Climatic trends, disturbances and short-term vegetation dynamics in a Mediterranean shrubland

Martín De Luís\textsuperscript{a,}\textsuperscript{*}, Maria Francisca García-Cano\textsuperscript{a}, Jordi Cortina\textsuperscript{a}, José Raventós\textsuperscript{a}, José Carlos González-Hidalgo\textsuperscript{b}, Juan Rafael Sánchez\textsuperscript{a}

\textsuperscript{a}Departamento de Ecología, Universidad de Alicante, Ap. 99, 3080 Alicante, Spain
\textsuperscript{b}Departamento de Geografía y Ordenación del Territorio, Universidad de Zaragoza, Zaragoza, Spain

Abstract

Fire and erosion are two major disturbances affecting Mediterranean ecosystems. Both of them are closely related to climate. There is evidence of decreasing precipitation in the Mediterranean, particularly during summer. There are also indications of an increased variability in the rainfall distribution. Climatic changes, though show high heterogeneity at a local scale. Based on these observations, we have evaluated the following hypotheses for the Region of Valencia (East Spain). (1) During the past three decades, climatic conditions have become more favourable for wildfires and high erosivity rainfall events. We have used 30-year climate records from 97 meteorological stations to examine this. Results indicate that in general the hypothesis is true, although trends are spatially dependent. (2) The effect of high intensity rain on burned land may substantially affect short-term ecosystem composition and function, and thus successional trajectories. Based on a plot scale study, we have assessed nutrient and vegetation dynamics after burning a pyrophytic community dominated by gorse (Ulex parviflorus). Erosion following high intensity rainfall affects physicochemical soil properties. As a consequence, plant cover is reduced and specific composition affected, changing the previous relationship between obligate seeder and resprouter species.

© 2001 Elsevier Science B.V. All rights reserved.

Keywords: Rainfall; Trends analysis; Fire; Functional groups; Short-term responses; Vegetation dynamics; Seeder and resprouter species

1. Introduction

In Mediterranean areas, wildfires constitute one of the most relevant environmental problems (Moreno, 1989; Vallejo, 1997). They are frequently considered a major cause of soil degradation and desertification (Rubio, 1987). Wildfires eliminate plant cover and leave the soil unprotected against the impact of raindrops (Elwell and Stocking, 1976). The Region of Valencia is characterised by low and uneven rainfall inputs. In fact, the western Mediterranean has the world’s highest density of cyclogenesis (Petterssen, 1956), and annual totals are determined by two or three precipitation events (Martín-Vide and Wheeler, 1988; Wheeler, 1991), occurring mainly in autumn (Romero et al., 1998, 1999). Rainfall events higher than 200 mm typically occur in a few hours in zones with a mean rainfall of 350 mm per year (Olcina, 1994; Lana et al., 1995; Millán et al., 1995). In these environmental conditions of strong and frequent periods of drought associated with wildland fires, as well as large floods and serious erosion problems (López-Bermúdez, 1990; Romero et al., 1992; Rubio and SanRoque, 1990; Albadalejo, 1995), water erosion

\textsuperscript{*}Corresponding author. Tel.: +34-96-590-3732; fax: +34-96-590-3464.

E-mail address: martin.deluis@ua.es (M. De Luís).

0378-1127/01/$ – see front matter © 2001 Elsevier Science B.V. All rights reserved.

PI: S0378-1127(00)00438-2
is the most important soil degradation process (Rincón and Erena, 1996). In this context, water can be considered both a resource and a disturbance factor for ecosystems.

In recent years, the synergistic effect of climatic and socio-economic forces may have aggravated desertification processes (Puigdefabregas and Mendizabal, 1998). Inland depopulation and the abandonment of agricultural land have affected the composition and structures of vegetation communities. These changes may have resulted in increases in the magnitude and frequency of wildfires (Moreno and Oechel, 1995; Moreno, 1998). Climatic changes may be occurring simultaneously. Thus, general circulation models (GCMs) agree in their predictions of an overall higher average temperature for southern Europe (Houghton et al., 1996). These changes have been paralleled by an increase in fire risk (Piñol et al., 1998).

