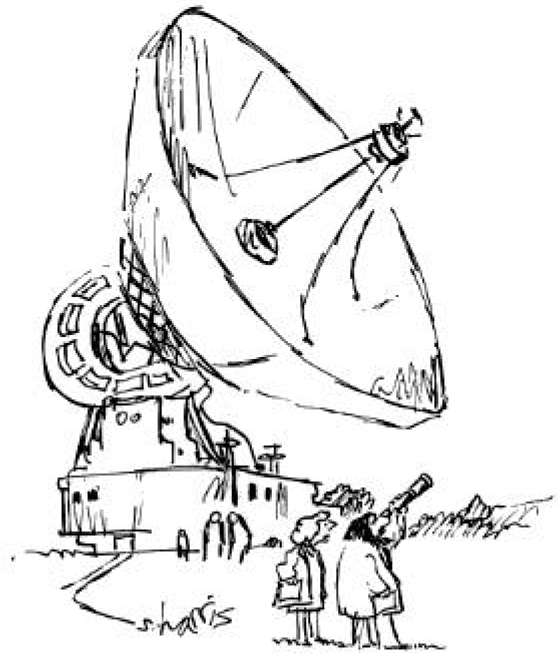

"Just checking."

Chapter 4

Factors influencing the formation of unburned vegetation islands within a large forest fire: the case study of a Mediterranean fire.

Abstract

Large forest fires are recently becoming more frequent and more severe in many ecosystems. As these disturbances affect large areas, they are likely to be heterogeneous in their effects. One of the characteristics of this heterogeneity is the formation of unburned islands of vegetation, and a spatial variability of fire severities in the affected ecosystem. The importance of these unburned patches relies on their contribution to ecological processes, such as regeneration patterns, soil erosion, fauna distribution and biodiversity conservation. The survival of these vegetation islands is conditioned by three major factors: topography, meteorology and fuels. The combined effect of these three factors will influence the characteristics of these islands: number and areas of the unburned patches.This study focuses on a large forest fire that occurred in north-east Spain, in 1998. The area of the fire is divided into slopes of different aspects, in order to separate the differential microclimatic conditions of contrasted aspects (i.e. wetter and more productive forests in northern aspects versus more water stressed and less productive forests in southern slopes). The number of vegetation islands and their sizes are related to 12 potential variables that influence their formation (i.e. land cover characteristics, aspects, rugged terrain (slope inclination), forest structure, and two landscape indices). We hypothesize that there is not a random pattern in the formation of unburned islands. Conversely, vegetation islands will be concentrated on northern aspects, in less flammable forests (i.e. broadleaves) and higher fragmentation, to interrupt the advance of fire. The results of our study suggest a non-random distribution of the islands within the fire perimeter. A higher number of vegetation islands (island frequency) was associated to higher slope areas, higher percent of forests, lower densities of infrastructures and lower diversities. Northern and western aspects enhanced the formation of vegetation islands. In the other hand, the area of these islands seemed to be conditioned by the percent of forest, the area of the slope, the existence of more mature forests (higher volumes of wood), steep slopes and lower levels of infrastructures. Among the results of this study, the negative relationships between larger islands and fragmented landscapes, suggests that, under severe meteorological conditions, fragmented forests can be more affected by wind and by water stress, burning more easily than forests that are protected from these edge-phenomenon. The importance of size, aspect, forest structure and landscape heterogeneity, as potential factors enhancing the formation of islands, had been already reported by several authors. The results of this study would reinforce those forest management strategies that avoided linear features (firelines, fire-breaks), to enhance any forest treatment that focused on areas and avoided fragmentation (i.e. fuel reduction over selected slopes, in northern aspects, larger slopes, higher percent of forest, and more mature forests).

Key words: forest fires, unburned patches, vegetation islands, terrain variables, landscape indices, fuels, topography, management strategies.

INTRODUCTION

In the last decades, the occurrence of severe fire episodes affecting large extensions of forested areas has called the public attention about the ecological, social and economical importance of these disturbances, in diverse forest ecosystems (Christensen 1989, Johnson et al. 1998, González-Cabán 2000, Retana et al. 2002). The effects of these large forest fires, an increased sensibility towards large-scale disturbances, and a recent popularity of ecological studies from broader-scales perspectives (Caley and Schluter 1997, Angermeier and Winston 1998), have resulted in a considerable number of studies dealing with factors that influence large forest fires (Bessie and Johnson 1995, Minnich and Chou 1997, Keeley and Fortheringham 2001, Minnich 2001) Among these studies, several have focused on the pre-fire heterogeneity of the landscape, as a way to determine the resulting variability of fire severity in the affected area (Eberhart and Woodard 1987, Turner et al. 1994,1999, Kushla and Ripple 1997, Cumming 2001, Finney 2001). The post-fire mosaic of burned vegetation and islands of unburned vegetation, is finally conditioned by those variables that influence fire severity: topography, meteorology, and fuels (Rothermel 1983, Pyne 1984). These factors play a key role in the intensity of the fireline and its rate of spread, which determine the final severity of a fire, and therefore, the formation of unburned islands within the fire perimeter (William and Rothermel 1992, Schimmel and Granström 1996, Tuner et al. 1997).

The importance of unburned vegetation patches relies on its role in diverse ecological processes such as i) vegetation re-establishment patterns (Turner et al. 1994), ii) forest succession, forest structure and forest-edge phenomena between the mature and early successional forest (Turner et al. 1994, Retana et al. 2002); iii) fauna establishment (Gasaway and DuBois 1985), and iv) erosion control and watershed dynamics (Lathrop 1994). The establishment of opportunistic or invader species may also be enhanced in large burned patches, making more complex and less predictable the successional dynamic following very large fires, when compared to small fires (Turner et al. 1994). In spite of the ecological importance of these unburned patches, research has devoted more studies to the burned areas than to the characteristics of this ‘residual vegetation’ (sensu Eberhart and Woodard 1987). More effort has also been invested in evaluating the effects of these surviving forest patches on biodiversity and species distribution, than investigating the causes that lead to the formation of these surviving islands (Llimona et al. 1993, Ferrán and Vallejo 1998, Elmqvist et al. 2001). Among the studies dealing with the survival of unburned forest patches, it has been reported the importance of topography, soils, streams, fire history, forest structure or landscape patterns (Van Wagner 1983, Baker 1993, Turner and Romme 1994, Kushla and Ripple 1997, Agee et al. 2000). Another variable that has also been reported to influence the resulting heterogeneity of fire severity is the fire size (Eberhart and Woodard 1987, Turner et al. 1994). Thus, Turner et al. (1994) hypothesized that large forest fires would display lower severity heterogeneities, because they were controlled by fewer environmental variables (mainly wind). Conversely, small fires would be more heterogeneous in their severities, due to their wider range of controlling variables: fuel moisture, fuel type, atmospheric humidity, wind, temperature and topography. However, their results suggested the contrary pattern: larger fires had a lower tendency to be dominated by a single burn class than did smaller burns. Moreover, larger fires were far more predictable than smaller fires in terms of burned-unburned proportions. Thus, when fires were small (i.e. less than 1250 ha), the proportion of burned area that was in crown fire varied from 5 to 60%, while this percent was reduced to 35-55% in larger fires. Corroborating the importance of fire size as a key factor controlling the abundance of unburned areas, Eberhart and Woodard (1987) analyzed several characteristics of “residual vegetation” within the fire perimeter. Among their results, they found that the percent of disturbed area -area without surviving islands- decreased significantly with increasing fire sizes, while the median area of the surviving islands significantly increased. Other variables that

