated by known distances. Unburned fuel was obtained by clipping whatever survived the fire from 6 square-meter samples per plot. These data were subtracted in order to calculate fire intensity.

**Statistical analysis**

To assess the effect of shrubland age on the rate of fire spread, biomass and fire intensity, we performed an analysis of variance (ANOVA) followed by an *a posteriori* comparison of means using the LSD test. The homogeneity of variances was assessed by the Cochran test. When necessary, log transformation of data was made (Day and Quinn, 1989).

The relationship between the rate of fire spread, weather parameters (air temperature, relative humidity and fuel moisture content) and structural fuel parameters (vegetation cover, height and fuel load) was assessed by stepwise multiple regression techniques (forward selection). The number of independent variables included in this analysis was reduced to avoid redundancy caused by strong intercorrelations.
We analysed the relationship between vegetation moisture and age in the 3- and 9-year-old shrublands for different species and by different size class of *Ulex parviflorus* (dead and live < 6 mm diameter and woody fuel > 6 mm diameter). Given the observed variance inhomogeneities, the data were arcsin-transformed before applying ANOVA (Sokal and Rohlf, 1995).

**Results**

*Fire characteristics and fire-line intensity*

Weather, fuel characteristics, fire-line intensity and rate of spread for the nine experimental burnings are summarized in Table 2. Statistical analysis of these data shows that fire-line intensity varied significantly with the development of the shrublands (Table 3). The values obtained at 3 years (124 kW/m) were significantly lower than the ones for 9 years (1433 kW/m) and 12 years (1027 kW/m). No significant differences were found between the last two. Because the heat of combustion can be considered constant (Alexander, 1982), our differences in intensity were mainly due to biomass variations and/or to rate of spread.

*Fire spread speed (R)*

The rate of spread in experimental burning was significantly lower in the 3-year-old shrublands (0.005 m/s) than in the 9- or 12-year-old shrublands (0.023 and 0.017 m/s respectively) (Table 3). No significant differences were found between the mature shrublands of 9 and 12 years of age. In the weather conditions under which the experimental burning was performed, fuel moisture content seemed to be the major factor controlling the rate of fire spread. The best regression obtained by step-wise regression analysis was:

\[ R = 0.03677 - 0.000407 \times FM \]

(where \( R \) = rate of spread, \( FM \) = fuel moisture content. \( R^2 = 0.487, P = 0.004, n = 9 \).)

*Temporal changes in fuel load*

The fuel load of the three-year-old Mediterranean gorse communities (1228 gm\(^{-2}\)) was significantly lower than that of the 9- and 12-year-old communities (3817 and 4426 gm\(^{-2}\), respectively). Fuel loads in the 9- and 12-year-old shrublands were not significantly different from one another (Table 3).

For the 3- and 9-year-old shrublands we performed a more detailed comparison of the communities specific composition. In younger shrublands, *Brachypodium retusum* and *Cistus albidus* account for 8 and 7% respectively of total fuel. This contribution in biomass shows no significant differences with mature shrublands (4 and 5% respectively). The relative contribution of *Rosmarinus officinalis* to total fuel is significantly higher in younger (15%) than in mature shrublands (only 5%). In contrast, the relative dominance of *Ulex parviflorus* is much

<table>
<thead>
<tr>
<th>Variable/Source</th>
<th>Sum of squares</th>
<th>DF</th>
<th>Mean square</th>
<th>F-ratio</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
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<td>Fire-line intensity</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between groups</td>
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<td>5.5743</td>
<td>25.80</td>
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<td>0.216056</td>
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<td>8</td>
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<tr>
<td>Rate of spread</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between groups</td>
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<td>1.51927</td>
<td>6.08</td>
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<tr>
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<td>1.49957</td>
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<tr>
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<tr>
<td>Between groups</td>
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<td>23.36</td>
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<tr>
<td>Within groups</td>
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<td>0.05596</td>
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<tr>
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<td></td>
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<tr>
<td>Between groups</td>
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<td>2</td>
<td>1095.44</td>
<td>6.16</td>
<td>0.035</td>
</tr>
<tr>
<td>Within groups</td>
<td>1066.25</td>
<td>6</td>
<td>177.708</td>
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</tr>
<tr>
<td>Total (Corr.)</td>
<td>3257.14</td>
<td>8</td>
<td></td>
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</tr>
</tbody>
</table>
higher in the 9-year-old shrublands (81%) than in the 3-year-old ones (58%). (Figure 1A).

These differences in *Ulex parviflorus* dominance are also based in an important structural evolution at the individual level. While in 3-year-old individuals the live fraction (<6 mm diameter) represents 51% of the total *Ulex parviflorus* biomass, in mature individuals this live fraction only represents 13%. In contrast, the relative importance of woody and dead fractions (<6 mm diameter) is significantly lower in 3-year-old individuals. While woody and dead fractions represent respectively only 4% and 3% of 3-year-old individuals, in mature ones, the relative importance of these fractions represents from 23% to 45% (Figure 1B).