Predictions with respect to precipitation changes are less clear. GCMs predict a decrease in annual rainfall and changes in the seasonal distribution in southern Europe (Houghton et al., 1996; Palutikof, 1996). But the level of confidence in these results at regional or local scales is low (Palutikof et al., 1996). In rainfall change detection, spatial and temporal variability is higher than in other climatic elements (Vinnikov et al., 1990; Groisman and Legates, 1995), and complementary techniques based on the study of empirical records are required (Houghton et al., 1990; Suppiah and Hennessy, 1998). Hulme et al. (1995) and Moron et al. (1995) indicate that model evaluation requires measurement data of the related variables that are directly comparable with model outputs over, at least, a 30-year period. For this reason, the use of WMO normal periods is recommended.

Mediterranean regions are transitional climate regions where it has been hypothesised that climate changes may have the most pronounced effects (Lavorel et al., 1998). The effects of climatic changes on ecosystems, and particularly those resulting from increased temperature and atmospheric CO₂ concentration, have been widely addressed in the literature (Moreno and Oechel, 1995). The effects of climatic changes will also depend on the relation between climatic conditions and the disturbance regime. This topic has received much less attention in the past (Landhausser and Wein, 1993; Clark et al., 1996; Arseneault and Payette, 1997), although it is contemplated in current research programs.

The Mediterranean climate is characterised by long dry summers and high rainfall concentration (Pérez-Cueva, 1995). Climatic trends as predicted from models and suggested from climatic records could favour common disturbances such as fire and autumn rainstorms (Quereda, 1994; Vázquez and Moreno, 1995; Piñol et al., 1998). The occurrence of both disturbances could affect ecosystem composition and function, and foster land degradation (Pérez-Trejo, 1994; Ghazi et al., 1997).

Numerous studies have examined the effects of fire on ecosystems (Terradas, 1996; Vallejo, 1997) including nutrient losses (Trabaud, 1994; García-Cano et al., 1998), and the sensitivity of burnt soils to rainfall erosion (Shakesby et al., 1993; Kutiel and Inbar, 1993; Rubio et al., 1997; Bautista et al., 1997). But the effect of an intense rainstorm on post-fire succession has seldom been addressed.

High intensity rainfall events may have a strong effect on soil erosion (Larson et al., 1997; McConkey et al., 1997). On the other hand, there are evidences of decreased productivity resulting from topsoil removal in agricultural (Pierce et al., 1984; Biot and Lu, 1995) and non-agricultural soils (Amaranthus and Trappe, 1993). These decreases may be related to a deterioration in soil properties, including biological properties (Ferrán et al., 1991; Amaranthus and Trappe, 1993; Gachene et al., 1997).

We have carried out a two-scale study to identify the recent trends in climatic conditions in the Region of Valencia (East Spain), and to assess the effect of fire and high intensity rainfall events on the composition and function of a Mediterranean ecosystem. Our main goals are: (i) to assess climatic trends favouring ecosystem disturbances in the last 30 years in the Region of Valencia, (ii) to assess the combined effect of fire and rainstorm on short-term ecosystem response, and (iii) to compare results obtained with different state-variables (e.g. demographic vs. non-demographic). The first part of the study is based on the 1961–1990 rainfall records from the meteorological stations. For the studies at the plot and individual level, we selected a 12-year-old community dominated by gorse (Ulex parviflorus).
2. Methodology

2.1. Precipitation analysis

The Region of Valencia is located along the Mediterranean coast of Spain (Fig. 1). It comprises an area extending between 38 and 40°N. The climate is Mediterranean, with high daily, seasonal and inter-annual rainfall variability (De Luís et al., 1996; Pérez-Cueva, 1995). For this study, we have used the monthly rainfall records from 97 pluviometric stations. The database covers at least the WMO normal period 1961–1990, and this represents the longest period available for highest quality data covering the whole Valencia Region (source in Pérez-Cueva, 1995). For each station, we estimated mean annual rainfall (Fig. 2), and the mean inter-annual precipitation concentration index (PCI) (Fig. 3; Oliver, 1980). The index is defined as

\[
PCI = 100 \frac{\sum_{i=1}^{12} p_i^2}{\left( \sum_{i=1}^{12} p_i \right)^2}
\]

where \(p_i\) is the amount of rainfall for the \(i\)th month. Values below 10 indicate uniform rainfall distribution, values from 11 to 20 denote seasonality in rainfall distribution, and values above 20 correspond to climates with substantial monthly rainfall variability.