An understanding of the pattern of island formation would improve forest management and would offer clues for the design of less fire-prone landscapes. Moreover, it would provide managers with knowledge of the on-site resources available to them for rehabilitation of the disturbed area and an indication of the possible impacts on other resources including wildlife (Eberhart and Woodard 1987). This study will search for environmental variables that influence the frequency and size of unburned islands within the fire perimeter, and will categorize their importance by means of a tree classifier. To fulfill this goal, a large forest fire occurred in north-eastern Spain (Catalonia) in 1998, will be analyzed. This large fire was characterized by a patchy fire dynamic that left a mosaic of small surviving islands immersed in a charred matrix. We hypothesize that these unburned patches are not randomly located, and that northern aspects, areas with higher landscape diversities, higher percents of less flammable materials (i.e. broadleaves), and more abrupt topography, will favor the formation of these unburned islands.

MATERIAL AND METHODS

STUDY AREA

The study area corresponds to the large forest fire occurred in 1998 in El Solsonès county (Lleida, North-Eastern Spain, between 41º 59‘ and 41º 44‘ North and 1º 21‘ and 1º 39’ East). Fire started in two consecutive days (18th and 19th of July) as two separate fronts. These individual fires combined into one large front (25 km), which was favoured by the extreme climatic conditions (warm and dry wind). Fire was finally extinguished on the 21st of July, affecting a final extension of ca. 26000 ha. Among the 16033 hectares of forested land affected, 88% corresponded to woods, regarding the Forestry and Ecological Inventory of Catalonia (IEFC 2000). The primary forest species affected included *Pinus nigra* (74%), *Pinus halepensis* (11%), *Quercus faginea* (7%) and *Quercus ilex* (3%) (González & Castellnou 1998). A revision of the data available in the IEFC, within the burned area indicated that, in 1988, 65% of the stations had small, dominated trees (individuals< 15 cm DBH), understory percents between 0-10%, and mean tree heights for the dominant trees between 8-13 m. Non-forested areas (7853 ha) were mainly represented by croplands (IEFC 2000). Regarding the climatic characteristics of the area, 69% of the fire land has 100-200 mm of hydric deficit (Thornthwaite classification, WWW1). Annual rainfall within this area is approximately 650-700 mm, with a summer mean precipitation of 140 mm. Annual temperatures oscillate is approximately 12ºC, with mean temperatures in the month of July of 21ºC (WWW1). Soils are mainly bright calcareous sandstones and loams.

The evolution of forest fires in this area is similar to the rest of Spain, in terms of an increased number of fires and burned areas, in the last three decades (Peix 1999). For the period of 1988-1997, fire fighting and control systems had efficiently reduced the number of fires in Catalonia, with the exception of the large forest fires, which are responsible for 0.43 percent of the incidences, and 75 percent of the annual affected area (Peix 1999). This situation partly relates to the accumulation of fuel loads which has not modified the fire regime in terms of the type of fire, but has enhanced the severity of the episodes. Thus, between 1970-1990, the arboreal area increased in a percentage of 20 percent in Catalonia (DARP 1990). High demographic pressure, rural abandonment, disappearance of traditional activities, marginality related to low agrarian cost-effective, changes in the spare time habits and the second residence phenomena are the remaining factors explaining this fire situation (Llasat 1997, Peix 1999).

Characterization of the unburned islands pattern

The unburned-island layer used in this study was obtained from a classified digital map of the burned area (Román-Cuesta et al. unpublished data). These authors performed a quantitative comparison between two broad methodologies for burned land classification: a field survey and four image processing techniques. The use of apparent reflectance data was the methodology that yielded better accuracies, and the best cost-effective ratio, as no transformation was required more than the image correction steps. This methodology resulted in a total of 2259 ha of unburned islands within the fire perimeter. For the purposes of this study, a minimum size of islands was selected (≥ 0.2 ha). Even though the ecological importance of these small islands, they represented an unaffordable number and they accounted for a reduced area (see results for further information). In order to diminish biases, surviving islands larger than 0.2 ha with a land cover different from forests (i.e. green crops), or islands where fire did not pass through, were also eliminated from the island digital layer (information was obtained from a Field Survey map, Casas et al. 1999). The final number of surviving islands, after all these exclusions, was of n=817, with a total area of 2023 ha (Figure 1). In order to characterize the pattern of these unburned islands, three indices were selected: i) the patch area (m2), ii) the perimeter-area ratio (L-S), and iii) the corrected perimeter-area (CPA). The perimeter-area ratio index ($m.ha^{-1}$) varies according to the size of the patch even when the shape is constant. The corrected perimeter-area (CPA) index informs about the shape of the patches. It partly diminishes the size effect of the previous index. It varies from 1 for a perfect circle, to infinity, for a long and narrow shape (Farina 1998):

$$CPA = (0.282*L) / \sqrt{S}$$

where L is the patch perimeter, in meters, and S its area, in ha.

A Lorenz curve was employed to visualize the pattern of these unburned patches within the fire perimeter. These curves represent cumulative frequencies, comparing two sets of ordinal, interval or ratio data (Díaz-Delgado and Pons 2001). Lorenz curves display the degree of concentration of a variable, in our case, the size of the surviving islands versus the number of islands. The evolution of the L-S ratio or the CPA versus the area of the islands was also revised.