**Fuel moisture content**

Comparisons on total fuel moisture content among the shrublands of 3, 9 and 12 years of age show significant differences between the shrublands of 3 and 9 years of age. However, the moisture content of more mature shrublands (12 years of age) is not substantially different from younger ones (Table 3). The lack of significance on the 12-year-old site could be attributed to rainfall events prior to fire. Because our experimental design does not consider variations in climatic variables, the following analysis took into account only the 3- and 9-year-old sites, which had been burned under similar weather conditions.

**Figure 1.** Fuel load and percentage of moisture content (mean ± SE) in a young shrubland (3 years of age) and in a mature one (9 years of age). (A) Total load and (B) percentage of moisture content in the most frequent species. (C) Total load per fractions of *Ulex parviflorus*. (D) Percentage of moisture content per fractions in *Ulex parviflorus*. Different letters indicate a significant difference (*P < 0.05, **P < 0.01, ***P < 0.001). The abbreviations correspond to: BR: *Brachypodium retusum*; CA: *Cistus albidus*, RO: *Rosmarinus officinalis*, UP: *Ulex parviflorus*, UPw: *Ulex parviflorus* woody (dead and live) >6 mm in diameter; UPd: *Ulex parviflorus* dead <6 mm in diameter; UPl: *Ulex parviflorus* live <6 mm in diameter.
We compared the fuel moisture in the most abundant species for the 3- and 9-years-old Mediterranean gorse communities burnt in spring. The moisture of Brachypodium retusum is the lowest of all the species (23% at 3 years and 17% at 9 years), not showing significant differences. Neither Rosmarinus officinalis nor Cistus albidus presented significant differences in moisture content between the 3- and 9-years-old communities (60–100%). In the case of Ulex parviflorus, a highly significant lower moisture content is observed in 9-years-old shrubland (25%) when compared with 3-years-old communities (73%) (Figure 1C).

In Ulex parviflorus individuals, we also analysed the moisture content by fuel fractions (live, dead and woody). In the live fraction, 9-year-old individuals show significantly lower moisture content (34%) than 3-year-old individuals (79%). The woody-fraction moisture content presented no significant differences regarding age (52% at 3 years and 41% at 9 years). As could be expected due to the similar weather conditions before fire, the dead-fraction moisture content also shows no significant differences regarding age (8% at 3 years and 13% at 9 years) (Figure 1D).

Discussion

The results of this study indicate that in moderate weather conditions (spring and autumn), fire behaviour in Ulex parviflorus shrubland is highly dependent on moisture fuel content. Values for fire-line intensity and rate spread are lower in the young communities (3 years) than in the older ones (9–12 years). Ulex parviflorus dominance is more evident in the oldest sites, and their structure shows a larger proportion of fuel fractions with low water content (woody structures and dead phyllodes). The greater moisture in the young sites is due to the dominance of fuels from species and plant fractions with greater moisture content. A decrease in water content with age has also been found in the live phyllodes, which are an active fraction. Similar decreases have also been reported for conifers in Australia and North America (Pook and Gill, 1993). The larger proportion of dead fine fuel in mature communities is related to an increase in combustibility, with the lower ignition times influencing the damping effect of live fuel.

One of the main aspects affecting vegetation moisture is the weather before burning. The shrublands of 3 and 9 years of age (except for the Torremanzanas site) were burned in spring after a period without rainfall. On the other hand, the burning of the 12-year-old shrublands took place 3–6 days after the first autumn rainfall which measured at least 15 mm. Papió (1990) observed that this threshold value for rainfall already had effects on the moisture content of vegetation. It is well known that a significant amount of precipitation in the last two or three weeks of the fire season may even bring an early closure to the period of high fire danger (Viegas and Viegas, 1994).

Our results on fire spread rate agree with Cheney et al. (1993), and support a negative correlation with vegetation moisture. In fire spread rate analysis, the water content of the vegetation is selected as the most determinant parameter. Cheney et al. (1993) for Australian grasslands and Burrows et al. (1991) for spinifex fuels found that wind and fuel moisture (in that order) are the main factors determining the fire spread rate and that fuel load influences other aspects of fire behaviour, such as its intensity.

Stand age has been related to both structural changes and fuel availability (Van Wilgen, 1982; Hobbs and Gimingham, 1984; Bradstock et al., 1998). Thus, intense and severe fires are more probable in mature and senescent vegetation phases than in the youngest states (Heilselman (1973) in Bessie and Johnson, 1995; Hobbs and Gimingham, 1984; Riggan et al., 1988; Whelan, 1995). The nine to twelve-year-old Ulex parviflorus communities have between two and five times more fuel than the three-year-old ones. In addition, this increase in fuel load corresponds to changes in species composition and fuel dynamics distribution.

Important changes affecting both the structure and the fuel moisture of Ulex parviflorus communities can be observed in relatively short periods of time. These changes occur mainly between the ages of 3 and 9 years. In Chamaespartium tridentatum and Erica umbellata shrublands in Portugal, Fernandes (1996) also described dramatic fuel modifications in short periods of time (4–8 years). Our results from Ulex parviflorus communities indicate that, in moderate weather conditions, both climatic and structural aspects are relevant because the changes regarding specific composition and plant population senescence are also related to the decrease in the vegetation water content.