Prior to the trend analysis, rainfall records were smoothed by calculating a 9-year moving average (Sneyers, 1992). This conventional procedure (Sneyers, 1992; Keim et al., 1995; Loureiro and Coutinho, 1995; Suppiah and Hennessy, 1998) offers a valuable way of filtering out year-to-year variations to reveal long-term trends (Wheeler and Martín-Vide, 1992; Salinger et al., 1995). For trend detection in climatological variables, non-parametric techniques are suggested (Clark and Hosking, 1986; Sneyers, 1992). We have used Spearman’s non-parametric rank correlation analysis (at a 5% significance level) to assess the significance of the trend (positive, negative or null) (Keim et al., 1995; Türk, 1996; Labajo et al., 1998; Suppiah and Hennessy, 1998). Examples of
series with positive, null or negative trends are shown in Fig. 4.

2.2. Study area and experimental design: fire and rainfall simulations

The study area is located in Onil, 40 km northwest of Alacant (East Spain), on three 21–26° slopes facing S, NE and N. Altitude is 800 m asl. Climate is dry Mediterranean. According to the nearest weather station (Banyeres), the mean monthly temperature is 13.8°C, and the mean annual precipitation is 466 mm. Soils are loamy Typic Calciexeroll (De La Torre and Alías, 1996) developed on Miocene marls. Soils are highly carbonated and pH is 7.7. Vegetation is 1.3 m height, 99% cover pyrophytic shrubland dominated by *U. parviflorus*. Subdominant shrubs include other obligate seeders such as *Cistus albidus* and *Rosmarinus officinalis*. Very few woody sprouters are present and the sparse herbaceous layer is dominated by *Brachypodium retusum*. The study site was covered with Aleppo pine (*Pinus halepensis*) forest until burned in 1985.

Fig. 3. PC1 (Oliver, 1980) distribution in the Region of Valencia (1961–1990).

Fig. 4. Annual rainfall (dots) and 9-year running mean (line) at three contrasted meteorological stations. Spearman’s correlation (r) and significance level are given inside each figure: (a) positive trend; (b) null trend; (c) negative trend.
Table 1
Weather, vegetation characteristics, and fire behaviour of the three
*U. parviflorus*-burned shrubland plots

<table>
<thead>
<tr>
<th></th>
<th>Site 1</th>
<th>Site 2</th>
<th>Site 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weather conditions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air temperature (°C)</td>
<td>19</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>Ambient humidity (%)</td>
<td>82</td>
<td>67</td>
<td>93</td>
</tr>
<tr>
<td>Soil and vegetation characteristics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total biomass (g dw m⁻²)</td>
<td>2152</td>
<td>3416</td>
<td>3902</td>
</tr>
<tr>
<td>Litter accumulation (g dw m⁻²)</td>
<td>416</td>
<td>326</td>
<td>627</td>
</tr>
<tr>
<td>Shrub height (cm)</td>
<td>123</td>
<td>128</td>
<td>134</td>
</tr>
<tr>
<td>Vegetation moisture content (%)</td>
<td>50</td>
<td>40</td>
<td>70</td>
</tr>
<tr>
<td>Soil moisture content (%)</td>
<td>27</td>
<td>14</td>
<td>19</td>
</tr>
<tr>
<td>Fire behaviour</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intensity (kW m⁻¹)</td>
<td>1438</td>
<td>1037</td>
<td>970</td>
</tr>
<tr>
<td>Rate of spread (cm s⁻¹)</td>
<td>2.9</td>
<td>1.1</td>
<td>1.1</td>
</tr>
<tr>
<td>Post-fire litter debris (g m⁻²)</td>
<td>91</td>
<td>46</td>
<td>237</td>
</tr>
<tr>
<td>Post-fire woody debris (g m⁻²)</td>
<td>210</td>
<td>304</td>
<td>545</td>
</tr>
</tbody>
</table>

We used a complete randomised block design with two treatments (fire and high intensity rainfall simulation) and two levels (presence/absence). In each of the three blocks (i.e. sites), we selected two 33 × 33 m² areas, and we burned one of them in October 1996. Inside each 33 × 33 m² area, we located rainfall simulation and control plots. Weather conditions, vegetation characteristics and fire behaviour for the three experimental plots are shown in Table 1.