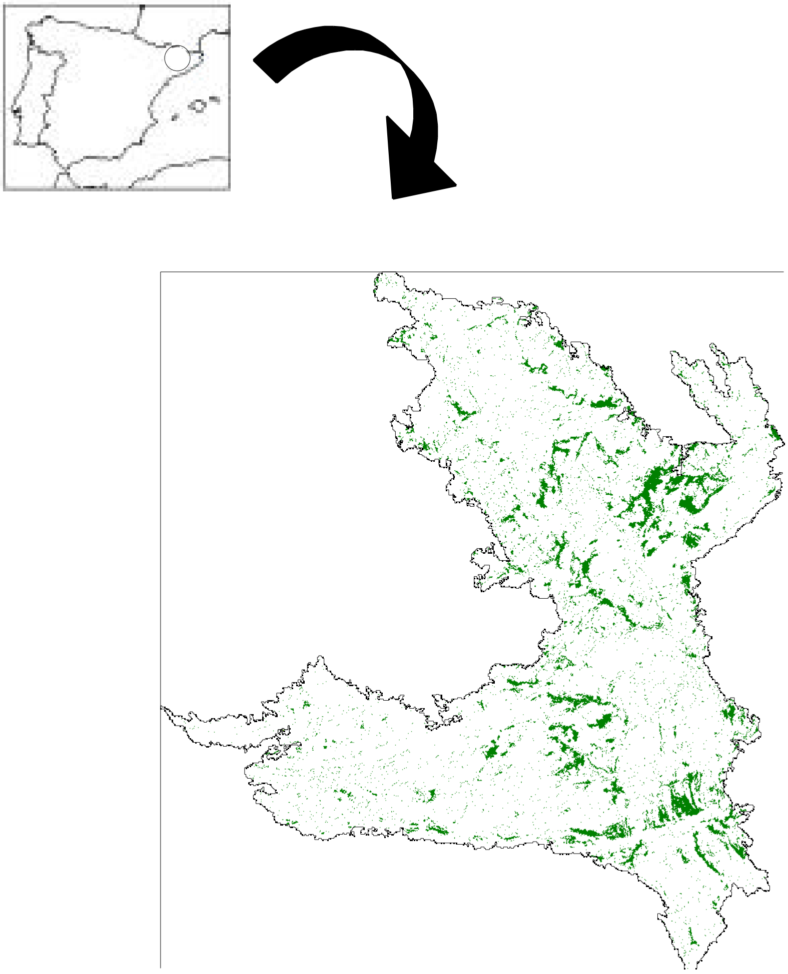

Figure 1: Unburned-island layer, obtained from a IRS-1C, LISS-III image, by means of a maximum likelihood algorithm applied to the apparent surface reflectance data . Source: Román-Cuesta et al. *unpublished data.*

Factors affecting the formation of islands

In order to characterize those variables that influence the formation and extent of unburned islands, the study area was divided into slopes larger than 2.5 ha, each of them associated to a given aspect. Smaller slopes represented an unaffordable number (10512, 86%) and were considered too small for landscape analyses. Slopes were, therefore, the spatial unit of all our analyses. This land division was considered the most appropriate for the Mediterranean conditions, in order to minimize the effect of aspect on different water stresses and vegetation distributions (Gràcia 2000). A total number of 1608 slopes were selected. Due to the threshold values of slopes (≥ 2.5 ha), and islands (≥ 0.2 ha), 17% of the total area of islands were eliminated from our study. Slopes with no forests or very small percents of forests (i.e. ≤ 5 %) were removed from the analysis, as no islands could be formed on them. Four major groups of variables were introduced in the analysis: unburned-island variables, topography, land cover, and landscape factors. Final variables were obtained by overlaying each considered variable upon the slope units, by means of the GIS system Miramon 4.0vh (Pons 2000). Multi-collineality analysis and elimination of redundant variables -correlation coefficients ≥ 0.8 and VIF (variance inflation factor) values higher than 10-, was also done.

Unburned-islands variables: Data were obtained regarding the incidence of islands: number of islands rated by the forest area in each slope (num.ha^{-1}) and the total area of the unburned-islands in each slope, rated by the forest area in each slope. It was expressed in percentages. Each unburned-island variable was finally categorized into three groups, considering a balanced distribution of percentiles, by means of the SPSS statistical program: slopes with no island formation (0), slopes with relatively low incidence of islands or low percents of unburned areas (**1**: 0.01-0.36 islands.ha^{-1}, 0-14.9 percent of unburned area), and slopes with relatively high incidence of islands or high percents of unburned areas (**2**: 0.36-4.57 islands. ha^{-1},14.9-100 percent of unburned area). The number of slopes in each category, both for the frequency and area of island was of n=791, n=409, n=408, for the categories 0,1 and 2 respectively.

Topographic variables included slope and aspect. These topographic variables were obtained from a Digital Elevation Model (DEM) of 25 m of pixel resolution. Elevation was not included as its range of variation in the study area (407-936 m) was considered insufficient to incorporate it in the analysis. Aspect was a categorical variable with four final classes: north, south, east and west. Due to the very reduced number of flat slopes, this category was eliminated from our study. Slope was calculated as the weighted mean of the slope area occupied by three categories of slope: 0-10 º, 10-30º, and >30º.

$$Sl_m = \mathop{}\limits_{i=1}^{n} s_i / 100 * p_i$$

where Sl_m is the mean slope, in degrees, and s_i refers to the percent of slope area with a category p_i .

Land cover variables: they were obtained from a digital land cover map (IEFC 1993, 1:3000), and from a digital land use map (CORINE 1986-1988, 1:250000) (broadleaves). The study area contained 14 different land covers, mainly concentrated on crop-fields and woods. Originally, there were 8 variables that were reduced to three: forested land, crop-fields, shrubland, and broadleaves. This last variable pretended to assess the effect of forest species on the final survival of forest stands. These land cover variables were incorporated in the analysis as the percent of slope area occupied by each of them. The percent of understory and the volume of wood ($m^3.ha^{-1}$) were derived from data collected within the fire area, in a National Forestry Inventory (IEFC) performed in 1988. There were 143 forest stations available within the fire area, which were used to create a continuous variable by means of a GIS interpolation. Each continuous layer was transformed into 6 categories, and a mean value per slope was given, by means of the following procedure:

$$Volwood_m = \mathop{}\limits_{i=1}^{n} [n_i * vi] / N$$

where *n*i is the number of cells in the slope with a mean volume of wood *vi*. The summatry is then divided by the total number of cells in the slope.
The density of infrastructures was derived from digital topographic data regarding the road network in the study area. It represents the appearance of roads in each slope, divided by the total area of the slope (num of cells with a road. ha^{-1}). It was also computed by means of a GIS system.

Landscape variables: two landscape indices were selected in order to determine if, and when, slopes affected differently the formation and characteristics of islands. These variables are a measure of the spatial arrangement of the patches in our selected landscapes (slopes). Selected indices were the Shannon diversity (H'), and a textural index: the angular second moment (ASM).

- Shannon diversity (H'): This index combines richness and evenness and is an indicator of the relative abundance of a land cover.

$$H= - \sum p * \ln(p)\text{'}$$

where p corresponds to the proportion of grid cells on the landscape for the land use *i* selected.