These results appear to confirm the existence of critical periods in shrubland development with structural changes producing fuel variability that can be relevant for fire behaviour in prescribed burning management. The detection of these critical periods in fuel dynamics is very important for the identification of areas with different levels of fire risk and also for the planned control of fuel...
loads. Hobbs and Gimmingham (1984) described a decrease in fire intensity on senescent Calluna vulgaris heathlands (30–35 years old) which can be attributed to an increase in vegetation discontinuities and to a reduction in fuel load. In Mediterranean Ulex parviflorus shrubland, the senescent phase can be reached after 20 to 25 years (personal observation), which is similar to Ulex europaeus (25–30 years) (Rees and Hill, 2001). Most of these shrublands are replaced by more or less open pine forests (Pinus halepensis), especially when the gorse was developed following a wildfire in a mature pine forest. The result is a plant community with more fuel load and with a more continuous fuel distribution both vertically and horizontally, which can favour more intense wildfires.

Fire intensities in mature Ulex parviflorus shrublands are higher than those measured in experimental burnings applied to Atlantic shrublands with Pinus pinaster in Galicia and Portugal (Botelho et al., 1994; Hernando et al., 1993) and in Scottish heathlands (Hobbs and Gimmingham, 1984). In Quercus coccifera shrubland, Trabaud (1979) measured intensities to 1880 kW/m, values very similar to those found in the mature Mediterranean gorses. In extreme weather conditions, fire intensities can be higher in this Mediterranean area, or at least equal to the corresponding chaparral and fynbos communities. This kind of situation is frequent in summer when dry winds from the west, at high speeds of 80–90 km/h, can decrease air humidity to levels of 10% and temperatures can exceed 40°C. In an especially dry year, 1994, these unfavourable climatic conditions produced the burning of 138 000 ha, 15% of the total forest in the region.

Under low or moderate climatic conditions, the observed changes in the specific and structural composition of these communities (especially on 12-year-old sites) caused fire intensity at mature sites (9–12 years of age) to rise to levels near or higher (860–2310 kW/m) than the upper limit for a direct attack (1000 kW/m) (Budd et al., 1997). These structural changes, even in moderate or low climatic conditions, cause Mediterranean gorse communities to have a high fire risk.

Papió (1990) classifies Ulex parviflorus as a high fire-hazard species because of its inflammability in some fractions of dead fine fuel (Elvira and Hernando, 1989). Our results show that fuel properties in young shrubland hinder the evolution of intensity burning, improving suppression procedures in prescribed burning. However, in mature states the possibility of escape is very high. In these situations it is necessary to take greater precautions in applying prescribed burning for fuel control. Although biological responses to fire place constraints on its application, safety is probably the most important constraint in prescribed burning, especially the danger that fire could escape to areas that should not be burned (Bond and van Wilgen, 1996). Minimizing escapes is an important constraint which contributes to increase the overall cost of the prescribed burning programme (González-Cabán, 1997).

To carry out prescribed burning with the lowest risk, the best conditions are after a rainfall and during the intermediate phases in gorse development (at 4–5 years of age). The dead fuel load should be low, and fire intensity can also be low. At present, there is very little information on regeneration in Ulex parviflorus communities after the application of different fuel control techniques despite the fact that knowledge to this effect would be basic for determining the most appropriate procedure to follow.

Conclusions

In moderate weather conditions (spring and autumn), age had a very important influence on the behaviour of fire in the Ulex parviflorus shrublands (3–12 years of age) studied. Fire spread rate, fire-line intensity and fuel load increased in the mature shrubland as compared to the young shrubland. Vegetation moisture content was the variable that played the most important role in the rate of fire spread. In these conditions, the observed changes in vegetation moisture content were due to the conditions before the experimental burning and the low moisture content in the dead fuel. Mature shrubland presented great amounts of fuel with low percentages of moisture content. Furthermore, 80% of the fuel corresponded to Ulex parviflorus, a species which accumulates large amounts of fuel.

The fire behaviour characteristics described in Ulex parviflorus shrubland indicate that the risk of developing intense fires is very high in mature states. Important structural changes in fuel characteristics are produced in short periods of time (3–9 years). In mature states, the fractions of dead fuel (with low moisture content) increase significantly, so fuel control will contribute to reducing the high risk of fire in these areas. Even in moderate or low weather conditions, mature Mediterranean gorse communities pose a high fire risk. Finally, in view of the results above we recommend a more frequent burning practice on young gorse communities.
whereas on older ones the mechanical means seem more suitable.

Acknowledgements

We especially acknowledge the Consellería de Medio Ambiente (Regional Ministry of the Environment) for their financial assistance and Ana Tomás and Jorge Suárez for their technical collaboration in the development of this work. We thank J. Cortina for helpful comments on the manuscript. We also thank CICYT (CLI95-1947-C03-03) and the EC Environment Research Programme: Climatology and Natural Hazards (EV5V-CT94-0475) for their financial assistance. This work could not have been carried out without the CEAM team’s help in the development of the experimental burning.

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