After the fires, we carried out a 240 mm rainfall simulation lasting 105 min, using a 2.5 m high rainfall simulator that covers an effective area of 7 m², with a spatial homogeneity of 86%. This type of rainfall has a return time lower than 10 years in some areas in the Region of Valencia, and lower than 50 years at the meteorological station nearest the experimental area (De Luís et al., 1998). We measured runoff, sediment yield and total P, total N and organic C export during high intensity rainfall simulations in 2 × 2 m² plots within the target area (Table 2). Of note are the sharp differences in runoff and sediment yields between site 2 and the other two sites. These differences are related to surface roughness (unpublished data). Pre-fire vegetation composition and structure, fire severity, and overall topography were similar at the three sites. Soil losses described in Table 2 occurred mainly during the first minutes of the simulation, and decreased exponentially thereafter (García-Cano et al., 1998). Because of the relatively small size of the plots, soil losses may be taken as a measure of sediment mobilisation rather than as an overall quantification of downslope-erosion rates.

2.3. Vegetation dynamics

We selected four 1 × 0.5 m² areas within each experimental plot to monitor first-year seedling recruitment. We tagged germinating seedlings every 2 months, and recorded seedling mortality for each of the previous cohorts. We used these data to estimate the survival rates ($t_i$) of *C. albidas, Helianthemum marifolium* (H.m) and *U. parviflorus*, the three most abundant obligate seeders (80% of total emerging seedlings). We grouped seedlings from all other species (12) within a single class.

One year after rainfall the simulation, we determined the height of obligate seeders and the relative cover of the dominant sprouter grass (*B. retusum*). We used allometric relations based on the destructive sampling of seedlings collected outside the experimental plots to estimate seedling biomass. We determined the relationship between *B. retusum* cover and biomass in the same way.

2.4. Statistical analysis

We used variance analysis to determine the significance of the two factors, site (random factor) and rainfall simulation (fixed factor), on seedling survival

Table 2
Runoff, sediment yield, nitrogen, phosphorus and carbon collected during a high intensity rainfall simulation on a burned *U. parviflorus* shrubland

<table>
<thead>
<tr>
<th>Site</th>
<th>Runoff (%)</th>
<th>Sediment yield (kg ha⁻¹)</th>
<th>P (kg ha⁻¹)</th>
<th>N (kg ha⁻¹)</th>
<th>C (kg ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1</td>
<td>18.2</td>
<td>859</td>
<td>1.4</td>
<td>5</td>
<td>80</td>
</tr>
<tr>
<td>Site 2</td>
<td>32.5</td>
<td>8423</td>
<td>8.2</td>
<td>42</td>
<td>708</td>
</tr>
<tr>
<td>Site 3</td>
<td>20.7</td>
<td>295</td>
<td>0.3</td>
<td>2</td>
<td>30</td>
</tr>
</tbody>
</table>
and plant biomass. We applied arcsin transformations to correct for heteroscedasticity when necessary. We calculated Gini’s coefficient \( G \) to evaluate differences in individual size caused by the rainfall simulation. Gini’s coefficient ranges from 0 (all plants are the same size) to unity (all but one plant are infinitely small in a population of infinite size) (Weiner and Solbrig, 1984).

3. Results

3.1. Trends in rainfall volume

Eleven pluviometric stations showed a positive trend in annual rainfall volume. Forty-four stations showed a negative trend and the remaining 42 stations showed no significant trend over the period of study. The spatial distribution of these trends is shown in Fig. 5. There was a relative accumulation of negative trends overlapping those of average rainfall volume (Fig. 2). That is, rainfall has decreased mainly in the more sub-humid and dry areas and remained constant or increased in most semiarid areas (i.e. average annual precipitation of less than 350 mm).

3.2. Trends in rainfall concentration

Forty stations showed a positive trend in rainfall concentration (gradually higher PCI values). The other stations showed a negative trend (16 stations) or no trend (41 stations). The spatial distribution of these trends is shown in Fig. 6. In general, stations with lower PCI (i.e. lower than 20), corresponding to inland areas (Fig. 3), showed an increase in rainfall concentration whereas in the areas with highest rainfall concentration, the PCI values remained constant or showed a gradual decrease over the three decades.