- Angular second moment (ASM). Texture measures are used to determine the brightness patterns within an image (see Haralick et al. 1973, Musick and Grover 1991 and Soares et al. 1997). They can be use as a measure of spatial complexity and contrast among patches. The angular second moment variable is the sum of co-occurrence probabilities:

$$ASM = \sum \sum (p_{i,j})^2$$

where p (i,j) is the relative abundance of cells *i* that are adjacent to cells *j* . ASM increases with mosaic homogeneity as the co-occurrence of identical values has a marked influence in this index. ASM is 1 when all co-occurrences are identical. This index is insensitive to the magnitude of the difference between cells of different values (Farina 1998).

In order to test the influence of the selected variables on the different levels of island formation, several tests were performed depending on the distribution of the variables. Normal and normalized variables (log or squared-root transformed) relied on univariate ANOVA tests, with the frequency of islands and the unburned area as fixed factors. The correspondent non-parametric test was applied when no normalization was possible (Kruskal-Wallis test). A classification tree analysis was performed both for island incidence and island area, as a further revision of the relative importance of the selected variables. The purpose was to determine which of the utilized variables was more useful to characterize the unburned island formation, rather than to evaluate the accuracy of this methodology. The decision tree algorithm is based on a process called recursive partioning, which consists of dividing the data into two sets that produce the largest decrease in deviance (i.e. measure of heterogeneity) (Andersen et al. 2000). After extracting training data from the user defined classes, it iterates to develop several splitting rules that divide the original data into progressively more homogeneous branches. Binary recursive partioning continues until the original data has been divided into pure nodes or the remaining data are too sparse. To create these trees, a randomly elected sample test was selected (n=981), while the remaining 609 cases were used to test the model. SPSS and STATISTICA, were the employed statistical packages.

RESULTS

Unburned island patterns

6102 islands were formed within the fire perimeter, with a mean area of 0.42 ± 3.0 ha and a median of 0.031 ha. The minimum island size was of 0.03 ha and the maximum of 137 ha. Even though this large number of unburned patches, most of these vegetation islands were small (i.e. 82% of the cases were islands ≤ 0.2 ha), and they accounted for 13% of the total unburned area (Figure 2 A,B). The Lorenz curve for the surviving islands indicated that 50% of the total number of islands were responsible for 3.7% of the total unburned area, while 4.5% of the total number of islands accounted for 75.57% of the total unburned area (Figure 2,C).

A revision of the attributes of these unburned patches indicated that the perimeter increased linearly with the size of the islands (R^2=0.95). The ratio perimeter-area of the islands, versus the island area, responded to a decreasing potential function (R^2=0.98). Thus, small islands were strongly conditioned by their areas, while larger patches ($\geq$ 10ha) were more balanced by their perimeters, oscillating around a fixed ratio value (0.02) (Figure 3,A). For the CPA variable, more regular shapes (lower values) corresponded to small islands, while patches larger than 16 ha were characterized by more irregular shapes (values above 3) (Figure 3, B).

Variables affecting the formation of vegetation islands

Several variables significantly differed when contrasting slopes without islands and with different levels of island formation (frequency) (Table 1). Table 2 displays the descriptive statistics for the considered independent variables, for each level of island frequency (0, 1 and 2). Table 1, 2 and 3 indicate how residual vegetation occurred in slopes characterized by higher areas, higher percents of forests, higher volumes of wood, and rugged terrain (steep slopes). Northern aspects did not influence the formation of islands, but they did influence the area of these islands, being significantly larger than southern slopes (Table 3). To test the influence of aspect on the formation of islands, it was preferred to use the continuous values of island frequency and island area, (i.e. ANOVA test), instead of their categorical versions (i.e. contingency table), to have a more accurate result. The percent of broadleaves and the percent of shrubs in each slope did not display a significant influence. Moreover, these unburned islands were more frequent in slopes with lower percents of crops, and lower understory levels. Regarding the landscape indices, and contrarily to what expected, residual vegetation was more frequent on slopes with lower densities of infrastructures, and lower diversities. The Angular Second Moment did not display a significant influence on the formation of islands. With the exception of the area of the slope, the percent of understory, and the density of infrastructures, the rest of the predictors did not display significant differences between low and high frequencies of islands, being more influenced by the dichotomy: island formation-no formation (Table 2). When revising the island area instead of the frequency of islands, the same trends were observed for all predictors.

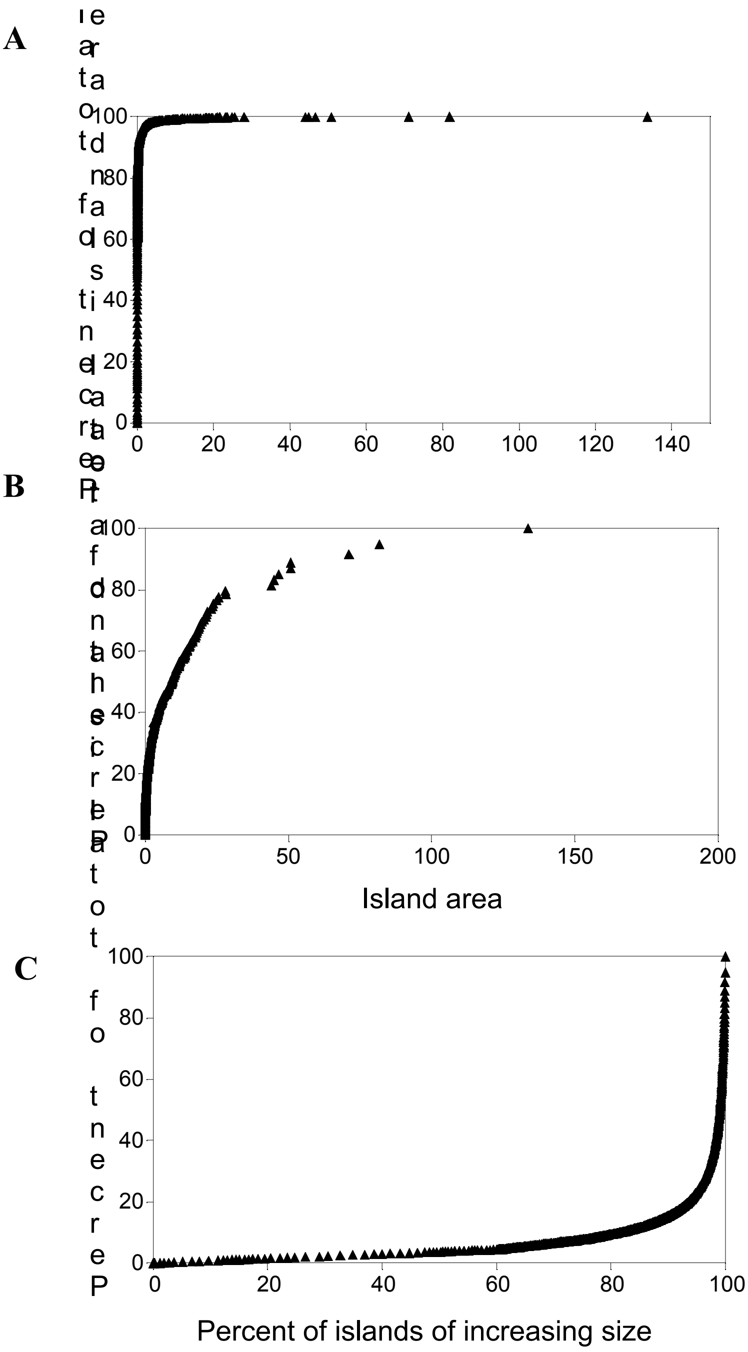

Figure 2: (A,B) Cumulated percent of the number of islands and cumulated percent of the total island area, versus the island area (ha). (C) Lorenz curve for the unburned islands within the fire perimeter in El Solsonès 1998 fire.

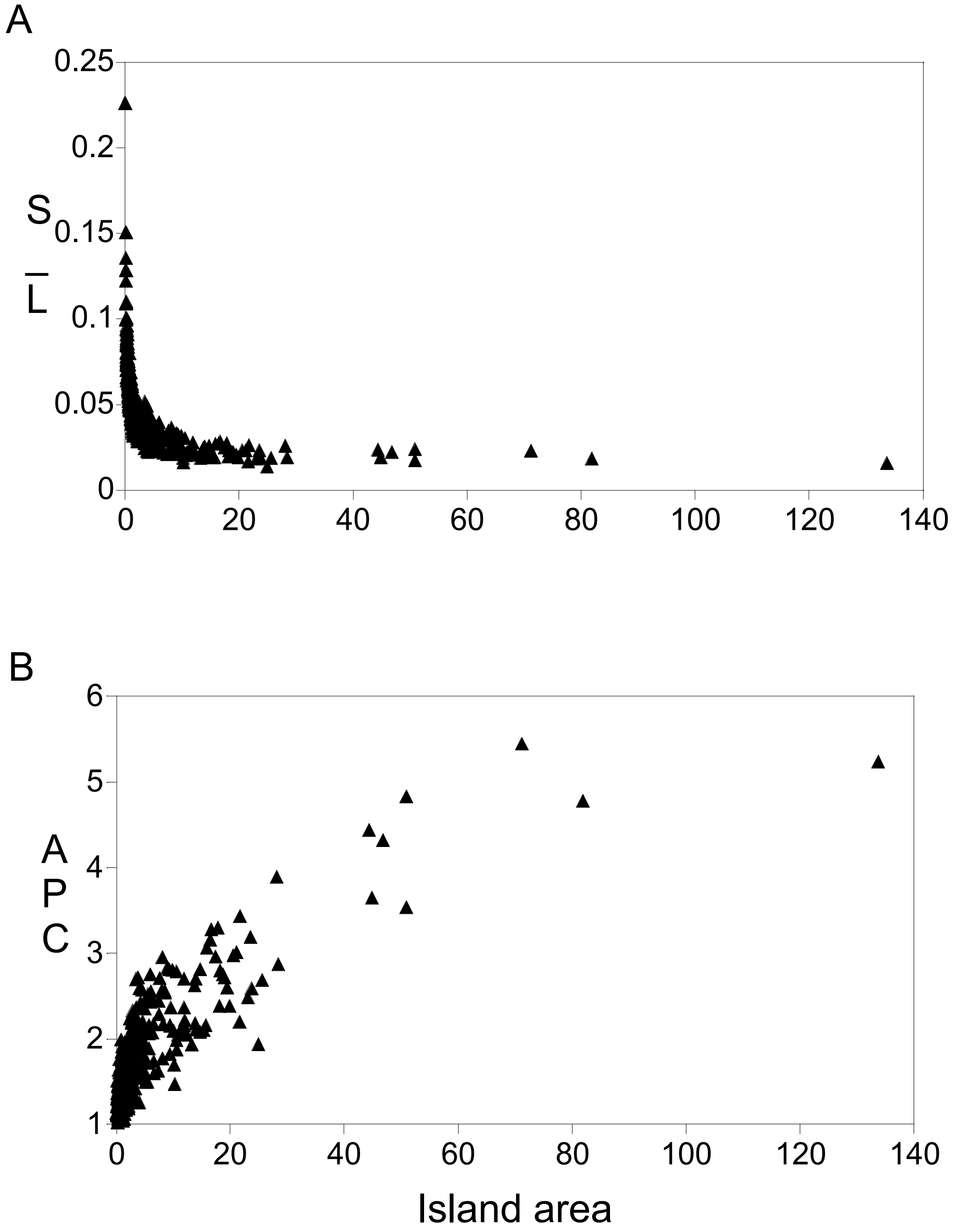

Figure 3: (A) Ratio perimeter-area of the unburned islands, versus the island area (ha). (B) Corrected Perimeter Area of the unburned patches, versus de island area (ha).

Figure 4 shows the relative importance of predictor variables on the frequency of islands, by means of classification tree, which is based in a learning sample of n=908. The area of the slope is one of the most influencing variables, followed by the percent of forests. Thus, more islands are expected in slopes with larger areas (≥ 15 ha), and larger amounts of forests (≥ 20%) (right side of the tree) . When the slope area is smaller, higher percents of forests (≥ 45%) favor larger island incidences, enhanced by the existence of higher volumes of wood (≥ 23 $m^3.ha^{-1}$), steeper slopes (≥ 8º), northern and western-faced slopes, lower understory (≥ 27%) and lower diversities (H<1.3). The predictive accuracy of this tree was of 56% (n-test sample=609).

When slopes with different categories of island areas are considered (Figure 5), large islands are conditioned by a minimum forest threshold (≥ 27.6%). Slopes with lower percent of forests are not very likely to form islands. Larger islands are formed in slopes with areas larger than 10 ha, higher percents of wood volume (≥ 23%) and lower infrastructures (< 0.25). Regarding this last variable, even though the number of islands is also high in slopes with high levels of infrastructures, the number of slopes with no islands increases drastically under this last condition (Figure 5). Steep slopes (≥ 21º) seem to slightly diminish the formation of large islands, enhancing the number of slopes without islands. When the are of the slope is lower than 10 ha, the presence of high percents of crops (≥ 28%) difficults the formation of large islands, which are more frequent in slopes with lower percents of crops, higher homogeneity (ASM≥ 0.4), higher volumes of wood (≥ 23.5%), and higher areas. The predictive accuracy of this tree was of 47% (n-test sample=609)

Table 1: Parametric and non-parametric tests for the 13 predictors of island formation. Significant coefficients (at α=0.05 when the sequential Bonferroni method is employed) are indicated in bold.