3.3. Vegetation dynamics

Obligate seeders were dominated by a few species. From a total of 1693 germinations occurring the first year after fire, \( C. \) \textit{albidus} accounted for 43%, \( H. \)
Table 3
Results of a two-way variance analysis to assess the effects of site and rainfall simulation on the first year survival rate of *H. marifolium* (H.m) (H.l), *C. albidus* (C.a), *U. parviflorus* (U.p) and other obligate seeders (Other), as well as for the whole population (Total)*

<table>
<thead>
<tr>
<th>Sources of variation</th>
<th>Degrees of freedom</th>
<th>F vs.</th>
<th>H.m</th>
<th>C.a</th>
<th>U.p</th>
<th>Other</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site (S)</td>
<td>2</td>
<td>S×R</td>
<td>223.95</td>
<td>91.95</td>
<td>334.64</td>
<td>113.98</td>
<td>4.568</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Probability</td>
<td>0.7313</td>
<td>0.6293</td>
<td>0.6899</td>
<td>0.7674</td>
</tr>
<tr>
<td>Rainfall (R)</td>
<td>1</td>
<td>Residual</td>
<td>3929.0</td>
<td>929.16</td>
<td>359.08</td>
<td>440.04</td>
<td>760.07</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Probability</td>
<td>0.0252</td>
<td>0.0366</td>
<td>0.2145</td>
<td>0.0077</td>
</tr>
<tr>
<td>S×R</td>
<td>2</td>
<td>Residual</td>
<td>609.48</td>
<td>156.11</td>
<td>744.515</td>
<td>376.03</td>
<td>239.27</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Probability</td>
<td>0.4148</td>
<td>0.4413</td>
<td>0.0546</td>
<td>0.0039</td>
</tr>
<tr>
<td>Residual</td>
<td>18</td>
<td></td>
<td>659.33</td>
<td>182.29</td>
<td>216.93</td>
<td>49.00</td>
<td>51.33</td>
</tr>
<tr>
<td>Transformation</td>
<td>arcsin</td>
<td>arcsin</td>
<td>arcsin</td>
<td>arcsin</td>
<td>arcsin</td>
<td>arcsin</td>
<td>arcsin</td>
</tr>
</tbody>
</table>

*Significant factors and interactions are in italics.

*H. marifolium* for 24%, *U. parviflorus* for 9%, and the remaining 23% corresponded to a pool of 12 poorly represented additional species. One-year seedling survival was lower in the plots affected by rainfall simulation than in the control plots (0.38 vs. 0.55, respectively). A significant interaction between site and treatment indicates that the effect of an intense rainfall was site-dependent (Table 3). The relatively low number of germinations on site 2 may be responsible for this interaction. The survival of *C. albidus* and *H. marifolium* (H.m) decreased with high intensity rainfall.

Rainfall affected the size distribution (measured as biomass) of obligate seeders and sprouting grass by increasing the relative number of individuals in the higher-size classes in the first case, and by increasing the number of bare and low-cover patches in the second (Fig. 7, Table 4).

### 3.4. Plant biomass

We found no significant differences in the first-year biomass of obligate seeders either analysed by species or pooled (Table 5, Fig. 8). In contrast, sprouting *B. retusum* was highly affected by rainfall. A single rainstorm reduced *B. retusum* biomass by more than 50% (Fig. 8). Total biomass was also reduced by an intense rainfall.

### 4. Discussion and conclusions

A decrease in rainfall volume and an increase in monthly rainfall concentration has occurred in most of the stations analysed over three decades. Results agree with GCM predictions of a decrease in rainfall volume, changes in seasonal distribution and an...
Fig. 7. Size distribution of (a) *H. marifolium* (H.m); (b) *C. albidus* (C.a); (c) *U. parviflorus* (U.p) seedlings, and (d) *B. retusum* (B.r) patches 1 year after an experimental fire as affected by an intense rainstorm.