Variables	Statistical test	p-level
Forest (%)	Kruskal-Wallis	**p<0.001**
Shrubs (%)	Kruskal-Wallis	p<0.025
Crop-fields (%)	Kruskal-Wallis	**p<0.001**
Broadleaves (%)	Kruskal-Wallis	p<0.8
Slope (º)	ANOVA	**p<0.001**
Aspect	ANOVA	**p<0.001**
Area (ha)	Kruskal-Wallis	**p<0.001**
Understory (%)	Kruskal-Wallis	**p<0.001**
Volume of wood (m3. ha-1)	Kruskal-Wallis	**p<0.001**
Diversity (H’)	ANOVA	**p<0.001**
ASM	ANOVA	p>0.15
Infrastructures (num.ha-1)	ANOVA	**p<0.001**

Table 2: Descriptive statistics for the selected predictors of island formation, for each categories of island. Letters indicate the post-hoc differences among classes, calculated with the Fisher's minimum significative distance, $\alpha=0.05$. Post-hoc differences among categories are only displayed for the significant variables.

Variables	Median			Mean ± Standard deviation					
	0	1	2	0		1		2	
Island frequency (num.ha^{-1})	0.00	0.2	0.6	0.00 ± 0.00	**a**	0.21 ± 0.09	**b**	0.76 ± 0.51	**c**
Island area (%)	0.00	4.8	34.3	0.00 ± 0.00	**a**	5.4 ± 4.0	**b**	40.3 ± 23.5	**c**
Forest (%)	52.2	75.8	69.4	53.8 ± 30.3	**a**	71.4 ± 21.4	**b**	64.96 ± 27.5	**b**
Shrubs (%)	3.3	1.6	1.4	10.8 ± 17.3		4.9 ± 7.7		9.53 ± 17.2	
Crop-fields (%)	32.7	19.6	18.4	35.2 ± 27.9	**a**	23.5 ± 20.0	**b**	25.16 ± 24.0	**b**
Broadleaves (%)	1.5	1.6	1.4	4.4 ± 9.0		2.8 ± 4.4		2.90 ± 5.89	
Slope (º)	20	21.6	21.0	20.3 ± 6.9	**a**	21.8 ± 6.6	**b**	21.77 ± 6.93	**b**
Area (ha)	5.8	15.7	5.6	10.0 ± 19.2	**a**	27.3 ± 32.7	**b**	9.10 ± 11.2	**a,b**
Understory (%)	7.5	6.0	7.5	10.2 ± 10.0	**a**	8.2 ± 8.1	**b**	9.21 ± 9.38	**a,b**
Volume of wood (m3.ha^{-1})	37.5	37.5	37.5	36.1 ± 12.8	**a**	39.6 ± 11.7	**b**	40.6 ± 13.1	**c**
Diversity (H')	1	1	1	1.0 ± 0.5	**a**	0.91 ± 0.5	**b**	0.90 ± 0.51	**b**
ASM	0.35	0.34	0.37	0.34 ± 0.13		0.33 ± 0.12		0.35 ± 0.14	
Infrastructures (num. roads.ha^{-1} *100)	0.22	0.16	0.27	0.27 ± 0.22	**a**	0.21 ± 0.17	**b**	0.32 ± 0.29	**c**

Table 3: Descriptive statistics for the aspect variable, versus the frequency of islands and the percent of unburned area.

	Statistical test		North		East		South		West	
Island frequency (num.ha^{-1})	ANOVA	n.s	0.25±0.3		0.26±0.4		0.25±0.5		0.23±0.2	
Island area (%)	ANOVA	p<0.001	15.5±22.8	**a**	11.8±20.8	**b,c**	8.9±18	**b**	12.7±21.6	**a,c**

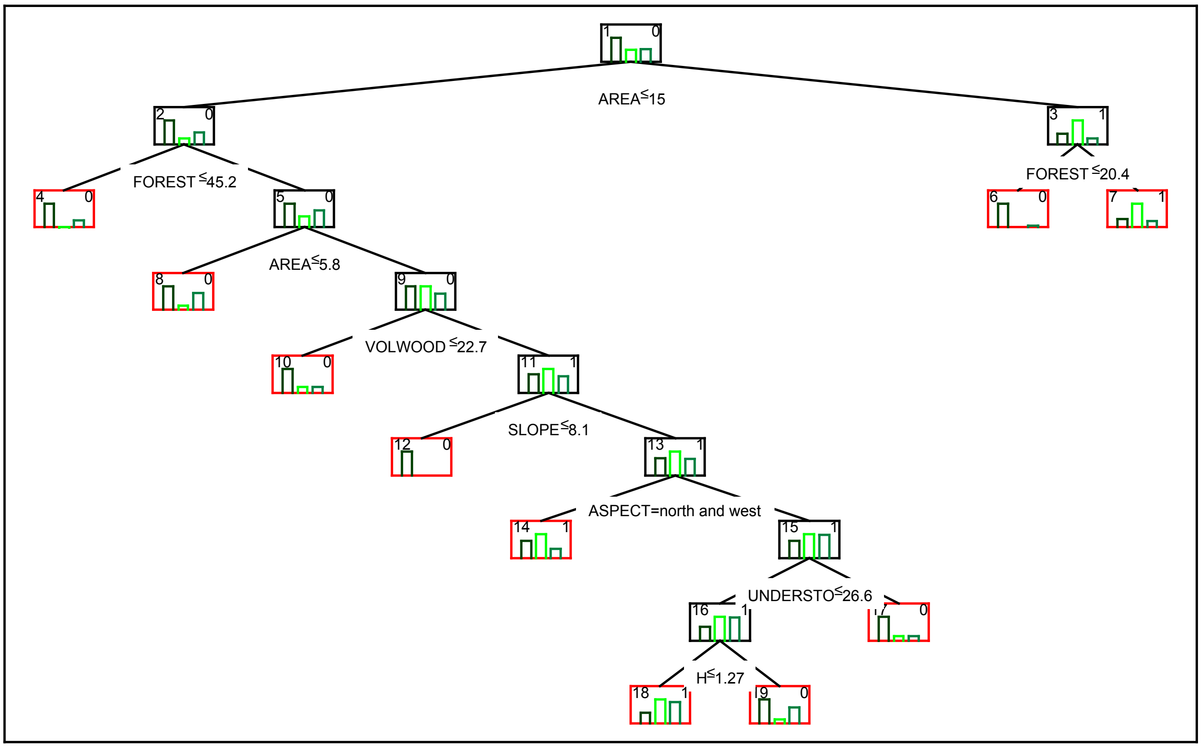

Figure 4: Classification tree for the frequency of unburned islands within each slope (n=981 cases were used to create the tree, and 609 were used to test the validity of the model.). Black bars indicate slopes with 0 islands. Bright green bars refer to slopes with low island incidences and dark green refer to high incidences. Red boxes are terminal nodes. Volwood:volumen of wood ($m^3.ha^{-1}$);Understo:understory (%); H:Shannon diversity. Numbers in the right top corner of the boxes refer to the predicted island category (0, 1, 2)