Table 5
Results of a two-way variance analysis to assess the effects of site and rainfall simulation on total biomass (Total), and on the biomass of *H. marifolium* (H.m), *C. albidus* (C.a), *U. parviflorus* (U.p), all obligate seeders (Seed), and *B. retusum* (B.r)*

<table>
<thead>
<tr>
<th>Sources of variation</th>
<th>Degrees of freedom</th>
<th>F vs.</th>
<th>H.m</th>
<th>C.a</th>
<th>U.p</th>
<th>Seeders</th>
<th>B.r</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site (S)</td>
<td>2</td>
<td>S×R</td>
<td>Mean squares</td>
<td>334.40</td>
<td>446.02</td>
<td>0.1210</td>
<td>702.90</td>
<td>114.46</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Probability</td>
<td>0.0047</td>
<td>0.2247</td>
<td>0.3212</td>
<td>0.1870</td>
<td>0.7571</td>
</tr>
<tr>
<td>Rainfall (R)</td>
<td>1</td>
<td>Residual</td>
<td>Mean squares</td>
<td>0.0127</td>
<td>52.261</td>
<td>0.0802</td>
<td>113.76</td>
<td>4603.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Probability</td>
<td>0.9746</td>
<td>0.4448</td>
<td>0.1168</td>
<td>0.2429</td>
<td>0.0000</td>
</tr>
<tr>
<td>S×R</td>
<td>2</td>
<td>Residual</td>
<td>Mean squares</td>
<td>1.5917</td>
<td>129.29</td>
<td>0.0522</td>
<td>161.63</td>
<td>356.72</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Probability</td>
<td>0.8777</td>
<td>0.2476</td>
<td>0.1994</td>
<td>0.1551</td>
<td>0.1379</td>
</tr>
<tr>
<td>Residual</td>
<td>18</td>
<td></td>
<td>Mean squares</td>
<td>12.114</td>
<td>85.614</td>
<td>0.0295</td>
<td>78.047</td>
<td>160.95</td>
</tr>
<tr>
<td>Transformation</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

* Significant factors and interactions are in italics.
structure, may be partly responsible for the decrease in fire-return time and increase in the surface area affected by wildfire in this region. In Spain, the annual area burned has increased by 600% from 1960 to 1990 (Prieto, 1993). In vast areas of the Region of Valencia, the wildfires return-time (a key factor affecting desertification) is very short (Abad et al., 1997). In the Region of Valencia, 600,000 ha of a total of 900,000 ha covered by forests and woodlands have burned in the last 20 years (Generalitat Valenciana, 1996; Abad et al., 1997). In this context, wildland fires and desertification processes seem to be fostered by a synergistic interaction between climate (Píñol et al., 1998; Stocks et al., 1998) and land-use changes (Moreno (1998); Puigdefábregas and Mendizabal, 1998) as driving forces.

Thus, our results indicate that climatic trends between 1961 and 1990, and in particular the decrease in the average annual precipitation, may have favoured drought and fire-frequency, and reduced productivity in the water-limited ecosystems of the Region of Valencia. Rainfall concentration is another relevant factor affecting erosivity (González-Hidalgo, 1996), and our observations (an increase in the areas of higher fire-risk) emphasise the risk of desertification that threatens a substantial part of the Region of Valencia (Pérez-Trejo, 1992; López-Bermúdez, 1990).

On a plot scale, the synergistic effect of fire and high intensity rain had a strong effect on the two functional plant groups identified. A higher mortality rate as a consequence of rainfall was observed in the most abundant species (C. albidos). Gini’s coefficient showed that 1 year after fire and rainfall, C. albidos and U. parviflorus seedlings, the two dominant obligate-seeders before the fire, were fewer but larger in the rainfall-affected plots. Although 1-year observations are not enough to predict long-term community dynamics, if maintained, these observed differences may significantly affect ecosystem composition and structure. Further, spatial and temporal analysis of seedling survival and growth will help to explain the observed patterns.

On unburned areas, B. retusum had been the dominant species, ranking first on the dominance-diversity curves for almost 20 years. Nine months after fire, this clonal grass species recovered its first-place position on the dominance-diversity curves.