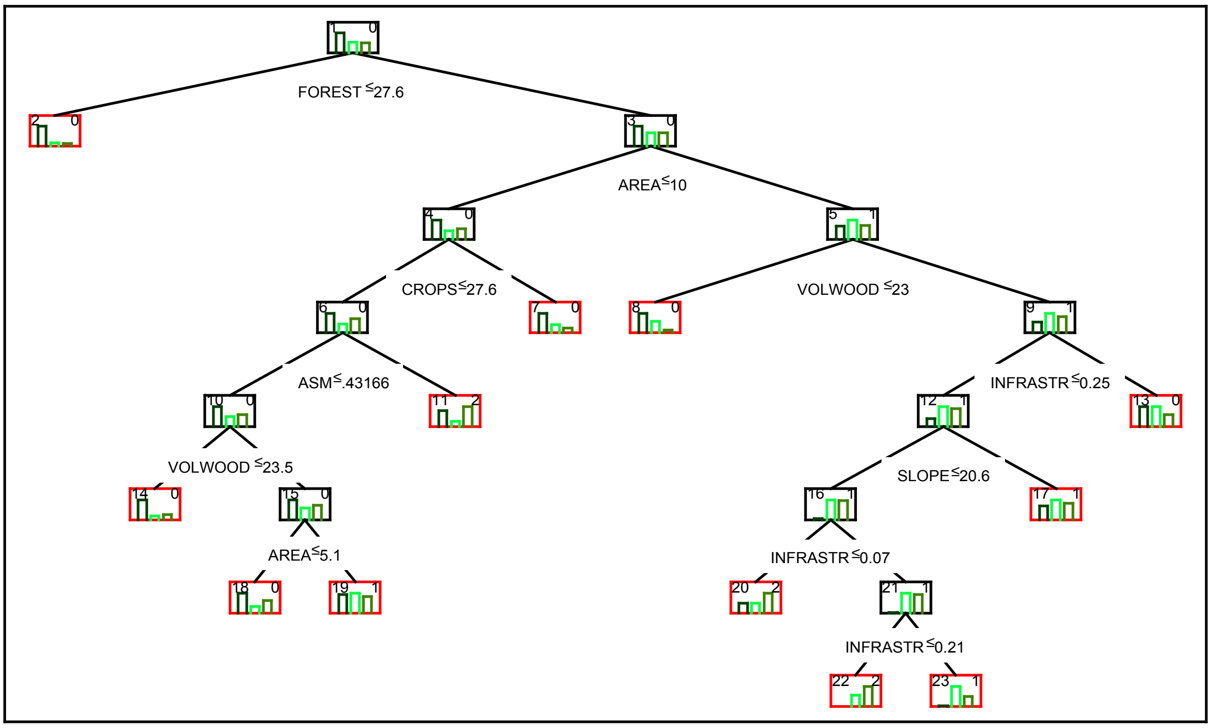

Figure 5: Classification tree for the area of unburned islands within each slope. Black bars indicate slopes with 0 islands. Bright green bars refer to low island areas and dark green refer to high island areas. Red boxes are terminal nodes. Volwood:volumen of wood ($m^3.ha^{-1}$);Understo:understory (%); ASM: Angular Second Moment; Infrastr:Density of infrastructures. Numbers in the right top corner of the boxes indicate the predicted island class.

DISCUSSION

Our study area was characterized by a large number of small islands, which were responsible for a relatively low percent of the total 'residual vegetation' (sensu Eberhart and Woodard 1987). There was a median incidence of 4.7 islands for every 100 ha of slope area (8 for 100 ha of forested area). This shows the patchy dynamic of our large fire, as the studies of Eberhart and Woodard (1987) resulted in an incidence of less than 1 island for each 100 ha. Regarding the area of the islands, the median island area was of 1 ha per 100 ha of slope area (1.8 for 100 ha of forested area). These results contrasted again with the values of Eberhart and Woodard (1987) who found median island areas of 8.8 ha for fires with total sizes between 2000-20000 ha. Our results reinforce the existence of a large number of small islands, which suggest ecological differences between Mediterranean and boreal fire behaviors.

When the shape characteristics of these unburned patches is considered, the increasing trend observed for the corrected perimeter-area ratio (CPA) versus their areas, indicates that the shape of the larger islands are less uniform than the smaller ones, associated to longer and narrower patterns. These complex fire shapes could be associated to exposures to greater variations in wind, during longer burning periods (Foster 1983). Even though the recognized importance of patch regularity-irregularity on organisms, biodiversity and ecological processes (Farina 1998, Laurance et al. 1997, 1998, Bascompte and Rodríguez 2001), most indices used in fire analyses have focused on fire shapes rather than on the shapes of residual vegetation (i.e. perimeter, perimeter-area, etc) (Eberhart and Woodard 1987, Turner et al. 1994).

The larger formation of islands in larger slopes (Figure 4, table 2) can assimilate the results of Eberhart and Woodard (1987) and Turner et al. (1994). The first authors pointed out how larger fires displayed larger numbers of surviving islands within the fire area, until reaching a fire size threshold where the tendency is reverted (2000-20000 ha). Turner et al. (1994) also reported how larger fires were characterized by higher heterogeneities of fire severity. Thus, as fire size increases, the probability of encountering fuel breaks or topographic features that may be associated with island formation also increases (Eberhart and Woodard 1987). Moreover, larger burning times subject large fires to variable winds that may also contribute to the formation of islands (Foster 1983). In this line, Díaz-Delgado and Pons (2001), for a Mediterranean country analysis, reported a positive correlation between fire sizes and the total number of secondary fire sources generated from the burn. Fire sizes were also correlated to the maximum distances reached by the spots produced by every main fire (Díaz-Delgado and Pons 2001). Larger distances reached by the spots and a higher number of secondary fires can aid the formation of residual vegetation between these secondary fires and the main advancing fire.