Fig. 8. First-year standing biomass of (a) *H. marifolium* (H.m), *C. albidos* (C.a), *U. parviflorus* (U.p); (b) total obligate seeders, *B. retusum* (B.r), and total plant biomass in a burned gorse shrubland as affected by an intense rainstorm. Error bars correspond to the standard error of the mean.

increase in rainfall intensity in some areas across the Mediterranean basin (Palutikof, 1996). Other studies based on meteorological records have also observed a trend towards decreasing precipitation in southern Europe since the 1930s (Máheras, 1988). The agreement between model predictions and observations suggests that this trend could be associated with global warming (Palutikof et al., 1996). However, we are aware of the fact that a 30-year period is not sufficient to fully encompass any climatic variability signal, so these changes should be cautiously considered.

Decreases in rainfall volume and increases in rainfall concentration are occurring mainly in dry, inland areas where most of the forest and woodland zones are located. Changes in the precipitation regime, together with land-use changes affecting the vegetation
(Caturla et al., 2000). This behaviour in relation to fire agrees with former studies (Speth, 1969a,b; Abad et al., 1997). In semiarid areas, B. retusum may be considered a promising species for the restoration of extremely degraded lands because of its high resilience to fire (Caturla et al., 2000). Rather surprisingly, B. retusum cover was highly affected by rainstorms. This fact had a greater impact on the first-year post-disturbance biomass and cover than a series of three fires occurring within 20 years (Caturla et al., 2000). We still do not know which factor affected B. retusum so negatively. It is probably related to the fact that rainfall erosion left surface fine roots exposed (the 2 cm surface soil contained as much as 23% of the roots, García-Cano, 1998), or that conditions for rhizome sprouting (e.g. water and nutrient availability, temperature, etc.) deteriorated as a consequence of soil losses (an average 3 mm on site 2, García-Cano, 1998). Although maximum rhizome density was below the surface soil affected by rainfall simulation, we cannot rule out a direct effect of erosion on rhizome activity.

After fire, vegetation resilience seems to be a key factor in preventing soil erosion. Empirical models indicate a negative exponential relation between the soil erosion rate and the vegetation cover (Elwell and Stocking, 1976). It has been suggested that below a 30% vegetation cover, plants may not be able to retain soil particles (thus being out-competed by erosion processes), and as a result, the soil-plant system may gradually degrade (Thornes, 1987). Complete vegetation removal may lead to irreversible soil degradation in semiarid areas (Castillo et al., 1997).

Thresholds in degradation trajectories have also been related to the elimination of functional groups (Hobbs and Norton, 1996; Aronson et al., 1993). We have found that a single rainfall event of extraordinary intensity falling on fire-denuded land may have a deleterious effect on the ecosystem not only through direct soil and nutrient losses (García-Cano et al., 1998), but also through a decrease in the potential of the vegetation to recover after fire. In this case, degradation would not follow the suppression of a functional group, in this case a sprouting grass, but rather the decrease in its abundance. Long-term monitoring of these sites will provide valuable data to assess the impact of the observed changes on future ecosystem composition and function. If confirmed in the long-term, results may contrast with current knowledge on successional trajectories which suggest a gradual increase in B. retusum dominance with disturbance regime (Papió, 1990; Carreira et al., 1992; Terradas, 1996; Thanos et al., 1996). We may emphasise that the characteristics of the study (in-site, climate, slope, bedrock, rainfall intensity, etc.) make them particularly sensitive to the disturbances tested, and that the results observed cannot be generalized to other experimental conditions.

In conclusion, if the observed trends in average annual precipitation and rainfall concentration are not reversed in the near future, climatic conditions may become more favourable to wildfire and high intensity rainfall in many areas of the Region of Valencia. Based on short-term observations, the synergistic effects of both disturbances could foster land degradation and desertification in sensitive areas.

Acknowledgements

We thank Dr. Pérez Cueva (Department of Geography, University of Valencia) and the Regional Government of Valencia (Conselleria d’Ordenació del Territori, Generalitat Valenciana) for facilitating our access to the database used in this study. This study was supported by CICYT (CLI95-1947-C03-03) and the Conselleria de Cultura, Educació i Ciència, Generalitat Valenciana (GV97-RN-14-2). Thanks to CEAM for help with the field work and English translation.

References


García-Cano, M.F., 1998. Avaluación de la pérdida de nutrientes y dels canvis en la fertilitat del sòl en un matollar de Ulex parvifloras afectat pel foc i la pluja torrencial. Tesis de Licenciatura (Ined.).