The association of residual vegetation with larger percents of forests in the slope (Table 2, Figure 5), is not directly obvious. Thus, islands are not formed where there are no forests, but there is not a priori reason to think that slopes with larger amounts of forests would favor the creation of unburned islands. On the contrary, considering the characteristics of our burned area, where crops are the major land cover substituting forests (R=-0.83), it would have been expected that slopes with less percentages of forests helped breaking the inertia of fire. Thus, the existence of larger percents of crops should helped diminishing fire intensity, and favor the formation of vegetation islands near the edges of the crops. This unexpected results were corroborated by the landscape indices, which also displayed lower values for slopes with larger residual vegetation. This fragmentation effect and the lower number of islands, might be related -under severe meteorological conditions- to a higher susceptibility of trees in the edges to fire, specially with strong winds, and with a high intensity fire approaching. Thus, fire spread is enhanced in these edges due to altered microclimatic conditions of the forests, as well as high winds. In protected forest areas (inner areas), both the combination of lower fire spreads associated to higher fuel loads, and diminished effects of wind, could help the formation of islands. Moreover, these larger forests stands can be distributed along a larger range of topographic variation, and are potential more susceptible to variations in wind speed. In opposition to our values, several authors have reported how fragmented landscapes better interrupt fire and enhance the survival of vegetation (Turner and Romme 1994, Turner et al. 1997, Kushla and Ripple 1997, Agee et al. 2000). Thus, Turner and Romme (1994) pointed out the different behavior of fragmented versus connected landscapes, in the final heterogeneity of fire severity. When the susceptible habitat is fragmented (rugged, dissected terrain, high number of infrastructures, diversity of land covers, etc), the disturbance spread is constrained by the spatial disposition of the patches and is primarily a function of the number of initiating fire events. Contrarily, when the habitat is connected, the disturbance can propagate across the entire landscape with a single initiation, if meteorological and fuel conditions help. Some possible reasons that could explained our observed trends refer to: i) the position of the crops in the slope: crops occupy the flatest areas (R= -0.65), at the lower locations of the slope. This might have favored the dispersal of fire spots to the opposite slopes avoiding the formation of islands. ii) Severe meteorological conditions can have reduced the importance of the pre-fire heterogeneity of the landscape. This has special importance in terms of fuel moisture. Thus, large fires frequently occur after severe drought periods, favored by strong, dry winds and low relative humidities. Under these conditions, fuel moisture levels are severely reduced, and the fuel contribution as modifiers of fire spread, is negligible (Miller and Urban 2000, Johnson et al. 2001). Kushla and Ripple (1997) also reported how under the extreme burning conditions of a crown fire with strong winds channeled across the ridge face, terrain variables played a lesser role. iii) A third reason relates to the selected spatial unit. Thus, even though recognizing the importance of establishing comparisons among slopes, larger spatial units might have help determining more clear trends.

The observed higher volumes of wood and lower percents of understory (Table 2, Figure 4), in slopes with a higher number of islands and a higher size of these islands, suggest the survival of more mature forest stands, with larger trees and closed canopies that avoid the formation of a dense understory layer. Several authors have analyzed the pre-fire heterogeneity of forests (structure, age, species composition, fuel continuity), as potential variables explaining the survival of forests following a wildfire (Minnich et al. 1983, Turner et al. 1994, Bessie and Johnson 1995, Minnich et al. 1995, Kushla and Ripple 1997, Agee et al. 2000, Cumming 2001, Finney 2001). There is generally an agreement in the importance of tree sizes (higher DBH's, higher heights, higher crown projections) in the final survival of the individuals. Trabaud and Valina 1998 reminded the association between tree size and the bark thermal isolation properties. Less consensus exists regarding the importance of successional stages (i.e. old versus young stands) or the forest development level that minimizes the susceptibility to fire (i.e. even-aged versus uneven-aged). The importance of fuels as an element that can actively interact with fire dynamic, is the basis of fuel management strategies. Considering the importance of fuel flammability for the survival of residual vegetation (Agee et al. 2000, Cumming 2001), the species compositions of our slopes was tested by determining the percent of the slope area occupied by broadleaves. It was expected that residual vegetation would be present on less flammable slopes, where deciduous forests were more abundant (i.e. oaks, holm oaks, riparian vegetation). However, its influence was not significant, probably related to a reduced number of slopes with percents of broadleaves above 15 % (i.e. 5% of the slopes).

Several factors other than those considered in this study may affect the distribution of residual vegetation surrounding and within large fires. This include meteorological conditions, number of burning days, day-night formation of islands or the level of fire suppression effort. Among them, the day-night formation of islands would have been specially interesting for our study, but no trustable data were available for this variable. With our available factors, the results of this study suggest the importance of concentrating forest management efforts on large slopes, excluding smaller ones, with priority given to northern and western aspects, specially in areas with large amounts of forests, and more mature forests. The unexpected trends displayed by the landscape indices and the density of infrastructures, suggest the importance of avoiding linear features (i.e. fire-lines or fire-breaks) as measures to reduce fuel hazard, as they are associated to a higher fragmentation, a lower formation of islands, and a lower area of these islands. Therefore, in our study area, fuel treatments affecting relatively large areas would be a better strategy. Among these “area” treatment, blocks of fuel-breaks (Agee et al. 2000) would be preferred to strips or linear treatments. This last author reported how fuel fragmentation does not have to be associated with structural fragmentation or overstory removal, but must be associated with declines of at least one of the factors affecting fire behavior: reduction of surface fuels and increases in height to live crown as a first priority, and decreases in crown closure as a second priority. Fuel reduction or fuel conversion measures (sensu Pyne et al. 1996), would also be preferred to fuel isolation. In this last strategy, fuel patches are separated on the landscape to restrict fire spread, frequently by means of linear features (i.e fire break, fire-lines). The other two fuel treatments concentrate on larger areas and include species shifts and fuel treatments to reduce fuel loads and fuel flammability.

The importance of analyzing the influence of landscape patterns on the resulting forest survival relies both on i) the role of large forest fires as severe disturbing agents, ii) the ecological implications that surviving islands have in terms of seedling dispersal, soil erosion, regenerating patterns, etc; and ii) the potential modifier effect of landscape characteristics on the behavior of crown fires. Thus, landscape patterns influence fire behavior in several ways (Turner and Romme 1994): First, topographic and physiographic features in the landscape can influence the local probabilities of unburned island formation. In our study, northern aspects, larger slopes, less fragmented, and less diverse slopes, are good candidates to hold a higher level of forest survival. Second, the spatial arrangement of fuels on the landscape, can influence the advance of fire and condition the presence of unburned islands. Thus, slopes with higher percents of forests, higher volumes of wood and lower understories were more prone to island formation in our study. This landscape influence, however, will be limited by the severity of the meteorological episode.

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